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# Neurosensitivity: Implications for Cognition and Creativity.

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University of Plymouth

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# UNIVERSITY OF PLYMOUTH

NEUROSENSITIVITY:  
Implications for Cognition and Creativity.

By  
DAVID BRIDGES

A thesis submitted to University of Plymouth in partial  
fulfilment for the degree of

DOCTOR OF PHILOSOPHY

School of Psychology

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Finally, I am very thankful I was lucky enough to share the CogNovo experience with my now wife, Dr. Raluca Briazu.

## Author's Declaration

At no time during the registration for the degree of Research Masters has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

Work submitted for this research degree at the University of Plymouth has not formed part of any other degree either at the University of Plymouth or at another establishment.

### Publications

#### Chapter 2

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**Signed:** \_\_\_\_\_

**Date:** \_\_\_\_\_

## **Ethical Statement**

This research project was approved by University Human Research Ethics Committee in the Faculty of Health and Human Sciences at University of Plymouth and was thus conducted in full compliance of the Good Code of Scientific Practice and those fundamental principles that ensure the protection of human participants.

## **Neurosensitivity: Implications for cognition and creativity.**

David Bridges

Sensory-processing sensitivity, or neurosensitivity, is a biologically-based personality dimension with implications for personality, creativity and cognition. This thesis focuses on sensitivity and its cognitive implications using recent state-of-the-art sensitivity and creativity assessments with an aim to identify objective cognitive tests of sensitivity that can supplement self-report measures, whilst providing insight into the brain basis for creativity. In Chapter 1, we review literature on creativity and sensitivity. Chapter 2 presents new evidence that positive-affect-related dimensions of sensitivity benefit creativity independently and/or interactively with Big-Five openness. Factor analysis in Chapter 3 provides important evidence that multiple dimensions of sensitivity are distinct from Big-Five personality traits. Chapter 4 and 5 explore sensitivity-related attention components in relation to endogenous and exogenous attention tasks, revealing that positive-affect-related sensitivity is characterized by differences in exogenous inhibition-of-return, and defocused, disinhibited attention states that facilitate creative potential. Chapter 6 shows sensitivity has positive implications for learning and memory processes, demonstrating that neurosensitivity affects neuroplasticity favourably. Chapter 7 explores how individual differences in unconscious cognitive mechanisms of latent inhibition (LI) may underlie higher creative potential and achievement in sensitive, open creators, as theory and evidence suggest low LI in high sensitivity and creative achievement. No evidence was found to support the hypothesis that LI differs in sensitivity, or underlies the sensitive creator. All findings are interpreted in light of a new sensitivity framework that is consistent with cognitive disinhibition and hemispheric asymmetry hypotheses of creativity and models of the creative process suggesting an important role for conscious and unconscious cognition.

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CHAPTER I

**Literature Review**





People differ widely in creative ability (Runco, 2014; Sawyer, 2012). Individual differences in cognition, affect, and personality have been explored extensively as factors in creativity, but pinpointing the exact factors has remained elusive (Sawyer, 2012). A creative personality exists (Feist, 1998, 2010), and openness to experience is the strongest predictor of creativity from the Big-Five traits, but controversies remain (Feist, 2010; Kaufman et al., 2016; Runco, 2014; Sawyer, 2012). Sensitivity is a biologically-based temperament dimension (Evans & Rothbart, 2007; Pluess, 2015a) that has been associated with creativity anecdotally but rarely investigated and with mixed results (Brodsky & Brodsky, 1981; Martindale, 1999; Martindale, Anderson, Moore, & West, 1996; Necka & Hlawacz, 2013; Shamay-Tsoory, Adler, Aharon-Peretz, Perry, & Mayseless, 2011). Critically, recent state-of-the-art sensitivity and creativity assessments have not been used, especially those reflecting recent advances in defining sensitivity (Aron & Aron, 1997; Evans & Rothbart, 2007, 2008; Pluess, 2015a) nor has the relationship between creativity and cognitive processes that should reflect sensitive neural processing been investigated. This thesis addresses these major gaps in understanding individual differences in creativity, focusing on sensitivity and its implications for cognitive processes supporting creative potential and achievement.

### **Neurobiological Theories of Creative Cognition**

Neurobiological theories of creativity combine fields of neurobiology, neurogenetics and cognitive neuroscience to explain individual differences in creative ability (Kaufman, Kornilov, Bristol, Tan, & Grigorenko, 2010). A complication for any theory of creativity involves its operationalization, as prior definitions of “creativity” are both ambiguous, and elusive with an abundance of definitions in the past literature offering little consistency (Plucker, Beghetto, & Dow, 2004; Runco & Jaeger, 2012; Simonton, 2012a). However, the general consensus, or “standard definition” defines creativity as something demanding both originality and effectiveness (Runco & Jaeger, 2012; cf. Simonton, 2016). Originality is essential for

something to be novel, whereas effectiveness determines the usefulness of an idea or product. Neither term alone is sufficient for creativity to emerge. For example, original ideas can stem from psychopathology, or randomness, but may lack value. On the other hand, effective or useful ideas lacking originality are not new, and so already exist.

Relevant to enquiries of individual differences are the models that attempt to explain how novelty and effectiveness emerge as a function of *product*, *place*, *process* and *person* (for a review of the Four P's of creativity, see Kozbelt, Beghetto, & Runco, 2010). *Products* and *place* examine creative products and places they flourish, whereas *process* and *person* advance the idea that creative ability emerges from basic human cognition, recognizing that individual differences explain all variation in creative ability (Smith, Ward, & Finke, 1995). In this project, we take the *person* and *process* approach taken from a neurobiological perspective to examine how individual differences in biologically-based temperaments shape personality and creative cognition.

In early seminal work, Colin Martindale developed new perspectives that explain individual differences in creativity have a neurobiological basis, combining primary process cognition (Kris, 1952), associative hierarchies (Mednick, 1962), and defocused attention (Mendelsohn, 1976), which themselves are thought to be cognitive “building blocks” in the overall creative process (Kaufman, Kornilov, et al., 2010; Martindale, 1999). Martindale (1999) theorized that creative inspirations are the result of a combined mental state in which attention is defocused, thought is associative and a large number of mental representations are simultaneously activated, occurring together in a state of cognitive disinhibition with comparatively more right than left hemisphere activation. Specifically, highly creative people have lower cognitive inhibition due to frontal lobe de-activation, with greater disinhibition in the right hemisphere, but only when engaged in the creative process. In his synthesis, Martindale combined two major theories of creativity under one model; the cognitive disinhibition and hemispheric asymmetry theories of creativity. In brief, cognitive

disinhibition allows usually-inhibited, seemingly irrelevant information to enter conscious awareness, thus facilitating the formulation of novel associations (Carson, 2014a) that are detected with right-hemisphere lateralized attention mechanisms. Today, both mechanisms are thought to reflect two separate stages of the creative process (Kaufman, Kornilov, et al., 2010).

Martindale's work is of particular interest because of the role of that cortical arousal plays in creative cognition. In a series of experiments, Martindale found that highly creative people were over-sensitive and more physiologically reactive than people low in creativity (for a review, see Martindale, 1999). Sensitivity is considered as an enduring biologically-based personality or temperament trait anecdotally linked to higher creativity (Aron & Aron, 1997) and may reflect individual differences in universal cognitive functions of attention (Evans & Rothbart, 2007), and cognition more generally through the mechanism of sensory-processing sensitivity (Aron & Aron, 1997), or neurosensitivity (Pluess, 2015a). The relationship between creativity and cognitive processes that should reflect sensitive neural processing have not been investigated prior to this project, thus we address these major gaps in understanding individual differences in creativity by focusing on sensitivity and its cognitive implications, providing a possible neurocognitive basis for creativity.

## **The Sensitive Creator**

### **Early Observations and Experiments on Creativity and Sensitivity**

The sensitive temperament has been associated with creativity mainly based on anecdotal observations, “every sensitive person is unusually creative“ (Shamay-Tsoory et al., 2011, p. 104), in qualitative research characterizing eminent creators (Martindale, 1989; Runco, 1998) or groups (Brodsky & Brodsky, 1981), and in a few early experimental studies (for a review, see Martindale, 1999). Inspired by the stereotype of the highly sensitive creator and the anecdotal accounts of extreme sensitivity in eminent creators (Martindale, 1989), Martindale and colleagues investigated the hypothesis that creative people have exceptionally sensitive temperaments, and findings suggest that creativity is associated with higher sensitivity to sensory stimulation (Martindale, 1999).

Martindale and Armstrong (1974a) performed an electroencephalogram (EEG) study in which subjects were required to either enhance or suppress their own alpha waves in the presence of an auditory tone. Alpha activity is oscillation of the EEG at a frequency between 8 – 12 Hz observed when a person is minimally aroused; relaxed but awake. Greater alpha activity is thought to indicate the low arousal state associated with internally oriented attention required for associative ideation (cf. Dietrich & Kanso, 2010; Fink & Benedek, 2014; Martindale & Armstrong, 1974a). Participants were separated into high and low creativity groups based on their composite fluency performance measured using the alternate uses task (AUT; Christensen, Guilford, Merrifield, & Wilson, 1960) and remote associates task (RAT; Mednick, 1962; Mednick & Mednick, 1967). RAT is a reliable divergent/convergent creative thinking task positively correlated with ratings of creativity (Mednick, 1962) and insightful problem solving (Schooler & Melcher, 1995). The AUT has been labelled a pure measure of creativity since it does not correlate with IQ (Martindale, 1977), although the AUT is essentially a divergent thinking (creative potential) task with

fluency factors correlated with IQ (Batey & Furnham, 2006; Silvia, 2008). Interestingly, when compared with low creative groups, high creative groups showed higher alpha blockade (i.e., less alpha) during habituation to tones over time, but also a greater ability to suppress alpha when required. This suggested that high creative groups were more sensitive to auditory stimulation (i.e., lower alpha suggesting greater attention to auditory stimuli), but also showed greater effortful control of attentional orienting. In another study, participants were delivered a series of electric shocks and asked to rate the shock intensity. Scores on both AUT and RAT were positively correlated with ratings of shock intensity, suggesting that creative groups have a greater sensitivity to sensory stimulation (Martindale, 1977). Another study by Martindale et al. (1996) found that high versus low creative groups were more physiologically responsive and slower to habituate to stimulation over time. In this study, participants fitted with headphones and habituated to 60db bursts of white noise for durations of 2.5 seconds. In the test phase, participants were exposed to the white noise at random intervals between 25-50 seconds and, to keep attention focused on the task, were asked to verbally report their preference (from displeasure to pleasure) for noises.

Electrophysiological skin conductance response potentials indexed sensitivity of the attention orienting response to the white noise, and creativity was measured using the RAT and AUT fluency scores (for a review of orienting reflex, see Barry, MacDonald, De Blasio, & Steiner, 2013; Bradley, 2009). The main result was that positive amplitude in skin conductance, reflecting an alerting response, increased across trials in high creatives (HC), but decreased for low creatives (LC). Furthermore, gamma EEG band responses, reflecting an attentional orienting and habituation response, showed that LC habituated after 3 trials, whereas HC did not habituate at all, an effect mainly related to RAT performance. In addition to demonstrating higher sensitivity and slower habituations in creative groups, the study also demonstrates that novelty seeking in creative people may not be the result of boredom and

fast habituation. Indeed, the slow habituation and high alerting response over time suggests that creative groups process more novelty in the mundane and are perhaps less inhibited than low creative groups, as would be explained by cognitive disinhibition hypothesis of creativity (Martindale, 1999) and also the related phenomenon of low latent inhibition in high creativity (Carson, Peterson, & Higgins, 2003; Lubow & Gewirtz, 1995; see Chapter 7).

Martindale's pioneering work has provided the first experimental evidence that physiological sensitivity and slower habituation of the attention orienting response is linked to creative potential. However, there has since been important work to consider for the interpretation of Martindale's findings. For example, fluency measures of DT tasks commonly used in Martindale's studies (e.g., Martindale, 1977; Martindale et al., 1996; Martindale & Armstrong, 1974a) show some relation to IQ (Batey & Furnham, 2006; Silvia, 2008) and AUT performance may simply reflect long term memory-retrieval strategies (Batey & Furnham, 2006; Gilhooly, Fioratou, Anthony, & Wynn, 2007). This suggests that the measures used were not entirely valid indicators of creative potential. However, in further support of Martindale's work, creativity has more recently been associated with a sensitivity to emotion, as people who are biologically sensitive to negative affect also tend to score higher on DT tasks and produce artistic works judged as more creative than people less vulnerable (Akinola & Mendes, 2008).

### **The Sensitive Temperament**

This thesis focuses on recent advances in defining the sensitive temperament including sensory-processing sensitivity (Aron & Aron, 1997), environmental sensitivity (Pluess, 2015a; Pluess & Belsky, 2009, 2013), and orienting sensitivity of the emotion-attention theory of temperament (Evans & Rothbart, 2007). Each theory offers unique but overlapping perspectives on the physiological processes underlying the sensitive temperament, and each offers a unique insight into how the sensitive temperament affects creativity. For current

perspectives on the relationship between temperament and personality, please see Appendix A: Temperament, Personality and Creativity.

### **Sensory-Processing Sensitivity**

Sensory-processing sensitivity (SPS; Aron & Aron, 1997) is a broad trait consisting of sensitivity types associated with different outcomes in personality, well-being and creative potential (Aron & Aron, 1997; Smolewska, McCabe, & Woody, 2006; Sobocko & Zelenski, 2015). Aron and Aron (1997) proposed that most species evolved personality types (bold vs. shy) that represent two strategies for dealing with novelty; either exploration, which is associated with approach behavior, or quiet vigilance (or inhibition), which is associated with withdrawal (or avoidance) behavior. The tendency for explore-approach or inhibit-avoid strategy is partly determined by individual differences in SPS (Aron & Aron, 1997). SPS is defined as a unidimensional genetically influenced temperament dimension characterized by differences in the transmission and processing of sensory information. People with high SPS tend to be more inhibited towards novelty, but show greater sensitivity to subtle, low-level information and engage in deeper processing strategies, in the sense of Craik and Lockhart (1972) levels of processing theory, for planning effective action, all of which is driven by a stronger biological or emotional reactivity (Aron & Aron, 1997; Aron, Aron, & Davies, 2005; Aron, Aron, & Jagiellowicz, 2012). Conceptually, SPS is related to the Behavioural Inhibition System (BIS), a "pause and reflect" inhibitory system sensitive to punishment, non-reward and novelty. The BIS is more active in neurotic-introverts, or those prone to anxiety (Carver & White, 1994; Gray, 1981), although SPS is partially independent of introversion and neuroticism (Aron & Aron, 1997).

SPS is measured using the highly sensitive person scale (HSPS) developed by Aron and Aron (1997). The HSPS consists of 27 items measuring sensitivity to both internal and external stimuli. The scale measures the sensitive processing of stimuli, rather than the



sensitivity of sense organs themselves. Items probe tendencies to notice subtleties in the environment, having a rich complex inner life, noticing other people's moods, and being deeply moved by arts, but also tendencies to startle easily, to become bothered, overwhelmed and withdraw when over-stimulated. The HSPS has good discriminant validity from personality factors suggesting that the HSPS is not contained within the Big-Five. For example, the multiple correlation of all Big-Five factors (e.g., Goldberg, 1990) with the full HSPS ( $r = .54$ ) leaves 71% of the HSPS variance unexplained by the Big-Five (Aron & Aron, 1997), with the caveat that the short form versions of the Big-Five personality scales were used. When short form measures are used to assess the discriminant validity, it is possible that both measures capture different factors of the same conceptual hierarchy, i.e., one general factor and one sub factor. If those two measures of the same construct are not highly correlated (i.e.,  $<.85$ ) then discriminant validity is assumed (Evans & Rothbart, 2007; Kline, 2015). However, the HSPS (Aron & Aron, 1997) and short-form Big-Five inventory (Goldberg, 1990) have high reliability and validity and capture the core of each trait independent of other traits so if short-form personality inventories do not capture sensitivity then core definitions of personality domains may be inadequate.

Using this scale, Aron and Aron (1997) identified two distinct groups of highly sensitive individuals. The smaller group of highly sensitive individuals reported substantially troubled childhoods and was more introverted and emotional, whereas the larger group scored equally high on sensitivity measures but were more similar to non-highly sensitive individuals with regards to childhood trauma, introversion and emotionality. Thus, sensitivity does not necessarily lead to proneness towards negative affective states. However, highly sensitive individuals are more vulnerable to developing negative affect when coming from adverse childhood environments, as research also supports links between sensitivity and negative affect and behavioral outcomes. Specifically, high sensory-processing sensitivity is

linked to higher incidence of anxiety (Neal, Edelmann, & Glachan, 2002), higher perceived stress (Kjellgren, Bood, Axelsson, Norlander, & Saatcioglu, 2007), more frequent symptoms of ill health (Benham, 2006), agoraphobia, and harm avoidance, a temperament variable linked to inhibition and shyness (Hofmann & Bitran, 2007). Aron et al. (2005) show that SPS leads to shyness when proneness to negative affect (i.e., depression and anxiety) develops through adverse parental environments. People who were not highly sensitive were less likely to experience negative affect and shyness as a result of adverse parental environments. Liss, Timmel, Baxley, and Killingsworth (2005) found that highly sensitive individuals who experience a low care (cold and rejecting) parental style were more depressed than non-highly sensitive people in low care groups. No differences in depression rates were found between high and low sensitive people when parental care levels were high. Individuals with high SPS may be more prone to depression and anxiety as the result of learned helplessness following repeated and unavoidable experiences associated with negative affective states. This maladaptive tendency in high SPS individuals was suggested to result from a greater awareness and non-acceptance of distress, exacerbated by low efficacy for emotional regulation (Brindle, Moulding, Bakker, & Nedeljkovic, 2015). Highly sensitive individuals are also more likely to experience symptoms of avoidant personality disorder, in particular when combined with pessimistic expectancies, that is, highly sensitive people who expect negative outcomes are more likely to withdraw and avoid (Meyer & Carver, 2000).

The HSPS as a measure of SPS may over-represent sensory discomfort and negative affect, under-represent positive affect and may actually reveal multiple dimensions of sensitivity or other traits. The items on the HSPS focus more strongly on sensory discomfort and negative affect associated with sensitivity (Evans & Rothbart, 2008), and the role of heightened emotional reactivity is not assessed fully because positive emotion items of the scale were removed (Aron et al., 2012). Furthermore, Aron and Aron (1997) proposed

originally that the HSPS is a unidimensional construct, but recent evidence has identified multiple subfactors within the HSPS (Evans & Rothbart, 2008; Smolewska et al., 2006), some of which are associated with more positive affect and outcomes (Sobocko & Zelenski, 2015). Consistent with this, Aron et al. (2012) propose at least four facets of the sensitive temperament, although the HSPS was not designed to distinguish these. Nonetheless, factor analyses of the HSPS, as reviewed next, are subject to technical limitations, including non-normal score distributions, gender differences, item correlations with negative affect, and self-report biases, and future work will need to provide clearer evidence for multiple dimensions of SPS (Aron et al., 2012).

**Multiple Dimensions of the HSPS.** Smolewska et al. (2006) used a large sample (n=851) to study the psychometric properties of the 27-item HSPS and its relation to BIS/BAS scales (Carver & White, 1994; Gray, 1981) and personality. In contrast to the Aron and Aron (1997) unidimensional model of SPS, factor analysis by Smolewska et al. (2006) identified three factors in the HSPS: Ease of Excitation (EOE) refers to becoming mentally overwhelmed by external and internal demands; Aesthetic Sensitivity (AES) refers to aesthetic awareness and Low Sensory Threshold (LST) relates to unpleasant sensory arousal to external stimuli. Whilst positive inter-correlations amongst the three factors are consistent with a higher-order SPS construct, the three factors seem to measure different facets of sensitivity. For example, the three factors are not equally associated with personality traits and BIS/BAS measures. In general, EOE and LST showed stronger positive associations with neuroticism, whereas AES was more positively associated with openness. The full HSPS and subfactors showed positive association with the BIS, but all except the LST factor were also positively associated with the BAS-reward responsivity. Also, the HSPS was unrelated to the extraversion trait, further evidence that SPS is at least partially independent of introversion

(Aron & Aron, 1997). More recent factor analysis by Sobocko and Zelenski (2015) supports a similar three-factor solution with a smaller sample ( $n=319$ ).

In Evans and Rothbart (2008) study ( $n=297$ ), the HSPS was characterized as measuring at least two temperament constructs, which differentiate between sensory sensitivity and sensory discomfort aspects of SPS. Evans and Rothbart (2008) propose that thresholds for sensory discomfort should be measured as a separate construct from the cognitive detection mechanisms used for fine grained perception of sensory sensitivity. The Adult Temperament Questionnaire (ATQ; Evans & Rothbart, 2007) captures sensory sensitivity and sensory discomfort within the respective orthogonal temperament constructs of orienting sensitivity and negative affect. Orienting sensitivity is the automatic attention to internal and external events, and negative affect relates to negative feeling, over-arousal and sensory discomfort. Indeed, Evans and Rothbart (2008) using ATQ data found no evidence for correlations between sensory sensitivity and sensory discomfort subfactors ( $r = .00$ ), as well as between the higher-order factors of orienting sensitivity and negative affect ( $r = .09$ ). This suggests orthogonality between the two constructs and therefore does not support the Aron and Aron (1997) hypothesis that higher sensory sensitivity is linked with tendencies towards over-arousal and negative affect. Using factor analysis, Evans and Rothbart (2008) also explored the factor structure of the HSPS and found the HSPS to contain two primary factors, the first relating to negative affect ( $r = .70$ ), and the second relating to orienting sensitivity ( $r = .63$ ). However, the two factors of orienting sensitivity and negative affect extracted from the HSPS show a small correlation ( $r = .25$ ). The authors note that only one item (i.e., “Do you seem to be aware of subtleties in your environment?”) of the HSPS fits the ATQ’s specific definition of perceptual/sensory sensitivity subfactor of the orienting sensitivity construct, and so it is possible the orienting sensitivity factor of the HSPS overlaps with the negative affect factor of the HSPS. The Evans and Rothbart (2008) findings lend

support for multidimensionality of the HSPS (Smolewska et al., 2006), but the correlation observed between the HSPS subfactors is challenging to reconcile with the orthogonal structure of the ATQ factors of OS and NA (Evans & Rothbart, 2008) as they suggest a higher-order, unidimensional factor of sensory-processing sensitivity (Aron & Aron, 1997). Indeed, this would be consistent with evidence that factor analysis of the HSPS does not always produce good fits for two- or three-factor solution (e.g., Liss, Mailloux, & Erchull, 2008), and with suggestions that factor analysis of the HSPS is fraught with technological limitations, for example item differences in social desirability and gender bias that could explain the emergence of multiple factors (Aron & Aron, 2013). Thus, it is possible that differences in orthogonality between OS and NA factors of the ATQ and the HSPS may result from qualitative item differences loading on each factor.

**Multidimensional HSPS and the different outcomes by factor.** Based on the links with sensitivity types, personality and BIS/BAS, different sensitivity types appear to be associated with desirable or undesirable traits or outcomes. Smolewska et al. (2006) show that the AES facet from the HSPS is associated with positive and desirable aspects of personality, such as openness, and the EOE and LST facets are associated with undesirable aspects of personality, such as neuroticism and BIS. Furthermore, EOE and LST factors are associated with poorer social and communication skills as well as depression (Liss et al., 2005). These findings may reflect the two distinct groups of highly sensitive individuals identified by Aron and Aron (1997) who differed in introversion and neuroticism as a result of adverse parental environment. Evidence for differences in happiness and well-being across SPS factors identified by Smolewska et al. (2006) was explored in a study by Sobocko and Zelenski (2015).

In addition to replicating the three-factor solution, Sobocko and Zelenski (2015) assessed associations of the three (Smolewska et al., 2006) and two (Evans & Rothbart, 2008)

factor models of the HSPS with personality, well-being, and emotion. Findings from the first experiment (n=154) indicated that sensitivity types are differentially related to measures of positive and negative affect, suggesting the HSPS can capture sensitivity related to both positive and negative affect. The full HSPS, and EOE, LST and NA factors showed moderate positive correlations with measures of neuroticism and negative affect. They also showed negative correlations with extraversion and measures of subjective happiness. In contrast, both AES and OS factors show equal and significant positive correlations with measures of openness and positive affect. This suggests that AES and OS factors measure something different than other sensitivity factors. However, the OS factor was also positively correlated with neuroticism, which may be explained by the lack of pure sensory sensitivity items comprising that factor, as identified by Evans and Rothbart (2008). For example, the HSPS item “When you were a child, did parents or teachers seem to see you as sensitive or shy?” is part of the OS factor, according to 2-factor HSPS models (Evans & Rothbart, 2008; Sobocko & Zelenski, 2015), although it does not load onto the OS factor (-.01) but instead loads onto the NA factor (.36) in Evans and Rothbart (2008) 2-factor model. Also, the HSPS item, “Do other people’s mood affect you” is part of the OS factor, according to 2-factor HSPS models (Evans & Rothbart, 2008; Sobocko & Zelenski, 2015) but shows equal loading on NA and OS factors (.32) in Evans and Rothbart (2008) 2-factor model. Such mixed factor items should be excluded from scales that aim to capture OS. Indeed, Sobocko and Zelenski (2015) excluded the former (“shy”) item entirely, and both these items are not included in the very short HSPS with the 6 best items that directly assess SPS and the more diverse 12-item short HSPS (Aron & Aron, 2013).

### **Environmental Sensitivity: Two Outcomes of Sensitivity**

A recent conceptualization of the sensitive temperament is the “environmental sensitivity” framework that refers to variation in the sensitivity of an individual’s response to

external environmental stimuli (Pluess, 2015a). Based on genetic, physiological, and psychological evidence, the central mechanism of environmental sensitivity is proposed to be “neurobiological susceptibility” or “neurosensitivity”. Neurosensitivity is determined directly and interactively by genetic and environmental factors which result in a central nervous system responding more strongly to sensory stimulation in more sensitive individuals (Pluess, 2015a). Neurosensitivity may occur due to neuronal hyper-excitability resulting from reduced inhibitory control (i.e., disinhibition) and increased synaptic spine density, providing a mechanism whereby stimulation accumulates to threshold levels more rapidly in sensitive individuals (Homberg, Schubert, Asan, & Aron, 2016). Interestingly, cognitive disinhibition (i.e., reduced inhibition) plays an important role in the creative process (Kaufman, Kornilov, et al., 2010; Martindale, 1999).

Environmental sensitivity captures both negative and positive aspects of sensitivity within a single account (Pluess, 2015a), and incorporates ideas about sensory-processing sensitivity (Aron & Aron, 1997), differential susceptibility theory (DST; Belsky & Pluess, 2009a) and biological sensitivity to context theory (BSCT; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & Van IJzendoorn, 2011). The DST (Belsky & Pluess, 2009a) within the environmental sensitivity framework explains the two sides of sensitivity, and sensitivity to positive experiences that enhance potential for creativity would be on the positive side; a “vantage sensitivity”. The sensitive temperament is associated with disproportionate susceptibility to negative life events, i.e., the negative side of sensitivity similar to diathesis stress models (Monroe & Simons, 1991), and to positive life events showing positive side or “vantage sensitivity” (Pluess, 2015a; Pluess & Bartley, 2015; Pluess & Belsky, 2013). The endogenous attributes including temperament, physiology and variation in serotonergic and dopaminergic genes (e.g., 5-HTTLPR short alleles and DRD4 7-repeat) that lead to vulnerability to stressors (i.e., sensitive temperament) may also allow one to benefit more from an enriching environment (Belsky & Pluess, 2009a; Pluess, 2015a). Some individuals may

therefore show "vantage sensitivity" and gain disproportionate benefits of positive enriching environments along with resilience to negative experiences (Pluess & Belsky, 2013). Indeed, as mentioned above, recent evidence has identified two- or three-factors within the HSPS associated with different outcomes in personality, emotion and well-being (Aron & Aron, 1997; Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015). By a 2-factor solution, a negative affect (NA) factor is associated with negative aspects of sensitivity, such as negative emotion, neuroticism, and sensory discomfort, while a 3-factor solution splits NA into ease of excitation (EOE; e.g., "more sensitive to pain") and low sensory threshold (LST; e.g., "overwhelmed by strong sensory input") (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015). By a 2-factor solution, a second orienting sensitivity (OS) factor is associated with positive aspects of sensitivity, such as positive emotion and open personality, and a 3-factor solution characterizes largely the same set of items into a third factor of aesthetic sensitivity (e.g., "deeply moved by the arts") so both these factors relate to OS and will henceforth be considered as such. Vantage sensitivity may thus relate to measures of positive outcomes in sensitivity (i.e., OS and openness), and the addition of resilience, which may be associated with such positive outcomes, may be important for creativity. Indeed, the openness and sensitivity to experience consciousness, but with a resilience so as not to suffer, is one of the paradoxical characteristics of the creative person (Csikszentmihalyi, 1996). This project proposes and investigates the novel hypothesis that vantage sensitivity includes an orienting sensitivity factor as a positive outcome of the sensitive temperament due to positive experiences and thus provides a cognitive basis for the role of sensitivity in creative cognition, through the mechanisms of attention (Evans & Rothbart, 2007).

### **Orienting Sensitivity in the Emotion-Attention Framework**

The emotion-attention framework defines four temperament factors based on emotion and dispositional attention (Evans & Rothbart, 2007, 2008, 2009). This framework motivated



development of the adult temperament questionnaire (ATQ), which includes NA and OS as two of four major temperament factors also observed in the two-factor split of the HSPS (Evans & Rothbart, 2008). The ATQ expands the definition of NA beyond sensory discomfort (part of the HSPS) to include fear, sadness and frustration. The NA construct is an orthogonal construct to sensitivity, which is defined entirely by OS (Evans & Rothbart, 2007, 2008). OS is defined as the sensitivity of automatic reactive attention and includes subfactors associated with sensitivity to percepts, associations, and affect. OS is a correlate with openness to experience ( $r = .65$ ), which is surprising given that OS measures awareness of low intensity stimuli, and openness is a broad, complex personality construct consisting of insightfulness, reflection and imagination (Evans & Rothbart, 2007). Evans and Rothbart (2007) explain the relationship with the proposal that orienting sensitivity may be the biological substrate for openness, consistent with the general idea that temperament interacts with experience to “grow” personality (Goldsmith et al., 1987; Rothbart, Ahadi, & Evans, 2000; Shiner et al., 2012b; Zentner & Bates, 2008). The OS construct is distinct from effortful control (EC), essentially executive attention, which includes effortful attention, inhibition, and activation control constructs (Evans & Rothbart, 2007, 2008). The two attention components of the emotion-attention model load on to separate higher order factors. In one higher-order factor, negative affect is negatively correlated with effortful control, and another higher-order factor consists of positively correlated affiliativeness, positive emotionality, and orienting sensitivity (Evans & Rothbart, 2009). As sensory-processing sensitivity of the HSPS (Aron & Aron, 1997) may capture positive and negative affect-related of the sensitive temperament (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015), it is possible that sensory-processing sensitivity would overlap with both higher-order factors that are related to negative affect and its effortful control, and the positive emotionality associated with orienting attention sensitivity and openness. The

relative strengths of those higher-order factors in the sensitive temperament would be an index of the developmental outcome, in a similar way that relative strengths of BIS/BAS define Eysenckian extraversion (Gray, 1981). For example, high sensitivity with negative childhood experiences (Aron et al., 2005) and lower resilience through maladaptive emotional regulation strategies (Brindle et al., 2015) develops tendencies towards negative affect, and high sensitivity in positive enriching environments leads to positive life outcomes, such as higher OS, openness and creativity (Lin, Hsu, Chen, & Chang, 2013; Pluess, 2015b; Sobocko & Zelenski, 2015). The disproportionate susceptibility to life experience thus determines the relative strength of scores on the negative affect and positive emotionality dimensions of the ATQ.

### **Mechanisms of Creative Potential and Achievement in Sensitivity**

SPS, environmental sensitivity and orienting sensitivity provide unique but overlapping explanations of the sensitive temperament. Both SPS and environmental sensitivity explain both the negative and positive outcomes of the sensitive temperament, that is, a disproportionate susceptibility to negative outcomes following childhood adversity (Aron & Aron, 1997; Aron et al., 2005; Pluess, 2015a) but simultaneously the potential for disproportionate gain in the presence of positive enriching environments resulting in positive outcomes i.e., OS, openness and resilience of vantage sensitivity. The HSPS can capture both of the two outcomes as indicated by the two- and three-factor solutions of the HSPS (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015), which includes the Evans and Rothbart (2007) definition of sensitivity (i.e., orienting sensitivity) as something separate from negative affect. Evans and Rothbart's theory adds unique value as orienting sensitivity is an observable, objective cognitive ability of orienting attention. How different factors associated with the sensitive temperament are related to creativity has not been explored, except for one recent study using the ATQ by Lin and colleagues (2013).

## **Sensitivity, Affect and Creativity**

Different sensitivity factors may affect creativity differently because different factors of SPS (OS vs. NA, respectively) have been associated with positive and negative affect (Sobocko & Zelenski, 2015), which have been associated in different ways with creativity (Runco, 2014; Sawyer, 2012).

The broad two-factor temperament theory (Evans & Rothbart, 2009) splits OS and NA into different overarching factors, combining OS, positive affect/extraversion, and agreeability/affiliativeness into one global factor, and NA and effortful control into a second global factor, similar to the meta-traits of stability and plasticity in personality theory (DeYoung, Peterson, & Higgins, 2002; Digman, 1997). OS is positively associated with openness (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015), which is the personality trait most associated with higher creativity (Feist, 2010; Kaufman et al., 2016; Runco, 2014; Sawyer, 2012). Both OS (Sobocko & Zelenski, 2015) and openness (Steel, Schmidt, & Shultz, 2008) are associated with positive affect. For activating mood states (approach vs. avoidance), positive affect is associated with higher creativity, whereas negative affect is associated with lower creativity (De Dreu, Baas, & Nijstad, 2008; cf. Kaufmann, 2003). Thus, consistent with a “positive-mood-promotes-creativity” hypothesis, the sensitive temperament factors associated with positive affect (i.e., OS) may promote higher creativity, while ones associated with negative affect (i.e., NA, or EOE and LST) may lower creativity.

Consistent with this, Lin and colleagues (2013) found that ATQ OS correlates positively with creativity, as measured by verbal and figural insight problem-solving tasks and subscales (fluency, flexibility, originality, and elaboration) of the ATTA (Goff & Torrance, 2002), an objective test of divergent thinking. However, when OS, 6-factor personality traits, and IQ are considered independently in a hierarchical multiple regression, OS accounts for unique variance in insight but not for subscales of divergent thinking (Lin et al., 2013). This

suggests OS is related only to the illumination stage of the creative process (Lubart, 2001; Wallas, 1926) leading to insight. However, the HSPS and NA were not assessed, nor were interactions of sensitivity types and personality, or overall ATTA score, and the tests were Asian versions. The evidence that OS promotes creativity, while controlling for negative affect, would provide important support that creativity is a positive outcome of the sensitive temperament within a positive experiential environment; a vantage sensitivity (Pluess, 2015a, 2015b).

### **Orienting Attention**

The present evidence for a relationship between sensitivity and creativity is consistent with early behavioural and physiological evidence from Martindale and colleagues for the cognitive disinhibition and hemispheric asymmetry hypothesis of creativity (for reviews, see Kaufman, Kornilov, et al., 2010; Martindale, 1999), and this evidence is also consistent with a role for sensitivity of orienting attention in creativity. For example, Martindale et al. (1996) found that creative people, as defined by RAT and AUT performances, were more physiologically responsive with slower habituation of the orienting response to auditory stimulation (i.e., white noise). Thus creativity is associated with lower ability to habituate to sensory stimulation, which is associated with a higher OR. In addition, Aron and Aron (1997) noted that about 70% of highly sensitive people are introverts, and introverts show a higher physiological orienting response with moderate stimulation (Zahn, Kruesi, Leonard, & Rapoport, 1994) and are slower to habituate than extraverts at high levels of stimulation (for a review, see O'Gorman, 2016). However, this was based on the HSPS, and recent work indicates that OS is an independent factor from introversion (Evans & Rothbart, 2007). Thus early work suggests sensitivity is related to a higher orienting response, and higher sensitivity of the attention orienting system is associated with creativity.

The orienting response (OR) reflects activity in basic motivational systems for behavior (defensive vs. appetitive) that evolved to support perception, action, and ultimately, survival (Bradley, 2009). The function of the OR is to immediately orient attention towards novel, important and relevant events in the environment (Sokolov, 1963, 1990). The orienting response is associated with several brain electrical potentials, including the centro-parietal “novelty P300” ERP known as the late positive potential (LPP), or the orienting “O-wave” (Bradley, 2009; Polich, 2007). The O-wave, starting from 300 to 400 msec after presentation of simple stimuli, shows the largest modulation in response to arousing and emotionally significant (pleasant or unpleasant) images and responds similarly to the skin conductance response associated with orienting attention (for a review, see Bradley, 2009). The OR can be active/voluntary or passive/involuntary (Sokolov, 1990) and has a neural basis in the distributed dorsal and ventral fronto-parietal orienting attention networks (Barry et al., 2013; Chica, Bartolomeo, & Valero-Cabre, 2011; Corbetta & Shulman, 2002; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Knight, 1996; Posner & Rothbart, 2007; Posner, Rothbart, & Tang, 2015; Spreng, Mar, & Kim, 2009; Spreng, Sepulcre, Turner, Stevens, & Schacter, 2013). Thus early work on creativity suggested that sensitivity of the orienting attention networks is associated with creativity.

**Two modes of orienting sensitivity.** Temperament theory of Evans and Rothbart (2009) suggest that emotion and motivation form the basis of human temperament through processes of reactivity and self-regulation. Reactivity relates the emotional characteristics of the individual’s response to an event, a process inextricably linked with the orienting reflex (Bradley, 2009). Self-regulation is the process which modulates reactivity, which includes patterns of approach/avoidance, and attentional orientation and selection (for a review, see Rothbart, Derryberry, & Posner, 1994). Two modes of orienting present in this theory include the initial automatic orienting to important events, and the effortful, voluntary orienting

according to task goal (e.g., self-regulation). This thesis is, in part, focused on how sensitivity of the orienting attention system relates to temperament, personality and creativity.

To understand orienting sensitivity one must consider the processes underlying the dorsal and ventral attention networks that Rothbart and colleagues propose underlie this temperament. Orienting attention could reflect two modes that serve a single system (Jonides, 1981; Posner, Rafal, Choate, & Vaughan, 1985) or two independent systems (e.g., Muller & Rabbitt, 1989). Recent evidence suggests spatially distinct, functionally competitive but interactive neural systems that subserve internally and externally oriented cognitions (Chica, Lasaponara, et al., 2011; Corbetta & Shulman, 2002; Dixon, Fox, & Christoff, 2014; Fox, Spreng, Ellamil, Andrews-Hanna, & Christoff, 2015; Spreng et al., 2013). The dorsal network supports endogenous attention, and the ventral network supports exogenous attention. Endogenous orienting attention is voluntary, controlled internally, and oriented to spatial locations or non-spatial features of stimuli that are relevant to the task goal and long term cognitive strategies. For example, biasing attention towards colored spots if hungry, or sudden movements or animal-like shapes if fearing a predator (Connor, Egeth, & Yantis, 2004). Endogenous attention involves top-down feedback from dorsal lateral prefrontal cortex, frontal eye fields (FEF), and intraparietal (IPS), although FEF and IPS are also modulated by stimulus-driven attention, as during stimulus driven reorienting of attention to relevant targets (Corbetta & Shulman, 2002). The dorsal attention network has been suggested to be a multiple-demand system of attentional control for flexible cognition that has a necessary role in standard tests of fluid intelligence, such as problem solving (Crittenden & Duncan, 2014; Duncan, 2010, 2013; Erez & Duncan, 2015; Fedorenko, Duncan, & Kanwisher, 2013).

Exogenous orienting attention has been implicated in early processes of bottom-up, involuntary/automatic, stimulus-driven attention and re-orienting of attention (Corbetta & Shulman, 2002). Exogenous attention involves aligning attention either with incoming bottom-

up processing of relevant sensory stimulation, such as becoming aware of a colored potentially fruitful blob in a bush or the sudden movements of an approaching predator (Connor et al., 2004; Posner & Rothbart, 2007), or with explicit memory (Binder & Desai, 2011; Buckner, Andrews-Hanna, & Schacter, 2008), as described in the attention to memory model (Cabeza et al., 2011; Daselaar, Huijbers, Eklund, Moscovitch, & Cabeza, 2013). The neuroanatomy of the ventral frontoparietal exogenous attention network includes the TPJ and the ventral frontal cortex (VFC). The parts of the TPJ component of the ventral system may have a role in switching between exogenous and endogenous orienting. Connections between the TPJ and IPS act as a circuit breaker on the endogenous attention, reorienting attention to relevant, unexpected information detected using exogenous orienting attention (Corbetta & Shulman, 2002).

**Orienting sensitivity as ventral exogenous attention.** Evans and Rothbart (2007) originally defined orienting sensitivity in a way that suggests an emphasis on exogenous more than endogenous orienting of attention. However, the neuroimaging studies using the attention network task (ANT; Fan et al., 2005), and work by Posner that informed development of the two attention temperament constructs of the ATQ (OS, EC) focus primarily on endogenous or dorsal (anterior) attention network (for a review, see Rothbart et al., 1994). Nonetheless, orienting sensitivity was originally defined as reactive attention that is separate from effortful attention (Evans & Rothbart, 2007) and later defined as “automatic attention to both external sensory events and internal events”, such as spontaneously occurring thoughts and images (Evans & Rothbart, 2008). Spontaneity in the definition fits ideas about exogenous orienting attention and sudden awareness, placing emphasis on a process distinct from top-down intentional control of attention and cognition (Dixon et al., 2014).

Exogenous attention has been considered to be purely automatic but may not be entirely, as some studies have found it to be modified by endogenous orienting attention, which is thought to be effortful and intentional (Chica, 2012). Further, while endogenous orienting was thought to be more closely related to consciousness, recent work indicates that exogenous attention is more strongly linked to conscious perception than endogenous attention (Chica, 2012). Recent findings suggest that exogenous attention is necessary, but insufficient for conscious perception, whereas endogenous attention may not be necessary or sufficient (Chica & Bartolomeo, 2012; Chica, Lasaponara, et al., 2011). Consistent with the association between consciousness and exogenous orienting, the orienting sensitivity items ask about awareness (“aware”, “notice”, “detect”, and “consciously”) of subtle information from perceptual, emotional, and memory sources. Intriguingly, the sensitive individual has been characterized as being more consciously aware of stimuli (Aron et al., 2012). In addition, the ventral attention system has been implicated in unilateral neglect (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; Corbetta & Shulman, 2002), and neglect patients are highly insensitive to stimuli in space contralateral to the lateral parietal lesion. For example, lesions to the TPJ can result in visuospatial neglect which can cause deficits in orienting of attention (Friedrich, Egly, Rafal, & Beck, 1998), although considerable pre-attentive processing of neglected stimuli can still take place without reaching conscious awareness (Driver & Vuilleumier, 2001). Thus, while dysfunction of the ventral attention system results in stimulus insensitivity, high function of this system might result in high stimulus sensitivity, as in the sensitive temperament. How orienting sensitivity (Evans & Rothbart, 2007) and SPS (Aron & Aron, 1997) or environmental sensitivity (Pluess, 2015a) relate to cognitive measures of endogenous and exogenous attention processes is not yet established, yet they may play a critical role in the sensitive and creative person.



**Implications for creativity due to sensitivity of exogenous orienting.** As mentioned previously, the neurobiological account of Martindale (1999) suggests that cognitive disinhibition and hemispheric asymmetry reflect two separate stages of creative cognition (Kaufman, Kornilov, et al., 2010). Cognitive disinhibition facilitates internally directed thought processes, such as day-dreaming, fantasy and ideation, and the exogenous attention network monitors, detects and signals the mind to orient towards novelty. How then would sensitivity, as defined in this thesis, relate to creativity? We now talk about sensitivity in relation to theories of creative cognition, with a particular focus on orienting sensitivity. Orienting sensitivity represents a positive outcome (Sobocko & Zelenski, 2015), a vantage sensitivity (Pluess, 2015b), or a sensitivity without childhood adversity (Aron & Aron, 1997). Thus, orienting sensitivity captures positive outcomes of all three perspectives of the sensitive temperament reviewed herein.

This thesis investigates whether sensitivity affects cognitive processes that play a role in key parts of the creative process. The four-stage model of creativity (for a review, see Lubart, 2001; Wallas, 1926) breaks the creative process down into separate cognitive processes involving preparation, incubation, illumination and verification. In this model the creative process begins with conscious work on a problem, which is followed by unconscious work involving exploration and rejection of associations and ideations related to a solution. Illumination is characterized as a flash of enlightenment or insight (the “A-ha” moment) and occurs when an interesting idea springs into conscious awareness. The insight is followed by verification, evaluation and refinement of the idea. Stage models can be recursive, in which an individual can, for example, go back to incubation stage in order to resolve difficulties in verification. The original stage models were based on introspective evidence but have since received some empirical support (Lubart, 2001). The first stage of preparation involves information gathering. A primary function of the orienting reflex is information gathering

(Posner, 1980; Sokolov, 1963, 1990), and of particular importance would be orientation towards novelty. Novelty seeking is a behavioral trait associated with positive affect and openness to experience, both of which are orienting sensitivity correlates (DeYoung et al., 2002; DeYoung, Peterson, & Higgins, 2005; Evans & Rothbart, 2007; Sobocko & Zelenski, 2015). A sensitive orienting system would be more able to extract and encode information. During incubation, cognitive disinhibition, a proposed mechanism of neurosensitivity (Homberg et al., 2016), that could also result from low arousal and low effortful control, could facilitate spontaneous mind wandering, day-dreaming etc. Recall, the orienting attention reflex responds to relevant information, surprise and novelty. Whilst unconscious associative processes take place during incubation, a sensitive exogenous attention system could have a greater ability to orient towards and retrieve low threshold novel and surprising associations in memory and bring them to the forefront of consciousness in a spark of insight, or illumination (e.g., Lin et al., 2013). This would predict, for example, higher scores on tasks such as the RAT, which has been used to measure creativity and insight. Consistent with this, greater insight in RAT performance is associated with higher alpha EEG (Jung-Beeman et al., 2004; Kounios et al., 2008). Indeed, reductions in alpha are associated with increasing demands of endogenous attention (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Laufs et al., 2003). Thus greater alpha may reflect internally directed cognitions required for associative ideation (cf. Dietrich & Kanso, 2010; Fink & Benedek, 2014; Martindale & Armstrong, 1974a) and also exogenous attention processes implicated through anti-correlation of exogenous and endogenous attention networks.

The hemispheric asymmetry hypothesis of creativity may also account for the role of orienting attention sensitivity in creativity. Recall from Appendix A, the right hemispheric lateralization of attention networks associated with global hierarchical perception (Ivry &

Robertson, 1998). Global, diffused attention may facilitate RAT performance (Förster & Dannenberg, 2010; Mendelsohn, 1976), creative insight (Schooler & Melcher, 1995), cognitive flexibility (Nijstad, De Dreu, Rietzschel, & Baas, 2010) and divergent thinking (Förster & Dannenberg, 2010; Friedman, Fishbach, Förster, & Werth, 2003; Friedman & Förster, 2001). Orienting sensitivity may index diffused, exogenous attentional processes associated with global hierarchical perception. Thus, higher orienting sensitivity could be associated with higher RAT, insight, and DT performance.

### **Thesis Objectives**

The aim of this thesis is to determine individual differences in temperament and personality and associated perceptual and cognitive processing that characterize the creative person. The first aim is to establish relationships between temperament, personality and creative potential and achievement using state-of-the-art measures, which are primarily based on self-report plus one objective test of creativity. The second aim is to establish objective measures of the cognitive processes associated with the temperament and personality factors that are associated with creativity, thus providing a possible neurocognitive basis for creativity. This thesis recognises the global dimension of sensitive temperament, termed SPS or neurosensitivity, but explores multiple factor solutions of the HSPS that suggest an alternative global dimension, known as orienting sensitivity (OS).

## CHAPTER II

### **The Sensitive, Open Creator**

#### Abstract

Identifying a creative personality has been challenging. Sensitivity was implicated in creativity in early studies but more recently defined as a personality dimension with a biological basis. This laboratory study with a large diverse sample used multiple recently established sensitivity and creativity measures while controlling negative-affect and Big-Five personality traits. Only higher orienting sensitivity and openness personality are associated with higher creativity by all measures and independently predict creative achievement and ideation. Further, orienting sensitivity predicts creative achievement and products in open personalities, but conscientiousness also predicts products. Only positive-affect-related orienting sensitivity and openness primarily determine diverse creative abilities, providing needed evidence and strongest to date that high sensitive personality (“vantage sensitivity”) promotes creativity. Neural mechanisms of attention, plasticity genes, and latent-inhibition may explain why sensitive, open people are more creative.



## Introduction

The present study investigated the relationship between sensitivity and creativity, using multiple state-of-the-art measures of each that reflect recent advances, while controlling negative affect-related factors and Big Five dimensions. Sensitivity measures were reviewed in Chapter 1, and so this chapter begins with a brief review of literature focusing on the measurement of creative potential and achievement, because those concepts will be explored in relation to sensitivity.

### **Creativity: Concepts and Measurement**

Different conceptualizations of creativity tend to be associated with different measurements. One important distinction to make is that between creative potential and creative achievement, as the two concepts may not actually be related (Runco, 2014). Creative potential is a normally distributed, person-oriented little-c creativity and refers to an ability to produce new and useful ideas, whereas creative achievement is a positively skewed, product-oriented dimension referring to tangible big-C achievements, such as awards, patents, or publications (Carson, Peterson, & Higgins, 2005; Jauk, Benedek, Dunst, & Neubauer, 2013; Runco, 2014). In this project, we investigate how individual differences in temperament, personality and cognition relate to both creative potential and achievement, considered as two measures on a single continuum of creative magnitude.

**Measurement of Creative Potential.** Creative potential can be observed by measuring divergent thinking (DT) abilities. It was Guilford (1950) who linked divergent production (i.e., thinking) to creative potential. DT has been defined as the ability to give a diversity of responses to open-ended problems and, through ideation, this often leads to originality, a central feature of creativity (Runco & Acar, 2012). In the Structure of Intellect theory (Guilford, 1967), divergent thinking was defined as a major operation of the human intellect and something distinct from convergent thinking. Convergent thinking typically

leads to a conventional, correct response to a clearly defined question and is more often associated with intelligence (Gardner, 2011a). Although seemingly distinct, divergent and convergent thinking are thought to exist on a single divergence-convergence continuum (Eysenck, 1993; Runco, 2014), in which both styles of thinking are important for creativity (Cropley, 2006). Indicators of divergent thinking measure cognitive abilities such as fluency, flexibility, originality and elaboration, and whilst not considered the same as creative thinking, can be seen as an indicator of creative potential (Runco, 2014).

Divergent thinking tasks generally have adequate reliability (Runco & Acar, 2012), although reliability estimates of originality differ across verbal and figural DT tasks and may be over-inflated due to high correlations with the fluency factor. Fluency contaminates originality in verbal DT tasks (Hocevar, 1979b), but originality is reliable in figural DT tasks at certain levels of achievement (Runco & Albert, 1985). To counteract this problem, alternative scoring methods which control for the effect of fluency on originality are used (e.g., Benedek, Mühlmann, Jauk, & Neubauer, 2013).

The discriminant validity of DT tasks is questionable. For example, Wallach and Kogan (1965) show the relation between DT and intelligence depends on the task instructions given. That is, under test-like conditions, the discriminant validity is affected by low correlations between IQ and DT, but under game-like conditions there is no correlation. A re-analysis of Wallach and Kogan's (1965) data suggests that, whilst fluency is strongly related to originality, it also has a significantly modest positive relation with IQ (Silvia, 2008). The discriminant validity of DT measures is further complicated by the divergence-convergence continuum which suggests overlap between the two processes of divergent and convergent thinking (Runco & Acar, 2012).

Regarding convergent validity, DT tasks are positively correlated with various indexes of creative ability (for reviews, see Barron & Harrington, 1981; Batey & Furnham,

2006), including measures of real world creative achievements ( $r = .47$ ) across several domains (Carson et al., 2005), although a recent meta-analysis by Kim (2008) suggest the correlation is weak ( $r = .216$ ). Scores in DT tasks have also been shown to be three times better than intelligence measures at predicting creative achievements (Plucker, 1999). However, the predictive validity of DT tasks is unstable and influenced by testing conditions (e.g., game-like vs. test-like, timed vs. untimed, instructions to “be creative” vs. generic instructions) and may also be susceptible to training effects (Plucker & Makel, 2010).

While this seems to cast doubt on the validity of DT tasks as measures of creative potential, the use of creative achievements as criterion measures of divergent thinking have been criticised. Runco, Plucker, and Lim (2000-2001) argue that DT is a measure of ideation and the potential for problem solving, rather than past creative achievements. As such, DT tests are improperly validated when past creative accomplishments are used as the criterion measure, which may explain the moderate or low predictive validity found in studies of divergent thinking (Kim, 2008). The evidence of discriminant, convergent and predictive validity presented is therefore adequate considering DT tasks are not considered as synonymous with creativity, but rather as indicators of ideation and creative potential (Runco & Acar, 2012).

The Runco Ideational Behavioural Scale (RIBS; (Runco et al., 2000-2001) was designed to address the need for a more appropriate criterion measure when looking at the predictive validity of divergent thinking/creative ideation. The RIBS is based on the notion that ideas are products of original, divergent and creative thinking. The scale is a self-report measure of overt behaviours that clearly reflect an individual’s use, appreciation and skill with ideation. The RIBS shows good reliability (Cronbach’s  $\alpha > .9$ ) and discriminant validity with estimates of intellectual ability and other self-report measures of creative thinking. The short form RIBS-S has good reliability (Cronbach’s  $\alpha = .84$ ) and correlates highly with long



form RIBS-V ( $r = .94$ ). In addition, RIBS-V offers no incremental predictive validity over RIBS-S, which itself shows concurrent validity with measures of creative activities and achievement, accounting for 22% variance in scores. RIBS is positively correlated with openness to experience (Batey, Chamorro-Premuzic, & Furnham, 2010; Von Stumm, Chung, & Furnham, 2011), the Big-Five trait with the strongest relationship with creativity (Feist, 2010; Kaufman et al., 2016; Runco, 2014; Sawyer, 2012) and shows weak positive correlations with DT tasks (Ames & Runco, 2005; Plucker, Runco, & Lim, 2006; Von Stumm et al., 2011). Weak correlations between DT and RIBS are consistent with the ambiguous construct validity of the RIBS (Runco et al., 2000-2001), which suggests creative potential may be more adequately captured with both objective divergent thinking tasks and subjective, self-report measures of creative ideation.

Together, DT tasks and self-report creative ideation can be used to measure creative potential, the little-c creativity differing only in magnitude to Big-C creativity (Finke, Ward, & Smith, 1992; Smith, Ward, & Finke, 1995). As both measures capture little-c creativity, they are useful indicators of everyday creative ideation, problem-solving and insight which is normally distributed throughout the population (Kaufman & Beghetto, 2009) making any findings highly generalizable. Whilst DT tasks and creative ideation are not synonymous with creativity (Runco, 2014), they will help fulfil the aims of this thesis by providing insights into specific cognitive processes responsible for any magnitude of creative achievement (Finke et al., 1992; Smith et al., 1995) which may differ across temperament and personality traits.

**Measurement of Creative Achievement.** The best predictor of creative behavior may be past creative behavior (Colangelo, Kerr, Hallowell, Huesman, & Gaeth, 1992). For example, greater engagement in everyday creative activities (e.g., wrote a poem, designed a piece of music, made a present) predicts real world creative achievement. Self-report measures of creative achievement can focus on creative behavior, achievement and self-

perception (for reviews, see Jauk, Benedek, & Neubauer, 2014b; Plucker & Makel, 2010; Silvia, Wigert, Reiter-Palmon, & Kaufman, 2012). The Creative Achievements Questionnaire (CAQ; Carson et al., 2005) is a recent self-report measure that captures creative achievements across 10 domains, focusing on observable but uncommon big-C creative accomplishments. The CAQ has adequate reliability and validity; the internal consistency of the CAQ is high ( $\alpha = .96$ ); the predictive validity is evident with CAQ scores strongly positively correlated with ratings of creative products ( $r = .59$ ); convergent validity is demonstrated through moderate positive correlations with divergent thinking tests ( $r = .47$ ) and openness to experience ( $r = .33$ ), a personality trait associated with higher creativity (Carson et al., 2005). The CAQ also covaries well with other measures of self-reported creative behavior, achievement and self-perception (Silvia et al., 2012). CAQ has discriminant validity but shows weak positive correlations with IQ (Carson et al., 2005; Keri, 2011). The focus on capturing big-C creativity means that CAQ scores are severely skewed with most scores piling up at the lower end of the scale and relatively few scores indicating significant creative achievements. CAQ scores also tend to be over-dispersed with variances larger than the mean resulting from excessive zero scores. The nature of CAQ distributions mean that researchers should pay attention to the assumptions of common statistical analysis techniques, and use robust methods or data transformations where appropriate (Silvia et al., 2012).

### **Study Aims and Hypothesis**

It is recommended that in order to gain accurate measurement of big-C and little-c creative achievements, as many measures as possible should be employed, given the time and resources available (Silvia et al., 2012). Creativity measures used in this study were (1) the Runco Ideational Behaviour Scale (RIBS), which is a questionnaire about creative ideation (Runco et al., 2000-2001), (2) the Creative Achievement Questionnaire (CAQ), which inventories real-world creative achievements (Carson et al., 2005), and (3) the Abbreviated

Torrance Test for Adults (ATTA) (Goff & Torrance, 2002), which is a gold standard, objective and independently verifiable measure of creative products and divergent thinking abilities critical for creativity (Runco et al., 2014). The CAQ and ATTA are not personality questionnaires and thus avoid shared method variance.

Sensitivity measures used in this study include the Highly Sensitive Person Scale (HSPS; Aron & Aron, 1997) and the Adult Temperament Questionnaire (Evans & Rothbart, 2007) which includes Orienting Sensitivity (OS) and Negative Affect (NA) components. The Big-Five personality traits were assessed using the Big-Five Inventory (Benet-Martinez & John, 1998; John, Donahue, & Kentle, 1991; John, Naumann, & Soto, 2008) because of the importance of measuring sensitivity independent of related personality traits, in order to determine pure sensitivity effects independent of the Big-Five traits, in particular Neuroticism (Aron & Aron, 1997) and Openness (Evans & Rothbart, 2007).

(i) The primary hypothesis is that different factors of sensitivity have different relationships with creativity. (ii) For positive affect-related personality traits, OS improves creativity, and the association between creativity and openness depends on sensitivity, insofar as openness reflects experience interacting with sensitivity and other factors to develop personality (Evans & Rothbart, 2007), and this interaction will vary with different sensitivity factors (i.e., specific to OS). In addition, we expect positive correlations between (a) OS and openness (Evans & Rothbart, 2007; Sobocko & Zelenski, 2015) and (b) openness and creativity (Feist, 2010; Lin et al., 2013). (iii) For negative affect-related traits, neuroticism is related to lower creativity, and the association between neuroticism and creativity depends upon NA (or EOE/LST) factors. NA has been associated positively with both neuroticism and negative emotion but negatively with both extraversion and positive emotion, while OS shows no (Evans & Rothbart, 2007) or positive association depending on two or three factor

HSPS models (Sobocko & Zelenski, 2015). This suggests that any association between neuroticism and creativity may vary with negative affect-related sensitivity factors.

## **Method**

### **Participants**

Stable correlation estimates require a sample size approaching 250 (Schönbrodt & Perugini, 2013). A diverse sample of 288 (215 female; aged 18-67 years,  $M = 21.05$ ,  $SD = 5.02$ ; education 7 - 27 years,  $M = 14.93$  years,  $SD = 2.18$ ) of 297 participants recruited from University of Plymouth students ( $n=252$ ) and local communities ( $n=45$ ), excluding 9 who did not complete, were educated to postgraduate level ( $n=8$ ), bachelor's degree level ( $n=73$ ), A-level ( $n=170$ ), college and or other vocational course ( $n=21$ ), GCSE ( $n=3$ ) or other ( $n=13$ ). Participants received £8 per hour or course credit. Study approved by Human Ethics Committee in the Faculty of Science and Environment at University of Plymouth. Participants gave informed consent beforehand and were debriefed afterwards.

### **Apparatus and Materials**

The study was lab-based, ensuring participant motivation, compliance, and data integrity compared to prior studies of sensitivity and personality where items were answered online (Sobocko & Zelenski, 2015), at home (Smolewska et al., 2006) or at an unspecified location (Evans & Rothbart, 2008). An online computerized battery was developed on *SurveyMonkey* (surveymonkey.co.uk) to assess sensitivity, personality and creativity and administered in the lab. Each questionnaire was presented on a separate webpage. Participants used a mouse to tick the response that best applied from response options on the right of each item. Sensitivity was measured using two questionnaires. 1) The full 27-item HSPS (Aron & Aron, 1997) is a modality general, self-report scale measuring SPS using items asking about tendencies to startle easily, become easily overwhelmed by sensory inputs but also awareness of subtleties in the environment, and enjoyment of fine and delicate

scents, tastes, sounds, and works of art (Aron & Aron, 2013). Responses range from 1 (not at all) to 7 (extremely). 2) The 77-item, Adult Temperament Questionnaire (ATQ) short-form (Evans & Rothbart, 2007) is a self-report scale measuring 4 temperament constructs, including the 2 HSPS factors of OS and NA, as well as effortful control and extraversion/surgency. Responses range from 1 (extremely untrue) to 7 (extremely true) and “not applicable”.

Five dimensions of personality were measured using the 44-item, Big Five Inventory (BFI) self-report questionnaire of openness, conscientiousness, extraversion, agreeableness, neuroticism (BFI-O, C, E, A, N, respectively, henceforth) (Benet-Martinez & John, 1998; John et al., 1991; John et al., 2008); note, the first 43 participants also completed the full 48-item openness scale of the NEO-PI-R (Costa & McCrae, 1992), which includes all BFI-O items. Responses range from 1 (disagree strongly) to 5 (agree strongly). We were primarily interested in openness, which is related to sensitivity (Evans & Rothbart, 2008) and has most often been associated with creativity (Sawyer, 2012), and secondarily in neuroticism, as a measure of negative affect (Aron & Aron, 2013; Evans & Rothbart, 2007, 2008), and extraversion, which is a second personality factor sometimes linked to creativity (Sawyer, 2012) and inversely associated with sensitive temperament based on the HSPS (Aron et al., 2012; Sobocko & Zelenski, 2015).

Creativity was measured using three of the most established and validated measures. (1) The RIBS (Runco et al., 2000-2001; Runco et al., 2014) is a 19-item questionnaire designed to measure a single factor, creative ideation, and has discriminant validity (Runco et al., 2000-2001; Runco et al., 2014). Items probe behavioural tendencies and abilities about ideas and thinking, with many items emphasizing creative, unusual, or imaginative thought (e.g., “I have many wild ideas.”). Responses range from 1 (never) to 5 (very often). (2) The \*CAQ (Carson et al., 2005) is a self-report questionnaire of objective creative achievement

across 10 domains. Common method bias (CMB) is not a problem between RIBS and ATQ-OS. Based on factor analysis testing with a 1-factor solution, if the model accounts for less than 50%, the CMB is not a problem, in this case it was 22%, and common variance using AMOS indicated a value of 15%. CMB is not a problem between RIBS and HSPS. Based on factor analysis testing for a 1-factor solution, the model accounts for 20% variance and common variance using AMOS indicated a value of 21%. (3) The ATTA (Goff & Torrance, 2002) consists of 3 timed (3-minute) figural and verbal tests administered in paper format with a pencil and eraser, and could not be part of the *SurveyMonkey* battery.

This study was also lab-based in order to administer additional pencil and paper and computerized tests as part of multiple studies used in this thesis (study 1 with  $n = 43$ , study 2 with  $n = 99$  [see Chapter 4], study 3 with  $n = 65$  [see Chapter 5], study 4 with  $n = 80$  [see Chapter 6 & 7], study 5 with  $n = 29$ ). As recommended for HSPS research (Aron & Aron, 2013), negative affect was controlled using BFI-N, as recommended by Aron and Aron (2013), and using the ATQ-NA.

## **Procedure**

This study used a within subjects correlational design to explore relations between temperament, personality, affect, and creativity. Participants sat at a table in a room with the experimenter. Participants first completed the ATTA and then were given a *Toshiba Satellite* laptop and mouse to complete the *SurveyMonkey* battery (see above). Order of questionnaires was: CAQ, RIBS, HSPS, BFI, and ATQ. Participants were instructed that the task was not timed, to complete the questionnaires in their own time, and to give honest answers.

## **Analysis**

The items of the HSPS were analysed in full and split according to factors of sensitivity. Based on the 2-factor solution (Evans & Rothbart, 2008), 7 items measured OS (HSP-OS), and 18 items measured NA (HSP-NA), excluding 2 other items. Based on the 3-

factor solution (Smolewska et al., 2006), 12-items measured ease of excitation (HSP-EOE), 6-items measured low sensory threshold (HSP-LST), and 7 items measured aesthetic sensitivity; note, for the HSP-OS/AS factor, 5 items were the same as in the 2-factor HSP-OS, 1 was the same as in the 2-factor HSP-NA, and 1 was the only conscientiousness item; because 5 of 7 items are the same as the HSP-OS factor, and the HSP AS factor is mainly orienting sensitivity (Sobocko & Zelenski, 2015) plus components of NA and conscientious personality; henceforth, we refer to this as HSP-OS/AS. For the ATQ, we focused on the two factors associated with the HSPS: orienting sensitivity (ATQ-OS) and negative affect (ATQ-NA). Negative affect was taken into account (Aron et al., 2012) using the NA temperament factor of both the HSPS and the ATQ, and the BFI-Neuroticism personality factor, all of which assess negative affect as a trait. For completeness, we explored the remaining temperament factors of effortful control and extraversion/surgency for correlations with creativity and personality and the remaining BFI personality traits (conscientiousness, extraversion, agreeableness) for correlations with temperament and creativity.

Before analysis, missing data points were replaced with the mean score across all participants (not including excluded participants) for that particular item of the scale. Following this, all variables were scaled so values ranged between 0 and 1, as follows. CAQ and ATTA scores were scaled so the score was a percentage of the maximum score achieved by the highest scoring participant. CAQ scaled scores were:  $\text{participant CAQ score} / \text{max score (86)}$ . ATTA scaled scores were:  $\text{participant creative index} / \text{max score (92)}$ . RIBS scaled scores were:  $(\text{participant mean score for all items} - 1) / (\text{maximum possible mean score} - 1)$ . For personality and temperament scales, scaled scores for each factor in each scale were:  $(\text{participant factor mean score} - 1) / (\text{maximum possible mean score} - 1)$ . For the HSPS, each participant was scored using the mean for the full HSPS and mean scores for each HSP factor based on 2-factor (HSP-OS, HSP-NA) (Evans & Rothbart, 2008) and 3-factor solutions

(HSP-OS/AS, HSP-LST, and HSP-EOE) (Smolewska et al., 2006). For the ATQ, each participant was scored on each factor giving a mean factor score for OS, NA, EC, and ES. For the BFI, each participant was scored on each personality factor yielding a mean factor score for each trait. The assumptions of linear regression were first checked (i.e., linearity, normality, multicollinearity, homoscedasticity). If violations could not be corrected, we chose non-parametric alternatives to analysis (e.g., Spearman's Rho correlation). For regression analysis, we chose to test 6 models looking at the predictive power of sensitivity measures with and without personality variables as covariates. Moderated regressions were performed using PROCESS (Hayes, 2013).

## Results

### Descriptive Statistics

See Table 2.1 for descriptive statistics.

### Correlations

A Kolmogorov-Smirnov test indicated that HSP-NA and EOE factors and ATQ-OS, NA and EC factors were the only normally distributed variables ( $p > .05$ ; see Table 2.1 for skewness and kurtosis values). Table 2.1 summarizes non-parametric Spearman's Rho ( $r_s$ ) correlations (two-way;  $n=288$ ).

**Creativity and personality.** Correlations between creativity and the personality factors demonstrated that (a) OS was the only factor of sensitivity and the only temperament factor, and (b) openness to experience was the only personality factor that correlated positively with creativity, as defined by all three measures (CAQ, RIBS, ATTA). Thus higher OS and higher openness are related to higher creativity. Specifically, creativity, as measured by the CAQ and RIBS, correlated highly positively only with all three measures of OS, the ATQ-OS, HSP-OS, and HSP-OS/AS, and with openness personality. Creativity, as measured by the ATTA, showed small positive correlations only with sensitive temperament, as



captured by the ATQ-OS, and with openness personality. Notably, only the ATQ-OS and BFI-O correlated positively with all three creativity tests. While not our primary goal, for completeness, we report that the RIBS showed a weak significant negative correlation with ATQ-EC, which measures effortful control ( $r_s = -.177, p < .01$ ).

**Creativity.** RIBS was weakly positively correlated with both the CAQ and ATTA. CAQ was weakly positively correlated with ATTA.

**Creativity and personality.** CAQ and RIBS correlated highly positively only with all three measures of OS (ATQ-OS, HSP-OS, and HSP-OS/AS) and with openness, whereas ATTA showed small positive correlations only with ATQ-OS and openness.

## **Regression**

The correlations suggested that orienting sensitivity (especially for ATQ-OS) and openness, which are positive-affect-related factors (Sobocko & Zelenski, 2015), are most consistently positively related to creativity. This supports the primary hypothesis. Model 1 tested the hypotheses that sensitivity and openness predict creativity using all Big-Five factors and ATQ-OS and NA. The two-factor sensitivity model was selected because this emerged as the most consistent solution in factor analysis using HSPS, ATQ-OS and openness items (see Chapter 3). In Model 2, hierarchical regression analysis was used to identify and remove redundant variables, and Model 3 used moderated regression to determine potential interactions.

### **Simultaneous multiple regression.**

**Model 1.** Model 1 explained significant variance in creativity scores (Table 2.2). Fits were significant for creative achievement (CAQ):  $F(7, 280)=11.58, p<.001, R^2=.21$ ; Ideation (RIBS):  $F(7, 280)=25.87, p<.001, R^2=.38$ ; Products (ATTA):  $F(7, 280)=3.02, p<.01, R^2=.05$ . OS and openness explain unique variance in creative achievement (CAQ) and ideation (RIBS). Regarding ATTA, openness and conscientiousness explained unique variance.

**Refined model 2.** Model 1 was simplified by removing redundant and nonsignificant personality covariates: Extraversion, agreeableness and conscientiousness were removed in that order, and the model fit assessed at each change. To control negative-affect most completely for theoretical reasons (Aron & Aron, 2013), both ATQ-NA and neuroticism were always retained.

For CAQ and RIBS, no significant differences in model fit occurred at any stage ( $ps > .05$ ) so ATQ-OS and ATQ-NA, openness and neuroticism were retained. For the ATTA only, removing conscientiousness changed the model significantly,  $F(1,282) = 7.986$ ,  $p < .01$ , so conscientiousness was retained. Table 2.2 summarizes results for refined model 2, demonstrating openness was a unique predictor for all creativity measures. For CAQ and RIBS, ATQ-OS was a unique predictor. For ATTA, conscientiousness was a unique predictor. For all creativity measures, changes in fit between models 1 and 2 were not significant ( $ps > .05$ ). Note, model 2 fit remained unchanged after removing negative-affect variables (ATQ-NA and BFI-N: CAQ,  $ps > .768$ ; RIBS,  $ps > .562$ ; ATTA,  $ps > .150$ ), or when HSPS ( $ps > .231$ ) or HSP-OS/AS ( $ps > .230$ ) replaced ATQ-OS.

**Moderated regression: Model 3.** Moderated regression assessed whether openness (as an estimate of effects of experience and other factors manifesting in behavior patterns) as a predictor of creativity varies with sensitivity. Mean-centred variables were used to reduce potential multicollinearity between predictor variables. Model 3 for each creativity measure differed from Model 2 by adding the interaction term (BFI-O $\times$ ATQ-OS). Using PROCESS (Hayes, 2013), simple slopes analysis assessed interactions (Aiken & West, 1991), and significant interactions were probed using the Johnson-Neyman (1936). Table 2.2 summarizes results and Figure 2.1 plots the points among ATQ-OS values where the conditional effect of openness on creativity became significant (CAQ, ATTA) or not (RIBS).

*CAQ*. Fit was significant and significantly ~4% higher than model 2,  $F(1,282)=4.9$ ,  $p=.028$ . Both ATQ-OS and openness still explained unique variance with the 2-way interaction between openness and ATQ-OS included, and this was significant, explaining unique variance. Johnson-Neyman results (Figure 2.1a) showed that the conditional effect of openness on CAQ became significant at scaled ATQ-OS value of  $-.17$  below the mean,  $b=.12$ ,  $t(282)=1.97$ ,  $p=.05$ , and above, which includes 89.58% of participants. A caveat is that skewness of CAQ scores violates assumptions of parametric tests, and analyses using robust Poisson regression or log10 transforms (which yields the most normal distribution, though Shapiro-Wilks test of normality is significant,  $p=.044$ ) reveal independent effects but not the interaction.

*RIBS*. Fit was significant but nonsignificantly higher than model 2,  $F(1,282)=.386$ ,  $p=.535$ . Both ATQ-OS and openness still explained unique variance with the 2-way interaction between openness and ATQ-OS included, but this was not significant. Thus openness and ATQ-OS independently predict RIBS.

*ATTA*. Fit was significant and significantly higher than model 2,  $F(1,281)=5.57$ ,  $p=.017$ . Openness explained unique variance. The covariate of conscientiousness and the interaction product were also significant, explaining unique variance. Critically, the 2-way interaction between openness and ATQ-OS was significant at average levels of ATQ-OS and above. Johnson-Neyman results showed that the conditional effect of openness on ATTA became significant at scaled ATQ-OS values of  $-.04$  below the mean,  $b=.113$ ,  $t(281)=1.97$ ,  $p=.05$  and above, which includes 61.46% of participants.

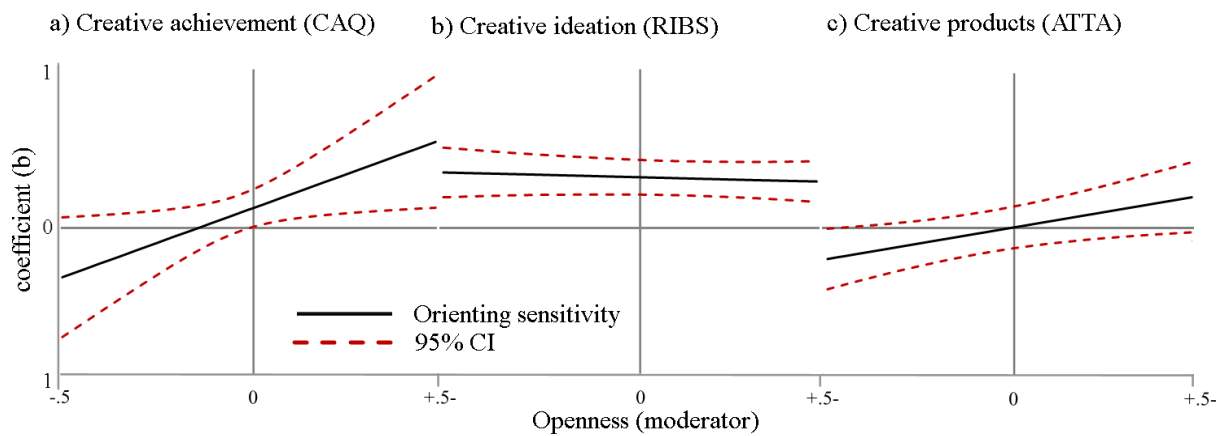


Figure 2.1. Model 3 conditional effects of openness on a) creative achievement (CAQ), b) creative ideation (RIBS) and c) creative products (ATTA) by levels of orienting-sensitivity, controlling negative-affect

*Negative-affect.* Results provided no evidence for the third hypothesis about negative-affect-related traits and creativity.

## Discussion

Overall, OS and openness, independently and/or interactively, underlie individual differences in diverse creative processes. Findings support the first two hypotheses: OS and openness are related to and predict creativity, and the relationship between openness and creativity increases with higher OS. No support was found for the third hypothesis that NA factors are related to creativity. Supporting the first hypothesis, only higher OS and openness are associated with higher creativity by all 3 measures. Further, only OS and openness independently predict creative achievement (CAQ) and ideation (RIBS). The second hypothesis is supported with the association between openness and creativity being moderated only by OS. Specifically, openness increases (i) creative achievement when OS is below average or higher and (ii) products (ATTA) when OS is average or higher. Thus, for the first time, OS and openness interact to predict creativity. These findings constitute the second empirical evidence for vantage sensitivity and the first in adults demonstrating

sensitivity benefits multiple creative processes, not just insight (Lin et al., 2013). Highly sensitive people are more creative.

Additional findings emerged. High correlations of openness with OS (Evans & Rothbart, 2007) and creativity replicated, the latter consistent with prior evidence that open personalities are more creative (e.g., Feist, 1998; Feist, 2010; Kaufman et al., 2016). Conscientiousness is weakly negatively related to OS and predicts higher creative products, although conscientiousness has a complex relationship with creativity that varies by task (King, McKee Walker, & Broyles, 1996; Runco, 2014). For correlations unrelated to the study aims, see Appendix B.

Altogether, the present findings provide strong evidence that people higher in OS are more open and creative, supporting early behavioural and physiological experiments associating sensitivity with creativity (for a review, see Martindale, 1999). Overall, findings to date indicate that OS predicts a wide range of creative processes associated with verbal and figural insight, achievement, ideation, and products (including divergent thinking). Our findings for openness and OS (on HSPS and ATQ), while controlling for NA, are consistent with those from a study using Asian versions (of ATQ and ATTA) and support cultural generalizability of OS as a strong indicator of creative potential. Lin and colleagues (2013) found openness predicts ATTA subscales and verbal insight on the remote associates task (RAT) when general intelligence is controlled. Further, ATQ-OS correlates with all ATTA subscales (fluency, flexibility, originality, elaboration) and verbal insight and predicts verbal and figural insight, but not ATTA subscales, when controlling for intelligence, 6 personality factors, and ATQ effortful control. In contrast, we found that, when conscientiousness and NA are controlled, openness predicts overall ATTA scores when OS is about average to high.

Altogether, the findings indicate that different creativity measures are associated with somewhat different processes. First, all creativity measures correlate but only moderately between achievement and ideation, which are weakly related to products; note, using the same measures, other studies did not find a correlation between total scores on achievement and products (Zabelina, Colzato, Beeman, & Hommel, 2016) perhaps due to smaller sample size ( $N=100$ ) yielding lower statistical power (Schönbrodt & Perugini, 2013). Second, OS and openness predict (a) creative ideation only independently, and (b) achievement both independently and interactively, and (c) openness predicts products alone and interactively with OS. Altogether, these findings suggest at least three personality-related processes underlie creativity: one for OS, a second for openness, and a third OS-openness interaction process that enables OS to influence the effect of openness on products and achievement. The present evidence that achievement involves multiple processes provides further evidence that multiple cognitive, personality and other individual differences contribute to real-world creative achievement (Carson et al., 2005; Eysenck, 1995; Jauk, Benedek, & Neubauer, 2014a), adding sensitivity to this list.

### **Mechanisms of the Sensitive, Open Creator**

Direct links between sensitivity, openness and creativity remain to be determined, but neural mechanisms of attention, dopamine, serotonin, and latent inhibition (LI) may explain why sensitive, open people are more creative (see Chapter 7). For example, an attentional-associative model of creativity (Schmajuk, Aziz, & Bates, 2009) proposes neural mechanisms that link attention, dopamine, learning and memory, and creativity, and we suggest may link these to sensitivity and openness. The model assumes that creative people attend more to novel stimuli and explains how enhanced attention to novelty improves creative processes but impairs generalization and LI. LI is a reduction in learning of a specific stimulus because that stimulus had been experienced previously as irrelevant. Therefore, when LI is lower, classical

conditioning effects become greater (i.e., learning improves). LI is due to memory retrieval mechanisms and attention processes within a "default automatic processing mode" (Lubow & Gewirtz, 1995; Lubow & Kaplan, 2005) which resembles the automatic reactive attention underlying OS. In the model, an increase in dopaminergic activity enhances effects of novelty on attention, thereby increasing attention and decreasing LI. Lower LI is thus associated with increased attention to previously-experienced irrelevant stimuli (i.e., as if they are more novel), and this manifests as a lower attentional gating threshold for sensory stimulation. Consequently, people with low LI show improved creativity on tests that involve these novelty, attention, and memory mechanisms, such as insight on the RAT and divergent thinking (ATTA) tasks.

Support for this model implicates evolutionary, genetic and epigenetic, developmental, and neural mechanisms that involve default or automatic reactive attention systems interacting with other attention and cognitive control systems, LI and "plasticity genes", especially those for dopamine systems. Regarding links with creativity, dopamine variation is related to creativity (Jauk, Neubauer, Dunst, Fink, & Benedek, 2015), and lower LI is associated with higher creativity (Carson et al., 2003; Chirila & Feldman, 2012). Further, neurophysiology (i.e., a P50) supports the idea that stronger very early, automatic attentional capture by an external stimulus ("sensory gating"), which is related to low LI, is associated with higher creativity (Zabelina, O'Leary, Pornpattananangkul, Nusslock, & Beeman, 2015; Zabelina, Saporta, & Beeman, 2016). Low LI is proposed to be a form of cognitive disinhibition that enables awareness of more information for creative association (Carson, 2014b). According to the cognitive disinhibition theory of creativity (Eysenck, 1995; Kaufman, Kornilov, et al., 2010; Martindale, 1999), highly creative people have lower cognitive inhibition due to frontal lobe de-activation, especially in the right hemisphere.

This theory and the attentional-associative model of creativity are consistent with evidence implicating anti-correlated attention networks for internally and externally directed cognition (Dixon et al., 2014) in creativity and studies linking ‘disinhibition‘ (Takeuchi et al., 2011), increased grey matter volume (Jauk et al., 2015; Kuhn et al., 2013), density (Fink et al., 2013) and function (Fink et al., 2012) of areas of a default mode network (DMN) with divergent thinking. The DMN is the large-scale frontoparietal cortical network for attention and cognitive control that has been most strongly implicated in creativity (Beaty, Benedek, Kaufman, & Silvia, 2015; Beaty, Benedek, Silvia, & Schacter, 2016; Beaty et al., 2014; Beaty, Kaufman, et al., 2016; Jagiellowicz et al., 2011; Jauk et al., 2015) contributes to creativity interactively with other frontoparietal attention and cognitive control networks, see Chapter 1.

Other evidence links sensitivity and openness with creativity, DMN attention, LI, dopamine, and plasticity genes. Regarding openness, lower LI is associated with higher openness (Peterson & Carson, 2000) and higher creative achievement, especially in highly intelligent people, suggesting creative people are more open to environmental stimuli (Carson et al., 2003; Chirila & Feldman, 2012; Keri, 2011). Such findings motivated a shared vulnerability model of creativity and psychopathology (Carson, 2014b) when combined with evidence that LI is low in people with schizotypal personality and schizophrenia, especially the acute form, and dopamine abnormalities in schizophrenia are associated with low LI (e.g., Carson, 2014b; Nelson & Rawlings, 2010).

Both sensitivity and openness have been associated with ‘plasticity’ genes, including genetic variation in the dopaminergic system that have roles in attention (Deyoung, 2013; Deyoung et al., 2011; Jauk et al., 2015; Pluess, 2015a, 2015b; Pluess & Belsky, 2013). DRD4 dopamine variants are associated with both sensitivity and openness. However, sensitivity has also been linked indirectly to the serotonin 5-HTTLPR variant (Aron et al., 2012; Homberg et



al., 2016), whereas openness is linked to COMT genes (catechol-O-methyltransferase - an enzyme that degrades dopamine and important for synaptic clearance) that affect the cortex and may be important for cognitive exploration (DeYoung, 2014) and creativity, as in divergent thinking and achievement (Zabelina, Colzato, et al., 2016). Similar genetics of sensitivity and openness could explain their interactions for creativity, while differences could explain their independent effects.

Consistent with attentional-associative model of creativity (Schmajuk et al., 2009), the sensitive behavioural profile suggests lower LI and greater automatic attention. HSPs seem to have a nonconscious tendency to attend irrelevant stimuli, i.e., trouble ignoring or filtering them out (Rizzo-Sierra, Duran, & Leon-Sarmiento, 2011), and, in lower LI, attention to previously irrelevant stimuli increases. Further, early work implicated automatic attention as a mechanism linking sensitivity and creativity. Specifically, early work defined sensitivity as less habituation to white noise, and this sensitivity was associated with creative potential (i.e., divergent thinking) and higher skin conductance response (Gearhart, 2014; Martindale et al., 1996), which indexes an automatic attention orienting response (OR) to irrelevant stimulation, but also greater novelty detection (Barry et al., 2013; Bradley, 2009).

Sensitivity and openness, alone among the big five factors, have both been associated with activity in the DMN, which suggests automatic reactive attention in the DMN links sensitivity, openness, and creativity. Both openness and creativity are associated with increased connectivity in the DMN (DeYoung, 2014), and openness is associated with the spatial distribution of automatic exogenous orienting attention (as defined by inhibition of return), a function of the DMN (Wilson, Lowe, Ruppel, Pratt, & Ferber, 2016). Both sensitivity frameworks imply an attention mechanism, and behavioural, brain imaging, and genetic findings support the idea that sensitivity affects attention (Aron et al., 2012). Neurobiological sensitivity in the environmental sensitivity framework could affect attention

systems (Kantor-Marynuska, 2012). The emotion-attention framework defines OS as differences in automatic reactive attention (Evans & Rothbart, 2007, 2008). Indeed, evidence reviewed in Chapter 4 links sensitivity to variations in attention networks associated with frontoparietal control and right lateralised exogenous orienting (Jagiellowicz et al., 2011), part of the DMN (Spreng et al., 2013). Right lateralisation of sensitivity effects is consistent with right hemisphere contributions to global, diffuse attention (Ivry & Robertson, 1998), insight (Förster & Dannenberg, 2010; Mendelsohn, 1976; Schooler & Melcher, 1995), and the hemispheric asymmetry hypothesis of creativity that posits a particularly important role for the right hemisphere (Kaufman, Kornilov, et al., 2010). The aim of Chapter 4 and Chapter 5 is to explore the relation between attention networks, sensitivity, personality, and creativity and to provide the first behavioural evidence that attention mechanisms partially explain the relationship between sensitivity, openness and creativity.

### **Relationship between Sensitivity and Openness**

Sensory sensitivity has been acknowledged as an aspect of openness (Shiner et al., 2012a; Shiner & DeYoung, 2013b) in part due to correlations between OS and openness (Evans & Rothbart, 2007), but SPS has been called a higher-order personality trait (Pluess & Boniwell, 2015a), and, as Aron and Aron (1997) suggested, the Big Five traits may not capture sensitivity adequately, and thus, openness does not capture sensitivity fully. This conclusion is supported by our findings that sensitivity and openness are related but not identical, and OS promotes creativity strongly independently and/or interactively with openness (i.e., OS predicts creativity even after controlling for openness). As OS and openness correlate imperfectly ( $r_s$  up to .62), OS only partially explains openness. Further, OS influences negative affect-related personality traits slightly, as indicated by mostly small correlations of OS factors with neuroticism and of HSP-OS additionally with introversion,

whereas openness shows no correlations with these personality traits. Such differences between OS and openness may underlie their ability to independently predict creativity.

This conclusion may be limited by the use of short-forms of the ATQ-OS and BFI-O here as the incremental predictive validity of these two measures needs to be determined. However, short-forms do capture the core of each trait independent of other traits (Aron & Aron, 2013; Evans & Rothbart, 2008; John et al., 2008) so if short-forms miss sensitivity then the core definitions of the personality domains may be inadequate. Further, these short-forms have high reliability and validity, and both the HSPS and the ATQ-OS have good discriminant validity from personality factors “suggesting that sensitivity is not fully contained within the Big Five” (Aron & Aron, 1997). Also, our factor analysis (see Chapter 3) identified NA, OS, and openness as independent factors. Further, here, long-forms of the ATQ-OS and NEO-PI-R openness were used for 43 subjects, and, with the normal regression models (and controlling for NA), ATQ-OS accounts for unique variance in RIBS scores when controlling for full openness ( $p < .01$ ), which alone does not account for unique variance; no other effects were significant, presumably due to low power with this small sample. Finally, factor analysis of many personality and temperament scales in preschool children yields no evidence for an independent openness component but shows that OS is one of six higher-order factors and loads only on temperament scales (De Pauw, Mervielde, & Van Leeuwen, 2009).

Altogether, this suggests that either a) openness and sensitivity are different dimensions, or b) definitions and assessments of openness need to capture sensitivity better, and, if the latter, OS captures a biologically-based core of openness. Chapter 3 elaborates further on the relation between openness to experience, HSPS and ATQ-OS with supporting evidence from factor analysis of the HSPS alone, and combined with the ATQ-OS and BFI-O

with the main aim to determine whether the orienting sensitivity factor of sensitivity measures is separate from, but related to, the openness personality trait.

## **Conclusions**

Individual differences in positive affect-related personality factors of OS and openness have major roles in determining a wide range of creative cognitive abilities: achievement-related processes, ideation, divergent thinking and insight. Different factors that have been associated with the HSPS (i.e., OS vs. NA, respectively) are related to positive versus negative affect-related Big Five factors (i.e., openness vs. neuroticism, respectively). Positive affect-related personality factors influence creativity, even when negative affect is controlled: higher OS and openness personality predict higher creativity. How they do so varies with the creative process: OS and openness both independently and uniquely predict creative achievement and ideation, and openness independently predicts creative products, but openness further predicts products and achievement with increasing sensitivity. Creativity is thus a benefit of the sensitive personality (“vantage sensitivity”) but especially so when higher OS develops into higher openness. The present evidence highlights the OS component of sensitivity is the most important for creativity. Multiple processes or factors underlie the relationship between OS, openness and creativity. Definitions and assessments of openness may need to capture sensitivity better, and OS may be a biologically-based core of openness. Individual differences research on creativity should focus more on higher-order personality factors that reflect stable, fundamental physiological and related behavioural characteristics that comprise the biologically-based core of personality. Future work will need to determine the underlying mechanisms by which OS and openness determine creative cognition by investigating evolutionary, genetic and epigenetic, developmental, and neural bases (i.e., neurobiological sensitivity and sensitivity of exogenous orienting or global attention in the

DMN interacting with other frontoparietal attention systems), “plasticity genes” in dopamine and serotonin systems, and LI.

## Tables

Table 2.1

*Descriptive statistics and non-Parametric Spearman's Rho ( $r_s$ ) correlations (N=288)*

		<i>Creativity</i>			<i>Descriptive</i>		
		CAQ	RIBS	ATTA	Raw. $\mu$	Scale. $\mu$	SD
<i>Creativity</i>							
Creative Achievement Questionnaire	CAQ	-			9.61	.11	1.00
Runco Ideational Behaviour Scale	RIBS	.343***	-		2.95	.49	.68
Abbreviated Torrance Test for Adults	ATTA	.153**	.279***	-	67.86	.74	.85
<i>Temperament factors</i>							
Highly-Sensitive Person Scale	HSPS	.247***	.300***	.083	4.15	.53	.77
Orienting Sensitivity	HSP-OS	.410***	.489***	.201***	4.44	.57	.81
Negative Affect	HSP-NA	.153**	.186**	.019	4.05	.51	.79
Orienting/Aesthetic Sensitivity	HSP-OS/AS	.459***	.555***	.236***	4.42	.57	.92
Ease-of-excitation	HSP-EOE	.093	.171**	-.007	4.51	.59	.78
Low-sensory-threshold	HSP-LST	.185**	.187***	.072	3.43	.40	.95
Adult Temperament Questionnaire	ATQ						
Orienting Sensitivity	ATQ-OS	.442***	.561***	.201***	4.58	.60	.13
Negative Affect	ATQ-NA	.072	.095	.031	4.09	.51	.12
Effortful Control	ATQ-EC	-.112	-.177**	.105	3.90	.48	.78
Extraversion/Surgency	ATQ_ES	.100	.064	-.075	4.61	.60	.68
<i>Big-Five Inventory of Personality</i>	BFI						
Openness	BFI-O	.456***	.530***	.253***	3.24	.56	.85
Conscientiousness	BFI-C	-.109	-.117*	.084	3.38	.59	.94
Extraversion	BFI-E	.123*	.103	.046	3.26	.56	.91
Agreeableness	BFI-A	.010	-.058	-.158**	3.76	.69	.75
Neuroticism	BFI-N	.086	.113	.083	3.17	.54	1.00

*Note.* 2-tailed significance: \*  $p < 0.05$  level, \*\*  $p < .01$ , \*\*\*  $p < .001$ . Raw.  $\mu$  = Raw mean score. Scale  $\mu$  = Scaled mean score. SD = standard deviation for scaled scores. Raw ATQ and HSPS scores = (score\*6)+1, raw personality and RIBS scores = (score\*4)+1, raw ATTA scores = score\*92, raw CAQ scores = score\*86.

Table 2.2

Summary of hierarchical multiple regression (Models 1-3) predicting creative achievement

(CAQ), creative ideation (RIBS), and creative products (ATTA)

	CAQ	RIBS	ATTA
	Beta	Beta	Beta
<b>Model 1</b>			
ATQ-OS	.163*	.343***	.030
ATQ-NA	.023	.056	-.022
BFI-O	.329***	.324***	.163*
BFI-C	-.091	-.032	.182**
BFI-E	.044	.089	.029
BFI-A	.000	-.034	-.092
BFI-N	-.017	.024	.120
<b>Refined model 2</b>			
ATQ-OS	.168*	.345***	.023
ATQ-NA	.008	.039	-.018
BFI-O	.343***	.338***	.171*
BFI-N	-.016	.003	.115
BFI-C	-	-	.166*
<b>Moderated regression model 3</b>			
ATQ-OS	.135*	.35***	.005
BFI-O	.362***	.335***	.18*
ATQ-OS × BFI-O	.171*	-.024	.09*
ATQ-NA	-.03	.044	-.038
BFI-N	.008	0	.127
BFI-C	-	-	.162*

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ . Beta = standardized coefficients.

## CHAPTER III

### **Sensitivity and Openness: A Factor Analysis**

#### Abstract

Factor analysis was used to explore the factor structure of the Highly Sensitive Person Scale (HSPS) alone, and together with the Adult Temperament Questionnaire Orienting Sensitivity (ATQ-OS) and Big Five Inventory Openness (BFI-O) factors, with the goal of establishing whether the OS factor of the HSPS and ATQ-OS relates to, but is separate from, the openness personality trait.

The factor analysis supports previous findings that the HSPS is best characterised by a three factor (Smolewska et al., 2006; Sobocko & Zelenski, 2015) or two factor model (Evans & Rothbart, 2008) in contrast to the unidimensional view of sensory-processing sensitivity (Aron & Aron, 1997). When HSPS, ATQ-OS and BFI-O are combined, results indicate that negative affect, OS, and openness emerge as distinct factors, with discriminant validity demonstrated between highly positively correlated OS and openness factors. Findings are consistent with the idea that OS is one distinct, but related factor that contributes to the development of openness personality (Evans & Rothbart, 2007, 2008).





## Introduction

There are several aims to this factor analysis described below, but the ultimate goal is to look for evidence that the orienting sensitivity factor of the HSPS and ATQ OS is related to, but separate from, openness personality trait. This evidence can justify the use of orienting sensitivity measures in addition to openness measures in studies of creativity, but will also show the inadequacy of the BFI-O measure for capturing the related but important construct of orienting sensitivity (see Chapter 2), given that some argue orienting sensitivity may be subsumed under the openness trait (Shiner et al., 2012b; Shiner & DeYoung, 2013a).

Aim 1: We will use exploratory factor analysis to explore the factor structure of HSPS. Previous research suggests a 2 (Evans & Rothbart, 2008) or 3 factor solution (Smolewska et al., 2006). Principal components analysis will identify an underlying factor structure, and CFA is used to analyse the model fit in relation to the unidimensional account of SPS, and with other multi-factor solutions.

Aim 2: Considering the HSPS is thought to be NA heavy (Evans & Rothbart, 2008), we will combine the ATQ OS with the HSPS to explore the factor structure thus balancing approximately the OS and NA items. Again, a unidimensional model of combined HSPS and ATQ OS will be compared with the multifactor models.

Aim 3: We will combine the HSPS, ATQ OS and Openness measures and explore which factors emerge. If openness and orienting sensitivity are the same construct, we would expect only two factors to emerge, a negative affect factor, and an orienting sensitivity/openness factor. However, if orienting sensitivity and openness are separate, we expect three factors to emerge. Following the PCA, we use CFA in two ways. First, the independence of the overarching latent sensitivity and openness structure will be tested using the existing measures loading onto a single

factor, i.e., all items measure only a single openness or sensitivity construct. Second, the factor structures emerging from the PCA will be compared with the unidimensional model. Finally, to look for independence between the OS and openness factors, a 2 factor structure consisting of NA and Openness/OS (OS and BFI O combined into a single factor) will be compared to the three factor structure emerging from the PCA showing OS and openness are independent but related factors.

### **Confirmatory Factor Analysis: Model Fit Indices Explained**

For model fits, we look at converging evidence from chi-square, RMSEA, CFI and AIC (Kline, 2015). Chi-square compares model fits to a perfect “just-identified” model fit. Chi-square is a “badness of fit” statistic in which larger values indicate a models greater deviance from explaining the data. Thus, smaller chi-squares and failure to reject the null hypothesis suggests a good model. However, chi-square is implausible to ask for a perfect fit to the data, furthermore such a model is not interesting. The chi-square is also very sensitive to sample size, thus converging evidence is required using several fit statistics. The RMSEA is a “badness of fit” index where values close to zero indicate a good fit, and higher values indicate a bad fit. RMSEA scores  $\leq .05$  indicate a close approximate fit, values between .05 and .08 indicate reasonable error in approximation, values between .08 and .1 indicate a mediocre fit, and values  $> .1$  indicate a poor fit (MacCallum, Browne, & Sugawara, 1996). The CFI is a comparative fit index, which compares model fit to a baseline (Kline, 2015). For the CFI, values  $< .90$  indicate a poor fit (Hu & Bentler, 1999). The Akaike Information Criterion (AIC) is a comparative fit used when comparing two models, and the smaller number of the two is the best fitting model (Kline, 2015).

## Method

### Participants

A diverse sample reported previously in Chapter 2 consisted of 288 (215 female; aged 18-67 years,  $M=21.05$ ,  $SD=5.02$ ; education 7 - 27 years,  $M=14.93$  years,  $SD=2.18$ ) of 297 participants recruited from University of Plymouth students ( $n=252$ ) and local communities ( $n=45$ ), excluding 9 who did not complete, were educated to postgraduate level ( $n=8$ ), bachelor's degree level ( $n=73$ ), A-level ( $n=170$ ), college and or other vocational course ( $n=21$ ), GCSE ( $n=3$ ) or other ( $n=13$ ). Participants received £8 per hour or course credit. Study approved by Human Ethics Committee in the Faculty of Science and Environment at University of Plymouth. Participants gave informed consent beforehand and were debriefed afterwards.

### Apparatus and Materials

The study was lab-based as reported in Chapter 2. An online computerized battery was developed on *SurveyMonkey* ([surveymonkey.co.uk](http://surveymonkey.co.uk)) to assess sensitivity, personality and creativity and administered in the lab. However, this factor analysis will focus specifically on temperament and personality. Each questionnaire was presented on a separate webpage. Participants used a mouse to tick the response that best applied from response options on the right of each item. Sensitivity was measured using two questionnaires. 1) The full 27-item HSPS (Aron & Aron, 1997) is a modality general, self-report scale measuring SPS and responses range from 1 (not at all) to 7 (extremely). 2) The 77-item, Adult Temperament Questionnaire (ATQ) short-form (Evans & Rothbart, 2007) is a self-report scale measuring 4 temperament constructs, including the 2 HSPS factors of OS and NA, as well as effortful control and extraversion/surgency. Responses range from 1 (extremely untrue) to 7 (extremely true) and "not applicable". This factor analysis uses only the ATQ OS factor from the ATQ.

Five dimensions of personality were measured using the 44-item, Big Five Inventory (BFI) self-report questionnaire of openness, conscientiousness, extraversion, agreeableness, neuroticism (BFI-O, C, E, A, N, respectively, henceforth) (Benet-Martinez & John, 1998; John et al., 1991; John et al., 2008). Responses range from 1 (disagree strongly) to 5 (agree strongly). This factor analysis uses only BFI O from the Big Five Inventory.

### **Factor Analysis**

Each principal components analysis was conducted with direct oblimin oblique rotations ( $\delta=0$ ). The Kaiser-Meyer-Olkin (KMO) measure verified sampling adequacy for the analysis if  $KMO > .5$  (Cerny & Kaiser, 1977). Items were retained based on factor loadings  $\geq .3$ ; the mean of criteria used by Evans and Rothbart (2008) and Smolewska et al. (2006). When an item loaded on two factors, it was also excluded from further analysis. Confirmatory factor analysis was performed using Amos (SPSS Version 22).

## **Results**

### **Aim 1: Explore and Replicate Factor Structure of the HSPS**

Principal components analysis was conducted on the 27-item HSPS. The  $KMO = .89$  verified sampling adequacy, and the Bartlett's test of Sphericity,  $\chi^2(351) = 6005.21, p < .001$ , indicates that correlations between items were large enough for PCA. The Velicer minimum average partial (MAP) test (O'Connor, 2000) suggested the extraction of three components, consistent with the Smolewska et al. (2006) three factor model of the HSPS. Table 3.1 shows the factor matrix of rotated components. Three components explained 43.06% of the variance. Item 4 was not retained as it did not meet the loading criteria, and items 19, and 21 loaded on two factors and were thus excluded. For comparison purposes and in line with theory and evidence provided by Evans and Rothbart (2008), we also forced the extraction of two factors (loadings

not reported) for comparison in the later stages of analysis. The 2-factor model explained 37.81% of the variance. A single item did not reach loading criteria (item 20) and was thus removed from future analysis.

**Confirmatory factor analysis of the HSPS.** Confirmatory factor analysis was used to test the model fit of the HSPS factor structure identified using the PCA. First, the unidimensional model of the HSPS was tested. For the unidimensional model, the model fit was poor  $\chi^2(324)=1136.06$ ,  $p<.001$ , CFI=.698, RMSEA=.093, 90% CI [.09, .1], AIC=2485.1. The two factor model was a mediocre fit,  $\chi^2(298)=882.05$ ,  $p<.001$ , CFI=.781, RMSEA=.083, 90% CI [.076, .089], AIC=988.05. A positive correlation was found between NA and OS factors ( $r=.51$ ). For the three factor model, the model fit was reasonable,  $\chi^2(272)=668.48$ ,  $p<.001$ , CFI=.831, RMSEA=.071, 90% CI [.064, .078], AIC=774.48. Correlations between EOE and LST were high ( $r=.74$ ) and moderate between EOE/LST and OS ( $r=.45$ ,  $r=.5$ , respectively).

The three factor model provides a better fit to the data than the unidimensional one factor model  $\chi^2_{\text{diff}}(52)=467.52$ ,  $p<.001$ , as did the two-factor model  $\chi^2_{\text{diff}}(26)=254.01$ ,  $p<.001$ . However, the three factor model provides a better fit than the two factor model  $\chi^2_{\text{diff}}(26)=213.51$ ,  $p<.001$ . In comparison to Smolewska et al. (2006) factor analysis, the OS factor in Table 3.1 shares five (items 2,8,10,12,15,22) out of seven items, the EOE shares six (items 14, 16, 20, 21, 23, 24) out of twelve items, and LST shares four (items 7, 9, 18, 25) out of six items reported by Smolewska et al. (2006). The reliability coefficients and mean inter-item correlations are also very similar to those reported previously (Smolewska et al., 2006), although not directly comparable as each factor consists of different items.

The evidence suggests that the HSPS is best characterised by a three factor (Smolewska et al., 2006; Sobocko & Zelenski, 2015) or two factor model (Evans & Rothbart, 2008).

However, regarding the three factor model, the high correlation between LST and EOE may suggest a two factor interpretation given the limitations of factor analysis. That is, both LST and EOE factors may represent negative affect at different levels of the same conceptual hierarchy, i.e., one general factor and one sub factor, but factor analysis is unable to detect this problem and would thus treat items representing a single NA factor as two different factors (Evans & Rothbart, 2008).

### **Aim 2: Explore Factor Structure of HSPS and ATQ OS Combined**

Principal components analysis was conducted on the 27-item HSPS combined with 15-item ATQ OS. The KMO=.87 verified sampling adequacy, and the Bartlett's test of Sphericity,  $\chi^2(861)=4507.18, p <.001$ , indicates that correlations between items were large enough for PCA. The Velicer minimum average partial (MAP) test (O'Connor, 2000) suggested the extraction of three components, consistent with the Smolewska et al. (2006) model of the HSPS. Table 3.2 shows the factor matrix of rotated components. Three components explained 36.44% of the variance. Note, a unidimensional model accounts for 21.52% variance. However, one factor in the model with only 3 unique indicator variables consisting of reverse scored OS had poor Cronbach's Alpha (.4) and inter-item correlations (.19), and so a two factor model was chosen instead. Justification for forcing the two factor model follows the common finding that reverse coded items tend to load onto a separate methods factor, and thus relates not to the construct under investigation, but to reverse item response bias (Weijters, Baumgartner, & Schillewaert, 2013). The 2-factor model explained 32.03% of the variance. Items which did not reach loading criteria include HSPS item 6 and 20, and ATQ OS item 6 and 14. The HSPS items relate to bodily sensations and OS items were reverse scored items, although OS item 1 is a reverse scored item which loaded on the OS factor. The same 5 items in our OS factor (2, 8, 10, 15, 22)

for both the 3-factor HSPS alone model and this combined 2-factor HSPS and ATQ model are the same as for previous OS (Evans & Rothbart, 2008) and AS/OS factors (Smolewska et al., 2006; Sobocko & Zelenski, 2015).

**Confirmatory factor analysis of the HSPS and ATQ OS.** Confirmatory factor analysis was used to compare the model fits of the factor structures identified with PCA for the 27-item HSPS and 15 item ATQ OS. First, the unidimensional model of the HSPS and ATQ OS combined was tested. Then the 2 factor model identified in the PCA is tested, and compared with the unidimensional model.

For the unidimensional model, the model fit was poor  $\chi^2(665)=2333.1, p<.001, CFI=.55, RMSEA=.093, 90\% CI [.09, .1], AIC=2485.1$ . The 2 factor model was a reasonable fit for the data  $\chi^2(664)=1529.35, p<.001, CFI=.77, RMSEA=.067, 90\% CI [.063, .072], AIC=1683.35$ . The correlation between factors was small (.38), suggesting discriminant validity between the two factors. Comparison of the two models shows that the two factor model provided a closer fit to the data than the unidimensional model  $\chi^2_{diff}(1)=803.75, p<.001$ .

Results so far indicate a 2-factor model best characterizes the HSPS and ATQ OS together, wherein similar numbers of negative affect and neutral/positive affect items are included, consistent with other models of adult temperament (Evans & Rothbart, 2007, 2009). While OS and NA are clear temperament factors, a third weak methods factor relates not to the HSPS or the sensitivity construct, but to reverse item response bias (Weijters et al., 2013). Notably, the combination of the HSPS OS and ATQ OS items have lower reliability than the full HSPS (.85) (Aron & Aron, 1997) and the ATQ OS short form (.85), but is still acceptable. The inter-item correlation is lower for the OS versus NA factor, suggesting fewer items are measuring the same construct in OS versus NA.



### **Aim 3: Explore Factor Structure of HSPS, ATQ OS and BFI O Combined**

Principal components analysis was conducted on the 27-item HSPS combined with 15-item ATQ OS and the 10-item openness to experience scale from the BFI. The Velicer minimum average partial (MAP) test (O'Connor, 2000) suggested the extraction of four components. The four factor model accounted for 38.4% variance, but again one factor in the model with only 3 unique indicator variables consisted of reverse coded OS items and so a 3 factor model was chosen. Table 3.3 shows the factor matrix of rotated components. The 3 factor model accounted for 34.85% variance. The KMO=.87 verified sampling adequacy, and the Bartlett's test of Sphericity,  $\chi^2(1326)=6046.39, p < .001$ , indicates that correlations between items were large enough for PCA. Items which did not reach loading criteria include HSPS item 6, ATQ OS item 6 and 14 and BFI O item 9. The HSPS item relate bodily sensations and ATQ OS and BFI O items were reverse coded items related to a methods factor (Weijters et al., 2013). The items which loaded on to two or more factors include only items which load on OS and openness factors (HSPS item 22, and BFI O items 6 and 10). For example, Table 3.3 shows BFI O item 6 loads onto both OS and Openness factors in the model. Those items failing the meet the criteria are excluded from further calculations, including Cronbach's alpha and inter-item correlations. Items failing to load on factors are removed from Table 3.3, but see Table 3.1 or Table 3.2 item details.

The three HSPS items in this OS factor (10, 15, 22) were included in both the three (Table 3.1) and two factor (Table 3.2) models above and are the same as for previous OS (Evans & Rothbart, 2009) and AS/OS factors (Smolewska et al., 2006; Sobocko & Zelenski, 2015), but HSPS item 22 also loaded on openness, and the other 2 items that loaded on OS in all other analyses here and elsewhere (2, 8) loaded only on openness. This demonstrates that items 10 and

15 are the two best items to capture OS, item 22 captures both OS and openness, and 2 and 8 are related to openness consistent with the correlations between OS and openness (see Chapter 2).

**Confirmatory factor analysis of the HSPS, ATQ OS and BFI openness.** Amos (SPSS Version 22) was used to perform a confirmatory factor analysis using the 27-item HSPS, 15-item ATQ OS and 10-item BFI O to test the model fit of the factor structure identified using the PCA for model comparison. First, the unidimensional model of the HSPS, ATQ OS and BFI O combined was tested. Then the 3 factor model identified in the PCA will be tested, and compared with the unidimensional model.

For the unidimensional model, the model fit was poor  $\chi^2 (945)=3215.47, p<.001$ , CFI=.48, RMSEA=.091, 90% CI [.088, .095], AIC=3395.47. The 3 factor model was a reasonable fit for the data  $\chi^2 (942)=2049.72, p<.001$ , CFI=.74, RMSEA=.065, 90% CI [.06, .068], AIC=2235.72, although whilst the CFI fit indices indicates a poor fit the 3 factor model is a better fit than a unidimensional model which makes no distinction between sensitivity (OS and NA) and openness (OP),  $\chi^2_{diff} (2)=1165.75, p<.001$ . The correlation between OS and NA ( $r=.34$ ) and OP and NA ( $r=.2$ ) factors was small and the correlation between OS and OP factors was high ( $r=.67$ ). However, the result still suggests discriminant validity between OS/OP factors and NA, as well as between OS and OP factors since the correlations between factors is  $<.85$  (Kline, 2015). Due to the high correlation between OS and OP factors, we compared the fit of the 3 factor model to a 2 factor model in which OP and OS factors are collapsed into one factor. The fit of the 2 factor model was reasonable,  $\chi^2 (944)=2223.20, p<.001$ , CFI=.71, RMSEA=.069, 90% CI [.065, .072], AIC=2405.20, with a weak positive correlation ( $r=.32$ ) between NA and OP/OS. However, the two factor model was a significantly poorer fit compared with the 3 factor

model  $\chi^2_{\text{diff}}(2)=173.48, p<.001$ , as shown also by a smaller AIC for 3 versus 2 factor model, although there is little difference in CFI and RMSEA fit indices.

These results indicate that NA, OS, and openness are distinct factors. OS and openness are highly correlated, but with discriminant validity. The results from the PCA and CFA could mean one of two things a) OS and openness are separate constructs, or b) OS and openness are different levels of the same conceptual hierarchy, i.e., one general factor and one sub factor, which cannot be determined due to the limitations of factor analysis (Evans & Rothbart, 2008). However, the findings are consistent with the idea that OS is one factor that contributes to development of openness personality (Evans & Rothbart, 2007, 2008).

### **Discussion**

Factor analysis was used to explore the factor structure of the HSPS alone, and together with the ATQ OS and BFI O, with the ultimate goal of establishing whether the orienting sensitivity factor of the HSPS and ATQ OS relates to, but is separate from, the openness personality trait. The factor analysis supported previous findings that the HSPS is best characterised by a three factor (Smolewska et al., 2006; Sobocko & Zelenski, 2015) or two factor model (Evans & Rothbart, 2008) in contrast to the unidimensional view of sensory-processing sensitivity (Aron & Aron, 1997). However, whilst the limitations of factor analysis mean that conclusions drawn regarding the best fitting model are theoretically driven, results suggest more strongly that a 2-factor model best characterizes the HSPS and ATQ OS when considered together, wherein similar numbers of negative affect and neutral/positive affect items are included, consistent with other models of adult temperament (Evans & Rothbart, 2007, 2009). When HSPS, ATQ-OS and BFI-O are combined, results indicate that NA, OS, and openness emerge as distinct factors, with discriminant validity demonstrated between OS and openness

factors. However, as with NA factors of the HSPS, the limitations of factor analysis do not allow strong conclusions to be drawn about the distinctness of OS and OP factors, but the findings are consistent with the idea that OS is one related factor that contributes to the development of openness personality (Evans & Rothbart, 2007, 2008).

It is important to establish whether OS and OP are distinct traits, as this will advance our understanding of the development of openness traits, and more generally how personality and temperament manifest in adulthood. If OS and OP are two similar factors at different levels of the same conceptual hierarchy, i.e., the broader openness trait that subsumes OS (Shiner et al., 2012b; Shiner & DeYoung, 2013a) then openness needs to capture sensitivity more completely. The definitions of openness and sensitivity do suggest fundamental differences in how each trait manifests. Openness forms part of the plasticity meta-trait (DeYoung et al., 2002; Digman, 1997) which relates to reward sensitivity, flexible cognition, explorative and novelty seeking behaviours (DeYoung et al., 2006). Sensitivity is associated with an inhibited, “quiet vigilance”, pause to check approach to exploration, although a sensitive animal or child who is shy and introverted in an unfamiliar, novel environment may become instead more curious and exploratory in a well-known, familiar context (Aron & Aron, 1997; Aron et al., 2012; Pluess, 2015a). The domain of openness that is closest to OS is aesthetic sensitivity (DeYoung, 2014) with items evaluating “values artistic, aesthetic experiences” and how many “artistic interests” (BFI-O). However, HSP-OS items ask about being “deeply moved by the arts or music”, which reflects a reactivity not captured adequately by openness. To “notice and enjoy delicate or fine scents, tastes, sounds, works of art” is a HSP-OS item which loads on to both OS and OP factors, and is an item capturing the fine resolution of sensory processing which is characteristic of OS, but not evident in openness items. The openness item closest to sensitivity is on the NEO-PI-R,

asking, “looking at a work of art, I feel a chill or wave of excitement”, and such “aesthetic chills” may be a universal marker of openness that captures the tendency of highly open people to be particularly sensitive to art (McCrae, 2007). Interestingly, the OP and OS (ATQ) items with the highest loading on the OP factor are ATQ-OS and BFI-O items relating to ideation, suggesting that those aspects of creativity are adequately captured by openness.

In summary, more OS questions could be added to openness inventories to capture sensitivity more fully if OS is subsumed under openness (Shiner et al., 2012b; Shiner & DeYoung, 2013a). Personality research may thus benefit from better capturing biologically-based elements of temperament, or higher-order personality traits, which are more clearly grounded in animal studies, child development, and biology (Aron et al., 2012; Rothbart, 2011; Strelau, 1998).

## Tables

Table 3.1

Three factor model of HSPS emerging from PCA

	Factor		
	LST	OS	EOE
1 Are you easily overwhelmed by strong sensory input?	.68		
7 Are you easily overwhelmed by things like bright lights, strong smells, coarse fabrics, or sirens	.70		
9 Are you made uncomfortable by loud noises?	.76		
13 Do you startle easily?	.63		
17 I try hard to avoid making mistakes or forgetting things.	.33		
18 I make a point to avoid violent movies and TV shows.	.44		
25 I am bothered by intense stimuli, like loud noises or chaotic scenes.	.72		
26 When I must compete or be observed while performing a task, I become so nervous or shaky	.48		
27 When I was a child, my parents or teachers seemed to see me as sensitive or shy.	.48		
2 Do you seem to be aware of subtleties in your environment?		.68	
3 Do other people's moods affect you?		.36	
6 Are you particularly sensitive to the effects of caffeine?		.36	
8 Do you have a rich, complex inner life?		.62	
10 Are you deeply moved by the arts or music?		.73	
12 Are you conscientious?		.43	
15 When people are uncomfortable in a physical environment do you tend to know what needs to		.61	
22 I notice and enjoy delicate or fine scents, tastes, sounds, works of art.		.70	
5 Do you find yourself needing to withdraw during busy days, into bed or into a darkened room			.64
11 Does your nervous system sometimes feel so frazzled that you just have to go off by yourself?			.49
14 Do you get rattled when you have a lot to do in a short amount of time?			.71
16 I am annoyed when people try to get me to do too many things at once.			.76
19 I become unpleasantly aroused when a lot is going on around me.	.39		.40
20 Being very hungry creates a strong reaction in me, disrupting my concentration or mood.			.37
21 Changes in my life shake me up.	.32		.53
23 I find it unpleasant to have a lot going on at once			.76
24 I make it a high priority to arrange my life to avoid upsetting or overwhelming situations.			.41
4 Do you tend to be more sensitive to pain?	-	-	-
Cronbach's alpha	.82	.75	.80
Mean inter-item correlation	.34	.27	.37

Table 3.2

*Two factors extracted from the HSPS (HSP) and ATQ OS (OS)*

	Factor	
	NA	OS
HSP1 Are you easily overwhelmed by strong sensory input?	.68	
HSP3 Do other people's moods affect you?	.33	
HSP4 Do you tend to be more sensitive to pain?	.44	
HSP5 Do you find yourself needing to withdraw during busy days, into bed or into a darkened room or any place where you can have some privacy and relief from stimulation?	.64	
HSP7 Are you easily overwhelmed by things like bright lights, strong smells, coarse fabrics, or sirens close by?	.67	
HSP9 Are you made uncomfortable by loud noises?	.72	
HSP11 Does your nervous system sometimes feel so frazzled that you just have to go off by yourself?	.64	
HSP13 Do you startle easily?	.58	
HSP14 Do you get rattled when you have a lot to do in a short amount of time?	.64	
HSP16 I am annoyed when people try to get me to do too many things at once.	.56	
HSP17 I try hard to avoid making mistakes or forgetting things.	.38	
HSP18 I make a point to avoid violent movies and TV shows.	.39	
HSP19 I become unpleasantly aroused when a lot is going on around me.	.69	
HSP21 Changes in my life shake me up.	.69	
HSP23 I find it unpleasant to have a lot going on at once	.76	
HSP24 I make it a high priority to arrange my life to avoid upsetting or overwhelming situations.	.54	
HSP25 I am bothered by intense stimuli, like loud noises or chaotic scenes.	.79	
HSP26 When I must compete or be observed while performing a task, I become so nervous or shaky that I do much worse than I would otherwise.	.61	
HSP27 When I was a child, my parents or teachers seemed to see me as sensitive or shy.	.47	
HSP2 Do you seem to be aware of subtleties in your environment?		.58
HSP8 Do you have a rich, complex inner life?		.43
HSP10 Are you deeply moved by the arts or music?		.69
HSP12 Are you conscientious?		.32
HSP15 When people are uncomfortable in a physical environment do you tend to know what needs to be done to make it more comfortable (like changing the lighting or the seating)?		.48
HSP22 I notice and enjoy delicate or fine scents, tastes, sounds, works of art.		.65
OS1 Barely noticeable visual details rarely catch my attention.		.34
OS2 When I am listening to music, I am usually aware of subtle emotional tones.		.68
OS3 I tend to notice emotional aspects of paintings and pictures.		.74
OS4 I'm often aware of the sounds of birds in my vicinity.		.50
OS5 I sometimes seem to understand things intuitively.		.51
OS7 When I am resting with my eyes closed, I sometimes see visual images.		.51
OS8 Sometimes my mind is full of a diverse array of loosely connected thoughts and images.		.46
OS9 I often notice mild odors and fragrances.		.38
OS10 I am often aware how the color and lighting of a room affects my mood.		.56
OS11 I sometimes dream of vivid, detailed settings that are unlike anything that I have experienced when awake.		.47
OS12 When I watch a movie, I usually don't notice how the setting is used to convey the mood of the characters.		.48
OS13 I am often consciously aware of how the weather seems to affect my mood.		.53
OS15 Without applying effort creative ideas sometimes present themselves to me.		.60
Cronbach's alpha	.90	.81
Inter-item correlation	.32	.24

Note, OS=orienting sensitivity factor; NA=negative affect factor.

Table 3.3

A three factor model of the HSPS (HSP), ATQ OS (OS) and BFI O (O)

Items	Factor		
	OS	NA	OP
HSP10 Are you deeply moved by the arts or music?	.61		
HSP15 When people are uncomfortable in a physical environment do you tend to know what needs to be done	.34		
HSP20 Being very hungry creates a strong reaction in me, disrupting my concentration or mood.	.39		
HSP22 I notice and enjoy delicate or fine scents, tastes, sounds, works of art.	.44		.37
OS2 When I am listening to music, I am usually aware of subtle emotional tones.	.70		
OS3 I tend to notice emotional aspects of paintings and pictures.	.60		
OS4 I'm often aware of the sounds of birds in my vicinity.	.31		
OS5 I sometimes seem to understand things intuitively.	.39		
OS7 When I am resting with my eyes closed, I sometimes see visual images.	.58		
OS8 Sometimes my mind is full of a diverse array of loosely connected thoughts and images.	.48		
OS9 I often notice mild odors and fragrances.	.38		
OS10 I am often aware how the color and lighting of a room affects my mood.	.60		
OS11 I sometimes dream of vivid, detailed settings that are unlike anything that I have experienced when	.41		
OS12 When I watch a movie, I usually don't notice how the setting is used to convey the mood of the	.43		
OS13 I am often consciously aware of how the weather seems to affect my mood.	.62		
O6 Values artistic, aesthetic experiences	.50		.33
HSP1 Are you easily overwhelmed by strong sensory input?		.69	
HSP11 Does your nervous system sometimes feel so frazzled that you just have to go off by yourself?		.63	
HSP12 Are you conscientious?		.31	
HSP13 Do you startle easily?		.56	
HSP14 Do you get rattled when you have a lot to do in a short amount of time?		.60	
HSP16 I am annoyed when people try to get me to do too many things at once.		.54	
HSP17 I try hard to avoid making mistakes or forgetting things.		.40	
HSP18 I make a point to avoid violent movies and TV shows.		.39	
HSP19 I become unpleasantly aroused when a lot is going on around me.		.69	
HSP21 Changes in my life shake me up.		.68	
HSP23 I find it unpleasant to have a lot going on at once		.74	
HSP24 I make it a high priority to arrange my life to avoid upsetting or overwhelming situations.		.56	
HSP25 I am bothered by intense stimuli, like loud noises or chaotic scenes.		.81	
HSP26 When I must compete or be observed while performing a task, I become so nervous or shaky		.60	
HSP27 When I was a child, my parents or teachers seemed to see me as sensitive or shy.		.45	
HSP3 Do other people's moods affect you?		.32	
HSP4 Do you tend to be more sensitive to pain?		.39	
HSP5 Do you find yourself needing to withdraw during busy days, into bed or into a darkened room or any place		.62	
HSP7 Are you easily overwhelmed by things like bright lights, strong smells, coarse fabrics, or sirens close by?		.70	
HSP9 Are you made uncomfortable by loud noises?		.76	
O7 Prefers work that is routine		.30	
HSP2 Do you seem to be aware of subtleties in your environment?			.45
HSP8 Do you have a rich, complex inner life?			.36
O1 Is original, comes up with new ideas			.80
O2 Is curious about many different things			.49
O3 Is ingenious, a deep thinker			.44
O4 Has an active imagination			.57
O5 Is inventive			.71
O8 Likes to reflect, play with ideas			.61
O10 Is sophisticated in art, music, or literature	.41		.44
OS1 Barely noticeable visual details rarely catch my attention.			.40
OS15 Without applying effort creative ideas sometimes present themselves to me.			.63
Cronbach's Alpha	.82	.9	.8
Inter-item correlation	.24	.31	.31

Note. OS=orienting sensitivity factor; NA=negative affect factor; OP=openness factor





## CHAPTER IV

### **Change Detection and Attention Networks in the Sensitive Creator**

#### Abstract

This chapter explores how sensitivity may explain individual differences in attention tasks, and how this performance relates to creativity. We employ a change detection task (Mueller, 2011) as change detection activates attention networks in high sensitive groups (Jagiellowicz et al., 2011), and the Attention Network Task (Fan, McCandliss, Sommer, Raz, & Posner, 2002) to measure individual differences in alerting, orienting and executive attention network efficiencies.

For the change detection task, positive correlations were observed between minor versus major difference response times (RT) and RIBS, as well as ATQ-OS, which also positively correlates with RIBS (see Chapter 2). Hierarchical multiple regression shows the relationship between minor versus major change detection can be explained by ATQ-OS, as change detection variance in RIBS is absorbed into the broader construct of ATQ-OS, suggesting a shared attention mechanism between the three measures. With the ANT, we show that sensitivity is not related to orienting attention networks, as hypothesised given the definition of OS as reflecting exogenous orienting (Evans & Rothbart, 2007), but is associated with individual differences in how alerting networks associated with broad, diffused attention states interact with executive control networks in flanker tasks. Further, we show those network interactions also predict creative ideation, but have substantial overlap with orienting sensitivity measures, providing support for the hypothesis that a shared attention mechanism underlies orienting sensitivity, diffuse attention and creative ideation.



## **Introduction**

This chapter explores how sensitivity may explain individual differences in attention tasks, and how this performance relates to creativity. In chapter 1 and 2 we have explained how the relationship between orienting sensitivity and creativity may be explained by individual differences in the orienting attention brain networks. Environmental sensitivity (Aron et al., 2012; Pluess, 2015a) and emotion-attention temperament frameworks (Evans & Rothbart, 2007) both imply an attention mechanism, and behavioral, brain imaging, and genetic findings support the idea that sensitivity affects attention (Aron et al., 2012; Jagiellowicz et al., 2011), with theoretical accounts placing emphasis on exogenous attention (Evans & Rothbart, 2007, 2008). Thus, if exogenous orienting networks underlie the sensitivity construct, they may explain the how sensitivity relates to diverse creative processes (see Chapter 2).

### **Change Detection and Attention**

Change blindness refers to the observation that human beings are notoriously bad at detecting salient changes in visual scenes if they occur in the presence of visual disruptions, such as eye movement or screen flicker (Rensink, O'Regan, & Clark, 1997). This surprising limitation of the human visual system was demonstrated in empirical studies showing visual change detection can only occur when attention is oriented towards change, for example by motion or high-level (top-down) interest (O'Regan, Rensink, & Clark, 1999; Rensink et al., 1997). Orienting attention networks (for a review, see Corbetta & Shulman, 2002) play an important role in change detection. Neuroimaging studies found that change detection results in greater activation of dorsal frontoparietal attention networks as well as ventral extrastriate visual areas, whereas the same dorsal frontoparietal activation is absent during periods of change blindness (Beck, Rees, Frith, & Lavie, 2001; Rees & Lavie, 2001). Electrophysiological studies also

implicate the P300 as an index of change detection, with greater P300 amplitudes around parietal sites associated with awareness (vs. unawareness) of change (Eimer & Mazza, 2005; Koivisto & Revonsuo, 2003). The “novelty P300” ERP component consists of two components (P3a, P3B) which reflect attention and memory processes involved in change detection, including (a) stimulus-driven frontal orienting networks which orient towards change and perform context-updating processes in working memory, and (b) temporal-parietal attention and memory processes associated with context-updating and subsequent memory storage (Polich, 2007).

Change detection studies suggest that perceptual awareness depends on attention, and implicate orienting networks thought to underlie the reactive orienting sensitivity construct (Rothbart & Posner, 2001). Accordingly, neuroimaging studies of change blindness have provided some evidence for individual differences in attention mechanisms in the sensitive personality. Jagiellowicz et al. (2011) found that sensitive versus non-sensitive participants (as defined using the HSPS) were slower, but no less accurate at detecting minor versus major changes in complex visual scenes. Further, sensitive groups show greater activation in brain areas related to higher-order visual and attentional processes during detection of minor versus major changes. Differences in visual attentional processes were evidenced by increased activation in the right hemisphere temporal-parietal junction (TPJ; inferior parietal lobule and superior temporal gyrus) and intraparietal sulcus (IPS; lying between the superior and inferior parietal lobes), and the middle frontal gyrus (i.e. precentral sulcus), all areas of the brain associated with the orienting attention (Corbetta & Shulman, 2002; Fan et al., 2005) and frontoparietal control networks which form part of, or interact with, the default mode network (DMN) (Spreng et al., 2013).

## Attention Brain Networks

Recent theories view attention as a system of three anatomically discrete brain networks responsible for different sets of attentional processes, including alerting, orienting and executive control (for reviews, see Petersen & Posner, 2012; Posner & Petersen, 1990). The alerting network includes the thalamic, frontal and parietal regions of the right hemisphere (Fan et al., 2005) which function to increase vigilance to important information by creating spatially broad, global attentional states required for rapid, but low quality information extraction (Fernandez-Duque & Posner, 1997; Posner & Petersen, 1990). The alerting network interacts with other networks, for example alerting inhibits the executive network leading to higher error rates, but produces a faster orienting response (Callejas, Lupiáñez, & Tudela, 2004; c.f., Fernandez-Duque & Posner, 1997; Posner, 1994). The orienting network operates to prioritize and select specific information from various sensory or internal events. Orienting can be reflexive (bottom-up), as when something catches attention, or voluntary (top-down), as during visual search. The orienting network subsumes (a) the dorsal top-down visuo-spatial orienting network, consisting of the frontal eye fields (FEF) and the intraparietal sulcus/superior parietal lobule (IPS/SPS) and (b) the ventral bottom-up reorienting system, consisting of regions of the TPJ, including the inferior parietal lobule/superior temporal gyrus (IPL/STG), and the ventral frontal cortex (VFC), including the inferior frontal gyrus/middle frontal gyrus (IFg/MFg) (Corbetta & Shulman, 2002). The executive control network, consisting of the anterior cingulate cortex (ACC) and lateral prefrontal cortex (IPFC) (Fan et al., 2005; Petersen & Posner, 2012; Posner & Petersen, 1990), is described as a limited capacity attention system responsible for focal attention and diverse operations including error detection and conflict-resolution (e.g., Fan et al., 2005), which

additionally regulates activation in the orienting and alerting networks, and may be a central component to conscious self-regulation (Rothbart, Sheese, & Posner, 2007).

The attention network task (ANT; Fan et al., 2002) was developed to measure efficiencies of alerting, orienting and executive control networks and has been used to evaluate attentional abnormalities in clinical populations, including patients with stroke/brain injury, attention-deficit hyperactivity disorder, schizophrenia, borderline personality disorder (for a review, see Fan & Posner, 2004; MacLeod et al., 2010) and also in individual differences studies identifying sources of individual variation in attention network efficiency (Fan, Fossella, Sommer, Wu, & Posner, 2003; Fan, Wu, Fossella, & Posner, 2001; Fossella et al., 2002).

Cognitive tasks which measure performance of attention networks are particularly useful tools for identifying the attention mechanisms underlying temperament constructs, including effortful control and orienting sensitivity components of the emotion-attention temperament framework (Evans & Rothbart, 2007, 2008, 2009). For example, temperamental effortful control has been linked to performance in conflict resolution tasks in child (Gerardi-Caulton, 2000; Rothbart, Ellis, Rueda, & Posner, 2003) and adult populations (Posner et al., 2002), and conflict resolution is a function of the executive control networks (Fan et al., 2005). The evidence linking temperamental effortful control to conflict resolution has lead researchers to stress the link between the executive control network and temperament constructs of effortful control (Rothbart et al., 2007). The orienting attention system is thought to underlie the reactive orienting sensitivity (OS) temperament (Rothbart & Posner, 2001), but there is little evidence linking orienting sensitivity to the orienting attention network. Using a modified ANT with only alerting and conflict conditions, Costa et al. (2013) show RTs following ‘alerting’ cues are slower for high versus low OS groups. Further, low versus high OS groups show a larger negative N2 ERP

component for cued, but not uncued trials, which could reflect group differences in response conflict (Folstein & Van Petten, 2008) for cued trials. This suggests that high OS groups are more sensitive to alerting cues which can impair ANT performance (Fan et al., 2002). Matthews and Zeidner (2012) show personality traits relate to ANT performance, which is interesting considering the associations between measures of temperament and personality (e.g., Evans & Rothbart, 2007, 2008, 2009). Matthews and Zeidner (2012) found openness to experience was significantly negatively correlated ( $r=-.21$ ) with alerting RTs, emotional stability (inverse neuroticism) was significantly negatively correlated ( $r=-.23$ ) with orienting RTs, and both extraversion and conscientiousness show significant negative correlations ( $r=-.31$ ,  $r=-.24$ , respectively) with executive control.

The Costa et al. (2013) findings are consistent with change detection studies using sensitivity dichotomies (e.g., Jagiellowicz et al., 2011) as both show slower performance in sensitive versus non-sensitive groups. However, the personality evidence is inconclusive. Openness is a positive correlate of orienting sensitivity (Evans & Rothbart, 2007), and higher openness is associated with faster alerting RTs (Matthews & Zeidner, 2012), however evidence suggests high versus low OS is associated with slower alerting RTs (Costa et al., 2013) and change detection performance (Jagiellowicz et al., 2011). Neuroticism is also a positive correlate of sensitivity due to a strong NA component (Aron & Aron, 1997; Evans & Rothbart, 2008), however neuroticism is associated with slower orienting RTs (Matthews & Zeidner, 2012) as with studies showing sensitive versus non-sensitive groups are slower in attention tasks (Costa et al., 2013; Jagiellowicz et al., 2011).

Further work is required to clarify the link between sensitivity and attention, and no links have yet been made between sensitivity, attention and creativity. However, evidence has already



linked parts of the DMN with sensitivity. The DMN is strongly implicated in creativity (Beaty et al., 2015; Beaty, Benedek, et al., 2016; Beaty et al., 2014; Beaty, Kaufman, et al., 2016; Jagiellowicz et al., 2011; Jauk et al., 2015), contributing to creativity interactively with other frontoparietal attention and cognitive control networks. DMN functions include processes important for creative cognition, including automatic orienting of attention towards internal (i.e., explicit episodic and semantic memory, thoughts, ideas) and external (i.e., exogenous) information (Binder & Desai, 2011; Cabeza et al., 2011), and mind wandering (Beaty, Benedek, et al., 2016). Right lateralization of sensitivity effects is consistent with right TPJ contributions to holistic, diffuse, insight and integrative creative processes, including attention, and the hemispheric asymmetry hypothesis of creativity that posits a particularly important role for the right hemisphere (Kaufman, Kornilov, et al., 2010).

## **Aims**

The aim of this study was to replicate the findings that sensitive versus non-sensitive groups perform differently in visual change detection tasks. In addition, we aim to look at how different sensitivity factors (OS vs. NA) relate to change detection. Further, we aim to explore how between-groups performance on the change detection task may relate to creativity. Based on previous findings reported by Jagiellowicz et al. (2011), we expect high sensitivity to be associated with slower RTs (positive correlation) in change detection tasks, specifically when detecting minor versus major changes. ATQ-OS is a positive-affect related factor (Evans & Rothbart, 2009; Sobocko & Zelenski, 2015) thought to index automatic attention orienting (Evans & Rothbart, 2007). How orienting sensitivity relates to change detection has not yet been examined. Based on prior studies exploring change detection in sensitivity (Jagiellowicz et al., 2010), we predict higher orienting sensitivity will be associated with slower, but no less accurate

change detection performance for minor versus major changes in visual scenes. If those attention processes at least partially underlie the association between sensitivity and creativity observed in Chapter 2, then minor versus major change detection performance should predict creative achievement, ideation and divergent thinking.

In a further extension, we look at how temperament and personality relate to efficiency of the attention networks, using the ANT (Fan et al., 2002). Specifically, we aim to look at how orienting sensitivity relates to efficiency of attention networks, and how this performance relates to creativity. Specifically, based on previous work by (Jagiellowicz et al., 2010), we expect orienting sensitivity to be associated with slower but no less accurate performance in measures of the orienting networks using the ANT, considering orienting sensitivity is defined as exogenous orienting attention (Evans & Rothbart, 2008). Further, based on work by Costa et al. (2013), we could expect higher orienting sensitivity to be associated with slower RTs following cued (alerting) versus uncued trials, and impaired conflict resolution following alerting cues (Fan et al., 2002). This is because alerting cues of the ANT are designed to produce broad, spatially diffused attentional states required for rapid information extraction which occurs at the expense of information quality, resulting in higher ER in attention tasks (Callejas et al., 2004; Fan et al., 2002; Posner & Petersen, 1990). Higher sensitivity of exogenous attention, as in high OS (Evans & Rothbart, 2007), may mean that HSPs are more sensitive to alerting cues, meaning greater global alerting states and thus poorer conflict resolution abilities than non-HSPs. Further, if those attention processes at least partially underlie the association between sensitivity and creativity observed in Chapter 2, then slower and less/more accurate performance following alerting cues on the ANT should predict creative achievement, ideation and divergent thinking.

## Method

### Participants

A sample of 99 participants were recruited for the study, however 2 Participants did not complete the study and so the final sample consisted of 97 participants (84 female and 13 male, aged between 18-33 years,  $M=19.76$ ,  $SD=2.29$ ). Participants were rewarded with course credit. This study was approved by Human Ethics Committee in the Faculty of Science and Environment at University of Plymouth. Participants gave informed consent before the study and were debriefed after completing the study.

### Apparatus and Materials

A computerized battery was developed on Survey Monkey to assess sensitivity, personality and creativity and administered in the lab. Each questionnaire was presented on a separate page within the software. For each item, the participant checked the blank in front of any item corresponding to the response that best applied to them.

Sensitivity was measured using two questionnaires. 1) The Highly Sensitive Person scale (HSPS) from Aron and Aron (1997) is a 27-item, modality general, self-report scale measuring sensory processing sensitivity using items asking about tendencies to startle easily, become easily overwhelmed by sensory inputs but also awareness of subtleties in the environment, and enjoyment of fine and delicate scents, tastes, sounds, and works of art. Item responses ranged from 1 (not at all) to 7 (extremely). 2) The two HSPS factors of orienting sensitivity and negative affect were also measured using the Adult Temperament Questionnaire (ATQ)-short form (Evans & Rothbart, 2007). The ATQ is a self-report scale with 77 items measuring general constructs of orienting sensitivity (ATQ-OS), negative affect (ATQ NA), effortful control (ATQ

EC), and extraversion/surgency (ATQ ES). Item responses ranged from 1 (extremely untrue) to 7 (extremely true) and “not applicable”.

The Big Five Inventory (BFI) assessed personality. This 44-item self-report questionnaire measures the Big Five dimensions of personality: Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Benet-Martinez & John, 1998; John et al., 1991; John et al., 2008; John & Srivastava, 1999). Item responses ranged from 1 (disagree strongly) to 5 (agree strongly).

Creativity was assessed using three of the most established and validated measures of creative processes. The Creative Achievement Questionnaire (CAQ; Carson et al., 2005) was chosen as an objective self-report measure of creative achievement across 10 domains of creativity. The Runco Ideational Behaviour Scale (RIBS; Runco et al., 2000-2001) is a 19-item questionnaire designed to measure creative ideation, which is thought to measure a single factor and has discriminant validity. Items probe behavioural tendencies and abilities regarding ideas and thinking, with many items emphasizing creative, unusual, or imaginative thought (e.g., “I have many wild ideas.”). The RIBS responses ranged from 1 (never) to 5 (very often). This study was lab-based in order to administer one pencil and paper creativity test: The Abbreviated Torrance Test for Adults (ATTA; Goff & Torrance, 2002) consists of 3 timed (3-minute) tests of figural and verbal divergent thinking abilities thought to be critical for the creative process (Runco, 2014). The ATTA is a gold standard, objective measure of divergent thinking. The ATTA thus is the one test that independently verifies creative products/divergent thinking. The ATTA was presented in the lab in paper format with a pencil and eraser, not part of the Survey Monkey battery.

The two experimental measures used in this experiment 1) a change detection task (Mueller, 2011) and b) the Attention Network Task (ANT; Fan et al., 2002) both presented using the Psychological Experiment Building Language (PEBL) and PEBL Test Battery (Mueller & Piper, 2014). All tasks were presented using a Philips Brilliance LED monitor 221P3LPYES P-line 21.5" widescreen operating at  $1920 \times 1080$  pixels with a 60Hz refresh rate.

## **Design**

This study used a within-subjects correlational and quasi-experimental design to explore relations between temperament, personality, creativity and objective measures of attention.

**Change detection task (CDT).** There were 4 conditions in which targets to be detected changed in colour, size, location and presence. There were 10 unspeeded trials per condition. Arrays of 50 circles occupying a  $600 \times 400$  (h  $\times$  v) pixel field were presented for durations of 400ms and were separated by a blank screen for durations of 100ms. Each circle varied randomly in size between 10 and 30 pixels with a pixel tolerance of 30 pixels for target circles. See Figure 4.1a for a visual demonstration of the different conditions.

**Attention Network Task (ANT).** The ANT has 4 cue types (no cue, centre cue, double cue and direction cue), two target locations (above or below fixation), target direction (left or right facing target arrow) and flanker type (congruent, incongruent or neutral). Note, direction cues were 100% predictive. There were 72 trials per cue type, and 96 trials per flanker type giving a total of 288 trials. Flanker types were each presented for 24 trials with each cue type. Before the main experiment block, participants were given 24 practice trials. Trial order was randomized. See Figure 4.1b for a visual demonstration of the different conditions and trial timing. The operational definitions of the efficiencies of the three attentional networks were

defined for behavioural analysis so as to create a positive score for each condition for reaction times (for accurate data only) and error rates (Fan et al., 2005; Fan et al., 2002):

*Alerting effect: no cue – double cue*

*Orienting effect: centre cue – direction cue*

*Conflict effect: incongruent – congruent*

**Outlier detection.** The CDT and ANT tasks were subject to outlier removal using the MAD median method. Mean RTs for each task are calculated based on correct responses only following outlier removal. Accuracy data is computed independently of outlier removal.

**Individual differences.** To replicate Jagiellowicz et al. (2011), additional sensitivity scores for both HSPS and ATQ-OS were calculated with BFI-E (introversion inverted) and BFI-N (neuroticism/negative affect) partialled-out (see also Aron & Aron, 2013) to create new variables henceforth referred to as HSPS (E, N) residuals and ATQ-OS (E, N) residuals.

The HSPS may be a taxon consisting of HSP's (i.e., those high on HSPS) and non-HSP's, therefore Aron and Aron (2013) suggest dichotomizing the sample allowing for group comparison using ANOVA and related methods. As the sample majority consists of Psychology majors who may include a larger percentage of HSPs than the typical 20%, the break point was chosen to be 30% (high) HSP's and 70% (low) non-HSP's (Aron & Aron, 2013). The HSP groups consisted of  $n=29$  participants and the non-HSP groups consisted of  $n=68$  participants. The HSP group ( $M=5.12$ , 95% CI [4.97, 5.28]) have significantly higher ratings on the HSPS,  $t(95)=12.21$ ,  $p<.001$ , than non-HSP groups ( $M=3.82$ , 95% CI [3.7, 3.95]).

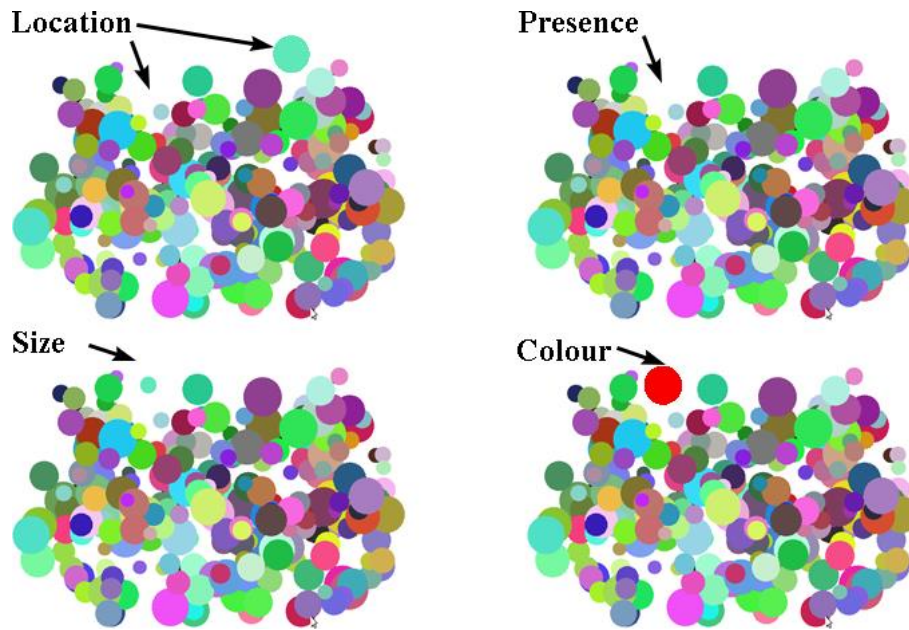
For each creativity measures, groups were formed based on a median split, where high creativity groups  $>$  median score, and low creativity groups  $\leq$  median score. The medians for CAQ, RIBS and ATTA are  $Mdn=7$ ,  $Mdn=2.84$ , and  $Mdn=69$ , respectively. The CAQ scores for

the high CAQ group ( $n=50$ ;  $M=12.68$ , 95% CI[11, 14.58]) are significantly higher than the low CAQ group ( $n=47$ ;  $M=3.68$ , 95% CI[3.14, 4.21]),  $t(95)=9.12$ ,  $p<.001$ . The RIBS scores for the high RIBS group ( $n=49$ ;  $M=3.26$ , 95% CI[3.16, 3.36]) are significantly higher than low the RIBS group ( $n=48$ ;  $M=2.44$ , 95% CI[2.35, 2.52]),  $t(95)=12.09$ ,  $p<.001$ . The ATTA scores for the high ATTA group ( $n=49$ ;  $M=73.59$ , 95% CI[72.68, 74.55]) are significantly higher than the low ATTA group ( $n=48$ ;  $M=62.48$ , 95% CI[59.44, 64.73]),  $t(95)=8.3$ ,  $p<.001$ . Note, all personality, temperament, and creativity measures are scaled between 0 and 1, see Chapter 2 for scaling. Max scores used for scaling CAQ are 31, and 83 for the ATTA in this chapter only.

### **Procedure**

Participants sat in a room at a table with a computer and positioned with their eyes at a distance of 60cm, in line with the top of the computer monitor. Participants were first administered the experimental attention tasks (CDT and ANT), with task order counterbalanced across participants.

**Change detection task.** For the CDT, participants were told that they would be searching for changes in colour, size, location or presence of a target circle appearing among an array of different circles. Participants were told that in each trial they would see a series of scenes made of coloured circles which flash briefly, and between blank screens one of the circles will change. Their task was to find the circle which changes as quickly and accurately as possible. Participants were instructed to press the space bar as soon as the change was detected, and to use the mouse to indicate on screen where the change was detected. As each trail ended participants were given the opportunity to check their decision by tapping the return key, or simply to press the space bar to move on to the next trial.



*Figure 4.1a.* Change detection task showing conditions of location, presence, size and colour.

Changes occur between screen flicker.

**Attention network task.** Participants were informed the task measures how they use and ignore information to make a decision to determine the direction of the center arrow, in an array of five. If the arrow was pointing left, participants were asked to press the left shift key, and if the arrow was pointing right, to press the right shift key. Participants were informed that target arrows would be either be surrounded to the left and right by arrows pointing in the same or opposite direction, or by neutral lines, but were asked to always ignore the surrounding symbols and respond only to the central arrow. Participants were then given examples. Participants were also informed that preceding the target, a cue would appear which may or may not provide information about the location of the target arrow (above or below fixation) and were given further examples. Participants were asked to perform the task as quickly and accurately as possible. The task began with a practice block of 24 trials followed by the main experimental block.



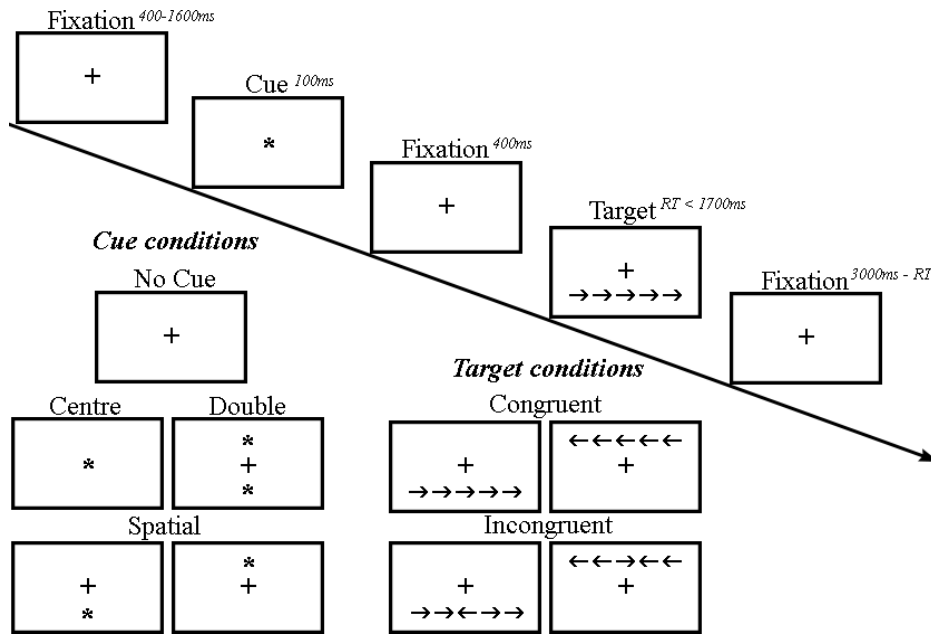


Figure 4.1b. Experimental procedure of the Attention Network Task showing order and timing of events, cue and target conditions.

**Survey data.** Following the experimental tasks participants were informed they could relax their seating position from the screen. Participants were provided with pencils and erasers, and were administered the ATTA. After completing this, participants were completed the Survey Monkey battery in order of the: CAQ, RIBS, HSPS, BFI, and ATQ. Participants were told that the task was not timed, to complete the questionnaires in their own time, and to give honest answers.

## Results

### Change Detection Task: Overall Performance

**Correlations.** A Shapiro-Wilks test of normality indicated that all RT and error rate variables of the CDT were not normally distributed ( $ps < .01$ ), with the exception of overall RT and location RT conditions. Therefore, non-parametric tests were selected to assess correlations (i.e., Spearman's Rho). Table 4.3 shows the results of the Spearman's correlations.

For RTs, each condition is at least significantly moderately positively correlated with overall RTs. Size is significantly positively correlated with location, size and colour. Location is weakly significantly positively correlated with presence and size. Presence is weakly positively correlated with size. For error rates, each condition is at least significantly moderately positively correlated with overall error rates and all conditions are positively inter-correlated. The relation between RTs and error rates can determine whether speed-accuracy trade-off strategies were implemented by participants. Overall RTs are significantly weakly negatively correlated with overall error rates, and both presence and colour RTs are weakly negatively correlated with error rates in those conditions. Scatterplots suggest that participants adopted a speed-accuracy trade-off strategy overall, but mainly in presence and colour conditions, where faster RTs are associated with higher error rates.

**Analysis of variance (ANOVA).** Table 4.2 and Figure 4.2 show the mean RTs and error rates overall, and per condition with 95% confidence intervals.

**Main effects for reaction times.** One-way repeated-measures ANOVA compared performance across conditions (location, presence, colour, size). Sphericity ( $\epsilon=.225$ ,  $p<.001$ ) was not assumed so the Greenhouse-Geisser correction ( $\epsilon<.75$ ) was applied. The ANOVA revealed a significant main effect of condition,  $F(2,148)=85.99$ ,  $p<.001$ . Post hoc tests using the Bonferroni correction revealed that all mean RTs across cue conditions were significantly different from each other ( $ps<.001$ ) with exception of presence and size conditions ( $p=.091$ ). The largest mean difference ( $M=12092\text{ms}$ ) was found between location and colour conditions.

**Main effects for error rates.** One-way repeated-measures ANOVA compared error rates across conditions (location, presence, colour, size). Sphericity ( $\epsilon=.583$ ,  $p<.001$ ) was not assumed so the Greenhouse-Geisser correction was applied. The ANOVA revealed a significant main

effect of condition,  $F(2,207)=78.82, p<.001$ . Post-hoc tests using the Bonferroni correction revealed that all mean error rates across cue conditions were significantly different from each other ( $ps<.001$ ) with exception of presence and size conditions, which were not significantly different ( $p=.376$ ). The largest mean difference ( $M=23.61\%$ ) was found between location and colour conditions.

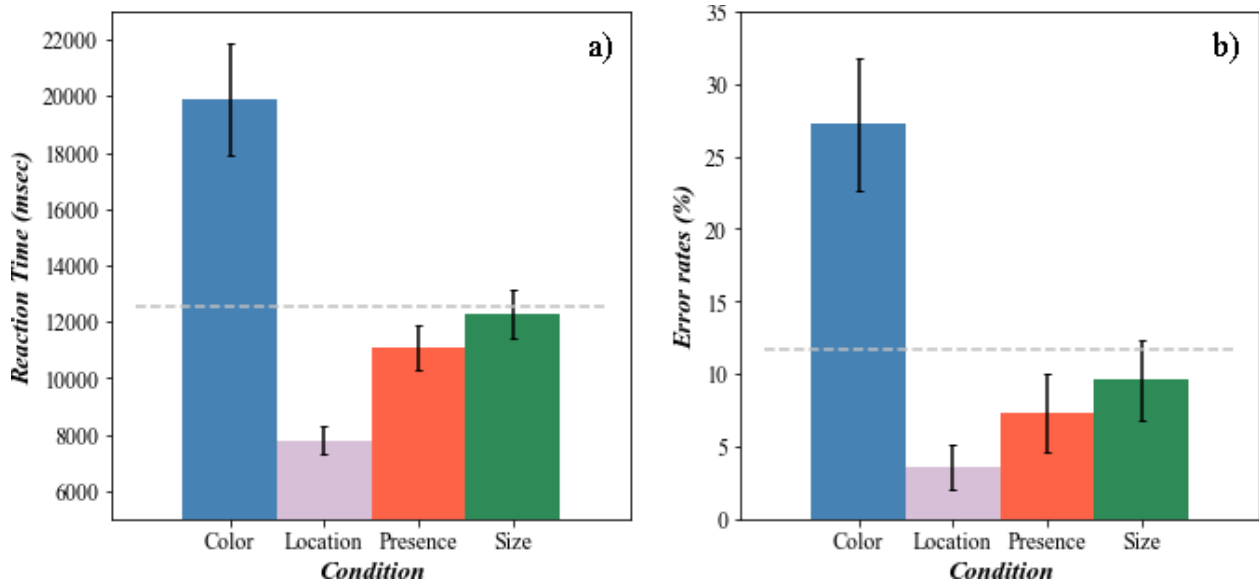


Figure 4.2. CDT performance showing mean a) RTs and b) error rates by condition. Error bars show 95% confidence interval, and silver dashed line represents overall mean performance.

**Minor versus major changes.** Further analysis compared differences in performance for minor and major changes in the CDT to replicate Jagiellowicz et al. (2011). We created variables based on correlational data (see Table 4.3) representing major (mean score of location and presence) and minor (colour) changes. The major variable was created on the reasoning that presence and location RTs were significantly faster and more accurate than colour RTs, and these conditions were also uncorrelated with colour RTs. Size RTs were not significantly different from presence RTs, however size RTs positively correlated with colour RTs and were

thus were excluded from the minor versus major analysis. ANOVA revealed a significant difference in RTs for minor and major conditions,  $F(1,96)=107.0, p<.001$ , where major changes were detected faster than minor changes. There was also a significant difference in error rates for minor and major conditions,  $F(1,96)=126.43, p<.001$ , where major changes had lower error rates than minor changes. Both minor RTs and error rates were significantly higher than overall RT and error rates ( $ps<.001$ ) and both major RTs and error rates were significantly lower than overall RTs and error rates ( $ps<.001$ ). See Table 4.2 for means and 95% confidence intervals by condition.

### **Individual Differences in CDT Performance**

A Shapiro-Wilkes test of normality revealed that several variables (BFI-C, BFI-A, BFI-N, and CDT minor vs. major difference variables) were not normally distributed ( $ps<.05$ ) so non-parametric methods (Spearman) were used to assess correlations between variables. See Table 4.1 for summary statistics of creativity, sensitivity and personality variables and Table 4.4 for correlation table summary of individual differences in CDT performance. Note, no significant correlations emerged between creativity, sensitivity, personality and CDT error rates.

**Creativity and CDT reaction time correlations.** RIBS weakly positively correlates with colour RTs and minor versus major difference RTs. The CAQ or ATTA scores do not significantly correlate with any CDT condition RTs (see Table 4.4).

**ATQ temperament and CDT reaction time correlations.** ATQ-OS weakly positively correlates with colour RTs and minor versus major difference RTs. ATQ-EC does not significantly correlate with RTs from any CDT condition, although shows a weak negative correlation with overall RT performance ( $p=.062$ ) and presence RTs ( $p=.076$ ). ATQ-NA weakly positively correlates with location RTs and ATQ-ES weakly negatively correlates with location

RTs. Note, the ATQ-OS (N, E) residuals correlates weakly positively with colour RTs ( $p=.057$ ) and significantly with minor versus major difference RTs, suggesting the ATQ OS correlations with colour and minor versus major RTs are not specific to NA.

**Hierarchical multiple regression: Sensitivity, personality and change detection as predictors of creative ideation.** The Spearman's rank order correlation (see Table 4.4) revealed that ATQ-OS, minor versus major difference RTs and RIBS are all weakly positively correlated. One question emerges whether the positive correlations between ATQ-OS, minor versus major RTs and RIBS reflect shared (i.e., attention) or independent but related processes. A hierarchical regression model will demonstrate whether ATQ-OS and CDT can account for unique variance in RIBS scores. In the hierarchical multiple regression, model 1 regressed minor versus major difference RTs onto RIBS. Model 2 added orienting sensitivity variables to Model 1. Model 3 added BFI-E and BFI-N variables to account for NA. Adding NA to this hierarchical model allows the examination of sensitivity effects with and without NA controlled. Model 4 added BFI-O, a strong correlate of ATQ-OS (Evans & Rothbart, 2007), to examine whether CDT and ATQ-OS effects are redundant in the presence of BFI-O. CAQ and ATTA were not analyzed using regression analysis as no relation was found between those measures and CDT performance (see Table 4.4). Table 4.5 summarize the hierarchical multiple regression analysis and model fits for continuous sensitivity. See Appendix C for dichomous sensitivity analysis.

Assumptions of ordinary least squares regression were checked. Note, the minimum number of participants required for multiple regression is  $N \geq 50+m$ , where  $m$  is the number of predictors. Regression equations with 6 or more predictor variables should aim for a minimum of  $N=10m$  (VanVoorhis & Morgan, 2007). In this study,  $N=97$  and regression models use 5 predictor variables, thus sample size requirements for multiple regression are satisfied.

Scatterplots indicate linearity between variables. Distributions were inspected using P-P plots and histograms which showed only the minor versus major RTs are positively skewed. Although no assumptions are made regarding independent variables in regression models, it is useful to find whether influential cases or outliers exist. Standardised residuals of the models indicate no outliers, and converging results from Mahalanobis distance, Cooks *D*, leverage and standardized DFBeta values suggest that no cases substantially influence the model parameters (Field, 2013). Homoscedasticity cannot be assumed as variance increases across residuals. Violation of this assumption may limit the generalisability of the findings beyond the sample.

**ATQ-OS.** Model 1 accounting for 5.2% variance shows that minor versus major RTs account for unique variance in RIBS scores. Model 2 accounts for 18.6% variance and gives a significantly better fit for the data. In Model 2, ATQ-OS accounts for unique variance in RIBS scores, however the addition of ATQ-OS in Model 2 renders minor versus major RTs coefficients non-significant, suggesting redundancy and overlap. Model 3 accounts for 19.2% but does not give a significantly better fit for the data ( $p=.26$ ), and neither BFI-E nor BFI-N account for unique variance, nor do they reduce the capacity of ATQ-OS to account for unique variance in RIBS scores. Model 4 accounts for 32.2% and gives a significantly better fit for the data. In Model 4, both ATQ-OS and BFI-O account for unique variance in RIBS scores. The final regression equation for Model 4:  $\hat{Y}(\text{RIBS}) = .169 + .077(\text{minor vs. major RT}) + .258(\text{ATQ-OS}) + .111(\text{BFI-N}) + .168(\text{BFI-E}) + .402(\text{BFI-O})$ .

### **Summary of CDT Results**

RTs and error rates from each CDT condition correlated positively with overall performance, suggesting each condition measured change detection. There are differences in how RTs by condition correlate, for example size RTs correlate with all conditions, but colour

only correlate with size. However, all error rates correlate positively across conditions. The ANOVA revealed that the colour condition shows the highest RTs and error rates than all other conditions. This analysis was used to divide conditions into minor (colour) and major (presence and location) conditions to replicate Jagiellowicz et al. (2011). Major conditions were faster and more accurate than overall performance, and minor conditions were slower and less accurate than overall performance (see Figure 4.2).

### **Summary of Individual Differences in CDT Performance**

The RIBS is the only creativity measure to correlate with CDT RT performance, specifically the colour and minor versus major difference RTs. Similarly, ATQ-OS (which positively correlates with RIBS, see Chapter 2) shows the same pattern of correlations, suggesting a link between creative ideation, orienting sensitivity and detection of minor versus major changes in the CDT. Further, the correlations are not strongly affected when NA is controlled, which is expected considering ATQ-OS is a positive-affect-related trait (Evans & Rothbart, 2009; Smolewska et al., 2006; Sobocko & Zelenski, 2015).

Key findings from the correlation analysis indicate a positive relation between minor versus major difference RTs (which includes colour) and RIBS. ATQ-OS also positively correlates with minor versus major difference RTs and RIBS (see also chapter 2). This suggests these measures have some shared underlying mechanism (i.e., orienting attention sensitivity). The hierarchical multiple regression was performed to see whether ATQ-OS and CDT performance could each account for unique variance in RIBS scores, or whether the shared underlying process would result in overlap and redundancy. The results (see Table 4.5) indeed show the relationship between minor versus major change detection can be explained by ATQ-OS as CDT variance in RIBS is absorbed into the broader construct of ATQ-OS. This suggests that ATQ-OS measures

attention mechanisms associated with a) minor versus major change, and b) creative ideation. These effects change when ATQ-OS is treated as dichotomous (see Appendix C), probably because a dichotomous split will reduce the power of ATQ-OS to account for unique variance in RIBS (MacCallum, Zhang, Preacher, & Rucker, 2002). Similar effects were not found with the full HSPS, and the lack of correlation between HSP OS/AES factors and minor versus major difference RTs suggests negligible overlap between those measures when accounting for variance in RIBS scores (see Appendix C).

One caveat is that whilst ATQ-OS shows overlap with minor versus major RT, the same could be said for BFI-O, considering the minor versus major RT coefficients become nonsignificant in Model 4 of the HSPS regression when BFI-O is introduced (see Table 4.5). Indeed, when the regression analysis is repeated, but with BFI-O replacing ATQ-OS in Model 2, the minor versus major RT coefficient becomes nonsignificant ( $p=.097$ ) when BFI-O is controlled, suggesting that the attention mechanism associated with minor-major RT performance is common to ATQ-OS and BFI-O.

### **The Attention Network Task**

Fan et al. (2002) found that target arrows flanked by incongruent flanker arrows produce slower response times than when targets are surrounded by congruent or neutral flankers (see Figure 4.1b for cue and flanker types). However, the type of cue used to alert or orient attention to the target onset location modulates the incongruency effect. Specifically, when alerting cues containing no spatial orienting information precede a target with incongruent flankers, RTs increase compared with no cue, or direction cue conditions. Further, incongruent flankers impair the ability to accurately resolve target conflict, compared with both neutral and congruent flankers (see also MacLeod et al., 2010). In this analysis, we aim to replicate Fan et al. (2002)



using a larger sample (see Appendix D). We then explore how ANT performance can be explained by individual differences in creativity, temperament and personality.

### **Individual Differences in ANT Performance by Condition**

A mixed ANOVA using within-groups factors of cue (none, centre, double, direction) and flanker (neutral, congruent, incongruent) and between-groups factors of group were used to explore individual differences in both ANT reaction time and error rate performance. Group differences were analyzed using ANOVAs for dichotomous orienting sensitivity groups. In ANOVAs where Mauchley's test of sphericity was significant, the Greenhouse-Geisser correction was applied. See Appendix D for ANOVAs using between groups factors of HSPS, and all three creativity measures.

**Mixed ANOVA for ANT performance using dichotomous ATQ-OS.** The mixed ANOVA revealed no significant between-groups effects ( $ps > .087$ ), 3-way ( $ps > .434$ ), or 2-way ( $ps > .490$ ) interactions for ATQ-OS or ATQ-OS (E, N) residual groups (see Table 4.6).

The mixed ANOVA revealed significant between-groups effect of ATQ-OS group (see Table 4.6) where HSP groups ( $M=2.58\%$ , 95% CI [1.75, 3.41]) have higher ER overall than non-HSP groups ( $M=1.51\%$ , 95% CI [.97, 2.05]). A significant cue  $\times$  flanker  $\times$  ATQ-OS Split was also found. Simple contrasts reveal a significant effect of accuracy,  $F(1,95)=9.3$ ,  $p=.003$ ,  $\eta_p^2=.089$ , for incongruent (vs. neutral) flankers following centre cues (vs. no cue) where HSP groups ( $M=6.38\%$ , 95% CI [2.9, 10.14]) have higher ERs than non-HSP groups ( $M=1.24\%$ , 95% CI [-.2, 2.76]). Simple contrasts also revealed a significant effect of error,  $F(1,95)=5.2$ ,  $p=.025$ ,  $\eta_p^2=.052$ , for incongruent (vs. neutral) flankers following double cues (vs. no cue) where HSP groups ( $M=4.9\%$ , 95% CI [2.14, 7.85]) have higher ER than non-HSP groups ( $M=1.4\%$ , 95% CI [0.0, 2.88]). The interaction is visualized in Figure 4.3. Note, the pattern of results, including

between-groups effects and interactions, remains the same for ATQ-OS (E, N) residuals (see Table 4.6).

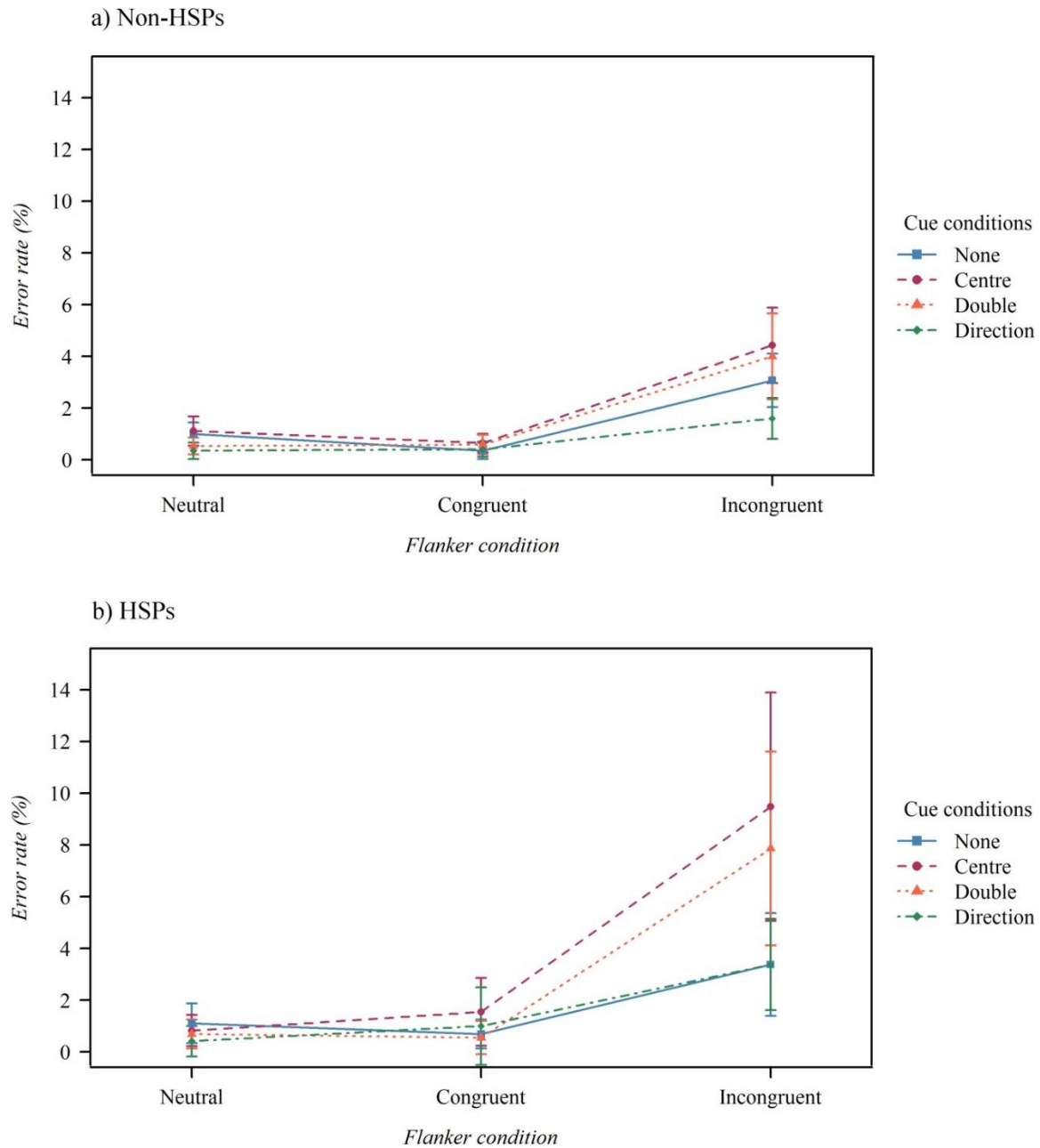


Figure 4.3. Visualization of the cue  $\times$  flanker  $\times$  ATQ-OS group interaction for error rates in the ANT task. Error bars show with 95% confidence intervals for a) non-HSPs and b) HSPs.

**Individual differences in alerting and orienting by congruity.** The mixed ANOVA conducted to explore individual differences in ANT performance was informative. However, the analysis suffers from limitations as measures of attention network efficiencies are obtained through comparison of conditions with appropriate reference conditions, as with alerting, orienting and conflict variables (Fan et al., 2002). Correlations suggest sensitivity relates to alerting RT and ER, and also conflict ER (see Appendix D), but no effects of orienting were found. However, the alerting and orienting variables suggested by Fan et al. (2002) do not consider the effects of cue on flanker congruity. In addition, the alerting variable does not consider centre and double cues separately, and evidence in this study suggests double and centre alerting cues are different and should be analyzed separately. Therefore, to study group differences in alerting, orienting and conflict networks we created additional alerting and orienting variables split by the flanker congruity factor: alerting-centre (centre cue – no cue) and alerting-double (double cue – no cue) and orienting (centre-direction) for congruent and incongruent flankers. Thus, for each flanker condition, positive alerting effects reflect slower and less accurate performance than no-cue conditions, and positive orienting effects reflect slower and less accurate performance in centre alerting versus orienting conditions. The conflict network can be studied using overall flanker effects in the analysis. A 3-way mixed ANOVA using within-subjects factors of cue (Alerting-Centre, Alerting-Double, and Orienting) by flanker (congruent, incongruent) and between-groups factors of group was conducted for RT and ER data separately. Group differences were analyzed in separate ANOVAs for a) dichotomous sensitivity: HSPS, and HSPS (E, N) residuals (see Appendix D) and for ATQ-OS, and ATQ-OS (E, N) residuals and b) median split creativity: CAQ, RIBS, and ATTA (Appendix D). In

ANOVAs where Mauchley's test of sphericity was significant the Greenhouse-Geisser correction was applied.

**ATQ-OS.** No significant between-groups effects ( $ps > .72$ ) and no significant 3-way ( $ps > .72$ ) or 2-way ( $ps > .15$ ) interactions were found with RT data for any ATQ-OS or ATQ-OS (E, N) residuals groups, see Table 4.7.

The mixed ANOVA with ER data revealed a significant ATQ-OS main effect of group, and ATQ-OS  $\times$  flanker interaction, see Table 4.7. The between-groups effect is the result of HSP groups ( $M = 2.99\%$ , 95% CI[1.93, 4.06]) having significantly higher ER than non-HSP groups ( $M = .98\%$ , 95% CI[.28, 1.67]) overall. However, Figure 4.4 shows that the interaction was found because HSP groups have higher ER than non-HSP groups for incongruent ( $p < .01$ ), but not congruent flanker conditions ( $p = .66$ ). Further, the effects remain significant when controlling for NA using ATQ-OS (E, N) residual as a between-groups factor in the ANOVA.

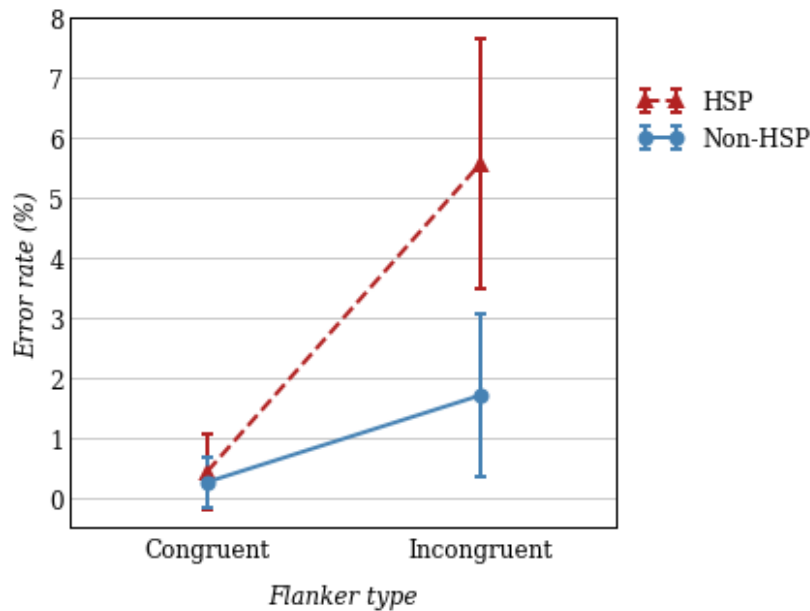


Figure 4.4. Visualisation of the ATQ-OS group  $\times$  flanker interaction. Error bars show 95% confidence intervals.

## **Sensitivity and ANT as Predictors of Creativity**

Sensitivity is associated with greater incongruity effects (i.e., higher ER for incongruent vs. neutral targets) following alerting cues, and greater incongruity effects overall when alerting and orienting variables split by flanker condition are considered together. These effects remain significant when NA is partialled out in the ATQ-OS (E, N) residuals group. High versus low creative ideation (RIBS) is also associated with higher ER for incongruent (vs. neutral) flankers (Appendix D). One question emerges whether incongruity effects associated with both ATQ-OS and RIBS reflect shared (i.e., attention) or independent processes. A hierarchical regression model will demonstrate whether ATQ-OS and incongruity effects can account for unique variance in RIBS scores. To finish, we explore using hierarchical multiple regression whether flanker congruity following alerting cues and ATQ-OS can account for unique variance in RIBS scores. For flanker effects, a new ‘congruity’ variable was created reflecting the difference in errors between incongruent and neutral conditions collapsed across centre and double alerting cues. The use of neutral versus congruent flankers is supported by the fact that only small differences are found between congruent and neutral flanker conditions (Fan et al., 2002), and because we found no difference between congruent and neutral flankers for ER ( $p=.931$ ). Also, there are no differences found between incongruent versus neutral flankers for centre versus double conditions ( $p=.691$ ). Thus, we can argue that any effects found relate to individual, rather than overall effects. In the regression, we use continuous variables to restore statistical power lost when using dichotomisation (MacCallum et al., 2002), but see Appendix D for dichotomous regression analysis. Regression analysis was also performed with the HSPS (Appendix D).

**Hierarchical multiple regression.** In the hierarchical multiple regression, Model 1 regressed congruity for ERs onto RIBS. Model 2 added a sensitivity measure to Model 1. Model

3 added BFI-E and BFI-N variables to account for NA Adding NA measures to this hierarchical model allows the examination of sensitivity effects with and without NA controlled. Model 4 added BFI-O, a strong correlate of ATQ-OS (Evans & Rothbart, 2007), to examine whether flanker congruity and sensitivity effects are redundant in the presence of BFI-O. CAQ and ATTA were not analyzed using regression analysis as the ANOVA did not reveal group differences in ANT performance (Appendix D). See Table 4.8 for regression coefficients and model fits of the hierarchical multiple regression analyses using continuous sensitivity.

Assumptions of ordinary least squares regression were checked. Scatterplots indicate linearity between variables. Distributions were inspected using P-P plots and histograms showing only the flanker congruity variable was positively skewed with kurtosis. Although no assumptions are made regarding independent variables in regression models, it is useful to find whether influential cases or outliers exist. Standardised residuals of the models indicate no outliers, however one influential case was identified if Mahalonobis distances > 15 and leverage values greater than  $(3[k + 1]/n)$ , although all standardized DFBeta values were < 1, which may also suggest that no cases substantially influence the model parameters (Field, 2013). Note. removal of the influential case identified by the converging Mahalonobis distance and leverage values did not change the outcome of the regressions. Residual variance indicates that homoscedasticity can be assumed.

**ATQ-OS.** Model 1 accounting for 5.1 % variance shows that congruity accounts for unique variance in RIBS scores. Model 2 accounts for 17.9% variance and gives a significantly better fit for the data. In Model 2, ATQ-OS accounts for unique variance in RIBS scores, however the addition of ATQ-OS in Model 2 renders congruity coefficients non-significant ( $p = .154$ ), suggesting redundancy and overlap. Model 3 accounts for 19.8% but does not give a

significantly better fit for the data ( $p=.127$ ). In Model 3, BFI-E, but not BFI-N, approaching significance accounts for unique variance ( $p = .058$ ), but this does not reduce the capacity of ATQ-OS to account for unique variance or change the effect of congruity. Note, in the dichotomous sample, the BFI-E coefficient is marginally significant ( $p = .048$ ). Model 4 accounts for 33.4% and gives a significantly better fit for the data. In Model 4, both ATQ-OS and BFI-O account for unique variance in RIBS scores and BFI-E approaches significance ( $p=.068$ ), as with the dichotomous sample ( $p=.061$ ), but not congruity or BFI-N. The final regression equation for Model 4:  $\hat{Y}(\text{RIBS})=.087 + .135(\text{congruity}) + .234(\text{ATQ-OS}) + .140(\text{BFI-N}) + .201(\text{BFI-E}) + .407(\text{BFI-O})$ .

### **Summary of Individual Differences in ANT Performance**

Mixed ANOVA did not reveal any sensitivity group effects in RTs, for either HSPS or ATQ-OS groups, or with NA controlled. The null findings with sensitivity measures does not support the hypothesis that sensitivity would be associated with slower RT performance for alerting cues, and thus not consistent with Costa et al. (2013) who found ATQ-OS group differences in RTs for alerting trials using a modified ANT. However, group interactions were found for ER with ATQ-OS measures, and for RIBS creative ideation (Appendix D). Group comparisons with the ATQ-OS support the hypothesis that high sensitivity groups would have poorer conflict resolution abilities following alerting cues. In this study, ATQ-OS groups show greater incongruity effects for both centre and double alerting cues, where HSP groups have higher ER than non-HSP groups for targets with incongruent (vs. neutral) flankers following both centre and double cues, and greater incongruity effects overall when alerting and orienting variables split by flanker condition are considered together. These effects remain significant when negative affect is partialled out using ATQ-OS (E, N) residuals, and thus provide the first

evidence, using the full ANT, that attention network efficiencies differ between HSPs and non-HSPs. However, no evidence was found to support the hypothesis that sensitivity would be associated with differences in efficiency of the orienting networks of the ANT, as the mixed ANOVAs did not reveal group interactions with spatial orienting cues, and no correlations (Appendix D) were found between sensitivity and orienting variables, for RTs or ERs, altogether suggesting that sensitivity as a continuous or dichotomous variable do not differ in their use of spatial orienting information in this task. The findings show that ATQ-OS affects only processes unique to the incongruency effect which are enhanced when alerting cues are given. As no RT effects were found, the group differences in ER do not reflect speed-accuracy tradeoff, suggesting that ATQ-OS HSPs maintain speed but at a cost of accuracy. Given that the ANT used was a speeded task, HSPs may have achieved slower, but no less accurate performance than non-HSPs given enough time. Indeed, this is evident in studies of change detection (Jagiellowicz et al., 2011) which involve attention (Beck et al., 2001; Rees & Lavie, 2001).

The creative groups showed very little difference in ANT performance across multiple analyses, however high RIBS groups was associated with greater ER for incongruent (vs. neutral) flankers compared with low RIBS groups (Appendix D). This suggests that measures of creative ideation are associated with differences in ANT conflict resolution, as with ATQ-OS. One question emerged whether congruity effects associated with both ATQ-OS and RIBS reflect shared (i.e., attention) or independent processes. The results from the hierarchical multiple regression (see Table 4.8) show the relationship between RIBS and congruity effects can be explained by ATQ-OS as congruity effects are absorbed into (i.e., made redundant by) the broader construct of ATQ-OS. This suggests that ATQ-OS measures attention mechanisms associated with a) alerting cue interactions with conflict resolution in flanker tasks and b)



creative ideation. Interestingly, similar effects were not found with the HSPS, suggesting that the HSPS does not capture the same underlying construct as completely as the ATQ-OS measure (Appendix D).

The CDT analysis showing both ATQ-OS and BFI-O overlap with CDT attention variables when accounting for RIBS variance suggest the same effects could be observed in the ANT analysis. However, the differences between ATQ-OS and HSPS regression models (Appendix D) are informative in showing that BFI-O does not overlap with congruity coefficients for RIBS scores. Table 4.8 shows in Model 4 of the HSPS regression analysis that congruity accounts for unique variance in RIBS scores in the presence of BFI-O, but not in the ATQ-OS regression models. Thus, the alerting congruity effects are specific to ATQ-OS, not BFI-O. However, considering the congruity variable is a subset of the conflict variable, ATQ-effortful-control (EC) is associated with conflict scores (Gerardi-Caulton, 2000; Posner et al., 2002), it is possible that these congruity effects may instead relate to ATQ-EC, rather than ATQ-OS. However, when the regression analysis is repeated, but with ATQ-EC replacing ATQ-OS in Model 2, the congruity coefficient remains significant ( $p=.015$ ) thus ruling out ATQ-EC effects.

It is not clear whether any single attention network is responsible, although alerting and conflict networks are implicated in ATQ-OS, and only conflict networks in RIBS, but this does not include temperament effortful-control thought to be linked to the executive control network (Rothbart et al., 2007). The alerting cues of the ANT are designed to produce broad, spatially diffused attentional states required for rapid information extraction which occurs at the expense of information quality, resulting in higher ER in attention tasks (Callejas et al., 2004; Fan et al., 2002; Posner & Petersen, 1990). The results from this study are consistent with the idea that ATQ-OS HSPs have higher sensitivity of alerting attention (see also Costa et al., 2013). HSPs

tend to have a harder time filtering out (inhibiting) the distracting incongruent information (i.e., more sensitive to irrelevant information) when attention has been alerted and diffused, similar to people high in creative ideation whose conflict resolution abilities are not specific to cue type. The mechanisms that could explain this performance include the cognitive disinhibition and hemispheric asymmetry hypothesis of creativity (Kaufman, Kornilov, et al., 2010; Martindale, 1999). Alerting cues produce higher ERs because alerting networks in the right hemisphere inhibit the executive control network, in particular the anterior cingulate which activates during inhibition of pre-potent responses required for conflict resolution (Posner, 1994). Alerting cues also decrease alpha power reflecting attention demands (Klimesch et al., 1998). Recall that high versus low creativity groups show higher alpha blockade (i.e., alpha suppression) during habituation to tones (Martindale & Armstrong, 1974b) and increased alerting skin potentials over time in response to bursts of white noise (Martindale et al., 1996) suggesting that higher creativity is associated with higher sensitivity of the alerting response. Considering that alerting inhibits executive control (Callejas et al., 2004; Posner, 1994), thus creating a state of disinhibition, one can speculate that higher ER for incongruent versus neutral flankers produced by alerting cues reflect a greater tendency towards cognitive disinhibition in sensitive, creative people.

### **Discussion**

Overall, this study replicates findings linking sensitivity to change detection of minor versus major changes in visual scenes (Jagiellowicz et al., 2011) and extends these findings by linking sensitivity, creativity and attention mechanism involved in change detection. Specifically, we argue that overlap between minor versus major RTs and ATQ-OS measures when accounting for unique variance in creative ideation reflect shared attention processes (i.e.,

automatic attention orienting) which partly define these measures. However, this effect is specific to positive-affect-related traits of orienting sensitivity and openness (Sobocko & Zelenski, 2015), and not the broader environmental sensitivity captured by the HSPS (Aron & Aron, 1997; Evans & Rothbart, 2008).

We update the literature regarding individual differences in the efficiencies of the three attention networks measured by the ANT, and provide a greater understanding of the attention networks associated with sensitivity and creativity. Specifically, we present evidence suggesting that sensitivity is associated with differences in how alerting networks interact with executive control networks to resolve conflict in flanker tasks. Further, we show those network interactions also predict creative ideation, but have substantial overlap with orienting sensitivity, rather than broader measures of environmental sensitivity captured by the HSPS, and are not explained by negative affect, BFI-O, or ATQ-EC. This suggests the shared underlying mechanism between creative ideation and congruity effects following alerting cues relates to automatic attention processes measured by the ATQ-OS, and can be explained more generally by cognitive disinhibition and hemispheric asymmetry hypotheses of creativity (Kaufman, Kornilov, et al., 2010; Martindale, 1999). The shared underlying mechanism proposed does not appear to include orienting attention networks measured by the ANT, as no effects were found with spatial cueing or orienting variables. This is interesting considering that ATQ-OS is thought to measure orienting attention. However, this null finding could be explained by the low reliabilities reported for the orienting network which potentially result from the calculation of difference scores. Low reliability can reduce statistical power and resulting in failure to identify between-groups effects (MacLeod et al., 2010). Further, the ANT specifically measures endogenous attention, leaving the question open as to whether ATQ-OS relates to exogenous orienting

processes. Thus, one aim of Chapter 5 is to establish whether orienting sensitivity of the ATQ has a brain basis in exogenous attention networks by exploring individual differences in a spatial Stroop paradigm which includes both endogenous and exogenous orienting conditions.

## Tables

Table 4.1

*Mean, standard deviation (SD) and lower (LCI) and upper (UCI) 95% confidence intervals for creativity, temperament, personality variables (N=97)*

	Mean	SD	LCI	UCI
<i>Creativity</i>				
CAQ	8.32	6.62	7.08	9.66
RIBS	2.85	.53	2.75	2.96
ATTA	68.09	8.62	66.2	69.79
<i>Temperament</i>				
ATQ-OS	4.53	.74	4.39	4.68
<i>Personality</i>				
BFI-O	3.16	.57	3.05	3.28
BFI-C	3.46	.68	3.33	3.6
BFI-E	3.22	.78	3.07	3.38
BFI-A	3.81	.66	3.68	3.94
BFI-N	3.36	.8	3.21	3.52

*Note:* CAQ=Creative Achievement Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults; ATQ-OS=orienting sensitivity factor of the ATQ; BFI-O=openness to experience factor of the Big Five Inventory (BFI); BFI-C=conscientiousness factor of the BFI; BFI-E=extraversion factor of the BFI; BFI-A=agreeableness factor of the BFI; BFI-N=neuroticism factor of the Big Five Inventory.

Table 4.2

*Mean reaction times (msec) and error rates (%) with standard deviations (SD) and 95% confidence lower (LCI) and upper (UCI) intervals for change detection task overall and by condition (N=97)*

	<i>Reaction Times (msec)</i>				<i>Error rates (%)</i>			
	Mean	SD	LCI	UCI	Mean	SD	LCI	UCI
Overall	12505	3446	11820	13191	11.67	11.48	9.39	13.95
Location	7787	2460	7298	8277	3.61	7.53	2.11	5.11
Presence	11096	3866	10326	11865	7.32	13.27	4.68	9.96
Color	19880	9946	17900	21859	27.22	22.53	22.73	31.7
Size	12259	4342	11395	13123	9.59	13.91	6.82	12.36
Major	9441	2490	8946	9937	5.46	8.81	3.71	7.22
Minor	19880	9946	17900	21859	27.22	22.53	22.73	31.7
Minor-Major	10438	9938	8460	12416	21.75	19.05	17.96	25.54

Table 4.3

*Correlations between mean RT and error rate performance overall and across condition for the change detection task*

	Reaction Times							Error rates							
	Overall	Location	Presence	Color	Size	Major	Minor	Mi-Ma	Overall	Location	Presence	Color	Size	Major	Minor
Overall	-														
Location	.396**	-													
Presence	.540**	.204*	-												
Color	.774**	.03	.122	-											
Size	.674**	.356**	.367**	.306**	-										
Major	.608**	.650**	.849**	.105	.481**	-									
Minor	.774**	.03	.122	1.00**	.306**	.105	-								
Mi-Ma	.598**	-0.15	-.105	.957**	.168	-.159	.957**	-							
Overall	-.328**	.021	-.159	-.363**	.011	-.089	-.363**	-.330**	-						
Location	-.146	.098	-.174	-.188	-.032	-.066	-.188	-.172	.523**	-					
Presence	-.337**	-.093	-.207*	-.308**	-.089	-.178	-.308**	-.251*	.674**	.292**	-				
Color	-.328**	-.001	-.163	-.308**	-.012	-.132	-.308**	-.267**	.897**	.358**	.471**	-			
Size	-.16	.089	-.045	-.280**	.057	.027	-.280**	-.272**	.705**	.454**	.488**	.447**	-		
Major	-.267**	.012	-.217*	-.284**	-.035	-.118	-.284**	-.247*	.741**	.681**	.856**	.479**	.549**	-	
Minor	-.328**	-.001	-.163	-.308**	-.012	-.132	-.308**	-.267**	.897**	.358**	.471**	1.00**	.447**	.479**	-
Mi-Ma	-.267**	-.015	-.115	-.244*	.022	-.121	-.244*	-.208*	.737**	.154	.248*	.942**	.328**	.206*	.942**

Note. \*  $p < 0.05$  level, \*\*  $p < .01$  (2-tailed), \*\*\*  $p < .001$ . Mi – Ma=Minor - Major difference

Table 4.4

*Spearman's correlations showing associations between creativity, temperament and personality measures and the reaction time and error rates for the CDT task*

	Reaction Times						Error Rates					
	Overall	Location	Presence	Color	Size	Mi-Ma	Overall	Location	Presence	Color	Size	Mi-Ma
<i>Creativity</i>												
CAQ	.057	-.005	-.106	.135	.019	.154	-.024	.009	-.017	-.003	.018	.028
RIBS	.114	.036	-.109	.204*	.091	.211*	-.007	-.06	.04	.031	-.018	.044
ATTA	.105	.015	.156	.061	.074	.042	-.076	-.196	-.088	-.041	-.089	-.005
<i>Temperament</i>												
ATQ OS	.111	.009	-.125	.202*	.003	.215*	-.086	-.088	-.116	-.049	-.101	-.012
<i>Personality</i>												
BFI O	-.012	-.098	-.193	.1	-.045	.158	-.132	-.008	-.002	-.144	-.032	-.146
BFI C	-.126	-.109	-.171	-.03	-.053	.005	.121	.136	-.068	.178	.06	.191
BFI E	-.015	-.221*	.043	.124	-.115	.148	.024	-.027	.077	.113	-.021	.132
BFI A	-.087	-.104	-.165	-.064	.005	-.025	-.059	.031	-.04	-.037	-.107	-.053
BFI N	.135	.241*	.044	-.012	.239*	-.034	-.056	-.065	-.095	-.142	.083	-.143

*Note.* \*  $p < 0.05$  level, \*\*  $p < .01$  (2-tailed). *Note:* CAQ=Creative Achievement Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults; ATQ-OS=orienting sensitivity factor of the ATQ; BFI O=openness to experience factor of the Big Five Inventory (BFI); BFI C=conscientiousness factor of the BFI; BFI E=extraversion factor of the BFI; BFI A=agreeableness factor of the BFI; BFI N=neuroticism factor of the Big Five Inventory; Mi – Ma=Minor - Major difference.



Table 4.5

*Hierarchical multiple regression – Continuous sensitivity, personality and change detection as predictors of creative ideation*

	RIBS		<i>t</i>
	ATQ-OS		
	Beta	SE	
<b>Model 1</b>			
Mi-Ma RT	.248	0	2.5*
<b>Model 2</b>			
Mi-Ma RT	.159	0	1.68
Sensitivity	.386	.068	4.08***
<b>Model 3</b>			
Mi-Ma RT	.121	0	1.249
Sensitivity	.407	.069	4.246***
BFI-N	.045	.081	.369
BFI-E	.181	.083	1.476
<b>Model 4</b>			
Mi-Ma RT	.077	0	.862
Sensitivity	.258	.068	2.739**
BFI-N	.111	.074	.989
BFI-E	.168	.076	1.491
BFI-O	.402	.087	4.321***
<b>Model fit</b>			
	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>
Model 1	6.23*	1,95	.052
Model 2	16.66***	1,94	.186
Model 3	1.37	2,92	.192
Model 4	18.67***	1,91	.322

*Note.* \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; Mi-Ma RT=Major – Minor RT; ATQ-OS=orienting sensitivity factor of the ATQ; BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory; *F*=*f*-change in model fit; *df*=degrees of freedom; *R*<sup>2</sup>=adjusted *R*<sup>2</sup>.

Table 4.6

*Mixed ANOVA output showing between-group effects for ATQ-OS (and ATQ-OS (E, N) residuals) and group interactions with cue and flanker conditions for reaction times (RT) and error rates*

	RT			Error rates		
	<i>F</i>	<i>df</i>	$\eta_p^2$	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>ATQ-OS</i>						
Group	2.98	1,95	.03	4.55*	1,95	.046
Group × Cue	.08	3,255	.001	3.54*	3,242	.036
Group × Flanker	.65	2,150	.007	5.99*	1,103	.059
Group × Cue × Flanker	.97	5,449	.01	3.51	3,322	.036
<i>ATQ-OS (E, N) residuals</i>						
Group	2.19	1,95	.023	6.74*	1,95	.066
Group × Cue	.27	3,255	.003	2.95*	3,240	.03
Group × Flanker	.33	2,150	.003	6.54**	1,104	.064
Group × Cue × Flanker	.66	5,449	.007	3.02*	3,321	.031

*Note.* \* $p < .05$ , \*\* $p < .01$ . *F*=ANOVA *F*-ratio; *df*=degrees of freedom;  $\eta_p^2$ =partial eta squared

Table 4.7

*Mixed ANOVA output showing between-group effects for ATQ-OS, including ATQ-OS (E, N), residuals and group interactions with cue (centre – none, double – none, centre-direction) and flanker (congruent, incongruent) factors for reaction times (RTs) and error rates*

	RTs			Error rates		
	<i>F</i>	<i>df</i>	$\eta_p^2$	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>ATQ-OS</i>						
Group	.13	1,95	.001	9.88**	1,95	.094
Group × Cue	.73	1,136	.008	.89	1,132	.009
Group × Flanker	2.09	1,95	.021	7.63**	1,95	.074
Group × Cue × Flanker	.25	2,147	.003	.26	1,131	.003
<i>ATQ-OS (E, N) residuals</i>						
Group	.04	1,95	0	7.07**	1,95	.069
Group × Cue	.86	1,136	.009	.65	1,132	.007
Group × Flanker	1.66	1,95	.017	6.85**	1,95	.067
Group × Cue × Flanker	.03	2,147	0	.51	1,132	.005

*Note.* \*  $p < .05$ , \*\*  $p < .01$ . *F*=ANOVA *F*-ratio; *df*=degrees of freedom;  $\eta_p^2$ =partial eta squared.

Table 4.8

*Hierarchical multiple regression: Sensitivity (continuous), personality and congruity (incongruent – neutral flankers collapsed across alerting cue conditions) as predictors of creative ideation*

	RIBS					
	ATQ-OS			HSPS		
	Beta	SE	<i>t</i>	Beta	SE	<i>t</i>
<b>Model 1</b>						
Congruity	.247	.007	2.49*	.247	.007	2.49*
<b>Model 2</b>						
Congruity	.139	.007	1.44	.25	.007	2.51*
Sensitivity	.384	.069	3.98***	.089	.069	0.9
<b>Model 3</b>						
Congruity	.144	.007	1.51	.263	.007	2.69**
Sensitivity	.393	.069	4.06***	.253	.097	1.81
BFI-N	.08	.08	.67	.014	.099	0.09
BFI-E	.229	.081	1.92	.296	.089	2.26*
<b>Model 4</b>						
Congruity	.135	.007	1.55	.195	.006	2.24*
Sensitivity	.234	.068	2.46*	.068	.089	0.53
BFI-N	.14	.074	1.27	.15	.089	1.13
BFI-E	.201	.074	1.85	.216	.079	1.85
BFI-O	.407	.085	4.45***	.479	.085	5.26***
<b>Model fit</b>	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>
Model 1	6.18*	1,95	.051	6.18*	1,95	.051
Model 2	15.84***	1,94	.179	.80	1,94	.049
Model 3	2.11	2,92	.198	2.94	2,92	.063
Model 4	19.81***	1,91	.329	27.69***	1,91	.292

*Note.* \*  $p < .05$ , \*\*\*  $p < .001$ . RIBS=Runco Ideational Behaviour Scale; ATQ-OS=orienting sensitivity factor of the ATQ; HSPS=Highly Sensitive Person Scale (full); BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory; *F*=F-change in model fit; *df*=degrees of freedom; *R*<sup>2</sup>=adjusted *R*<sup>2</sup>.



## CHAPTER V

### **Endogenous and Exogenous Attention in the Sensitive Creator**

#### Abstract

Tasks used in Chapter 4 were inadequate to fully investigate the hypothesis that sensitivity is grounded in exogenous orienting networks and did not capture all orienting sub-functions, including detection, disengagement, movement, and engagement of attention (Posner, 1980; Posner & Petersen, 1990) and evidence suggests temperament moderates particular orienting sub-functions (Avila, 1995; Derryberry & Reed, 1994; Poy, del Carmen Eixarch, & Ávila, 2004). In this chapter, we establish a) whether orienting sensitivity is grounded in exogenous attention networks by exploring individual differences in a spatial Stroop task sensitive to both endogenous and exogenous orienting, and detection, disengagement, movement, and engagement sub-functions thereof, and b) whether exogenous orienting and sub-functions are underlying mechanisms in the sensitive creator (Chapter 2).

ATQ-OS shows reliable Inhibition-of-Return (IOR) in exogenous attention tasks, consistent with ATQ-OS as “automatic” exogenous attention. However, ATQ-OS measures do not relate to orienting sub-functions. No evidence was found to suggest exogenous IOR mechanisms associated with orienting sensitivity are implicated in higher creativity by any creativity measure used in this study.



## **Introduction**

In Chapter 4, we hypothesized sensitivity would be associated with individual differences in efficiency of the orienting networks measured with the attention network task (ANT; Fan et al., 2002). However, null findings were explained to result from task limitations as the ANT specifically measures endogenous attention, meaning the ANT is inadequate to fully investigate the hypothesis that sensitivity, specifically orienting sensitivity, is grounded in exogenous orienting attention. Further, the ANT does not capture all important aspects of the orienting process, including detection, disengagement, movement, and engagement of attention (Posner, 1980; Posner & Petersen, 1990) and evidence suggests temperament moderates particular orienting sub-functions (Avila, 1995; Derryberry & Reed, 1994; Poy et al., 2004). The aim of Chapter 5 is to establish a) whether orienting sensitivity has a brain basis in exogenous orienting attention networks by exploring individual differences in a spatial Stroop paradigm, which includes tasks sensitive to both endogenous and exogenous orienting and the detection, disengagement, movement, and engagement sub-functions thereof, and b) whether the exogenous orienting networks and sub-functions are underlying mechanisms in the sensitive creator (see Chapter 2).

### **Endogenous and Exogenous Orienting**

To understand how orienting attention may relate to sensitivity one must consider the processes underlying the dorsal and ventral orienting attention networks that may underlie this temperament. The function of orienting is to align attention towards novel, important and relevant sensory input or internal cognitive events (Posner, 1980). Orienting of attention is strongly related to the orienting reflex (Sokolov, 1963, 1990), although the orienting reflex does not distinguish between mental operations of detection, disengagement, movement, and engagement involved in



orienting (Posner, 1980; Posner & Petersen, 1990). A general framework explains orienting of attention in terms of elementary mental operations of facilitation and inhibition (Posner, 1980; Posner & Cohen, 1984; Posner et al., 1985). This framework has been extensively tested using spatial cueing paradigms (for reviews, see Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014; Posner & Petersen, 1990), in which participants must detect or discriminate targets that appear at cued or uncued locations. Intervals between cue and target are known as the stimulus-onset-asynchrony (SOA) and manipulation of this interval can provide facilitation or inhibition of target processing depending on length of SOA and cue type (Jonides, 1981; Posner, 1980). Spatial cueing paradigms can capture two modes of orienting (for a review, see Chica et al., 2014). Top-down, endogenous, voluntary orienting can be manipulated with a central symbolic indicator, such as a central arrow (but see Tipples, 2002), that predicts the location of a target stimulus with high probability (typically 75% predictability). Bottom-up, exogenous, involuntary orienting can be manipulated using non-predictive peripheral cues, such as salient, abrupt changes in luminance giving the impression of a brief flash that occurs equally often at target locations (Chica et al., 2014; Posner, 1980). Facilitation effects in spatial cueing paradigms are found for both endogenous and exogenous cues (Posner, 1980), but with some differences. Typically, endogenous cue facilitation effects are observed with long cue-target SOAs of approximately 300ms and can last for several seconds (Posner, 1980), and exogenous cue facilitation effects are observed more briefly with short cue-target SOAs of approximately 100ms, but not with cue-target SOAs greater than 250ms (Jonides, 1981; Muller & Rabbitt, 1989). Instead, at longer SOAs and following exogenous cues only (cf. Frischen & Tipper, 2004), both reaction times (Posner & Cohen, 1984) and accuracy (Klein & Dick, 2002) show negative facilitation effects, or impairment of target processing. This negative facilitation effect is known as inhibition-of-return (IOR; Lupiáñez et al.,

2004; Posner & Cohen, 1984; Posner et al., 1985), an adaptive impairment of reflexive attention and perception mechanisms (Klein & Dick, 2002) that bias attention in favor of novel versus familiar locations, thus creating favorable conditions for foraging, visual search and novelty detection (for a review, see Klein, 2000).

### **Individual Differences in Spatial Cueing**

The spatial cueing paradigm has been useful for exploring individual differences in orienting attention, providing valuable information regarding the underlying cognitive mechanisms associated with major personality dimensions, such as Behavioural Inhibition System (BIS) and BAS Behavioural Activation System (BAS; Carver & White, 1994; Gray, 1981), which is relevant considering the conceptual overlap of the sensitive temperament with BIS/BAS factors. Conceptually, sensory-processing sensitivity (SPS) measured by the HSPS is related to the BIS, a "pause and reflect" inhibitory system sensitive to punishment, non-reward and novelty. The BIS is more active in neurotic-introverts, or those prone to anxiety (Carver & White, 1994; Gray, 1981), although SPS is partially independent of introversion and neuroticism (Aron & Aron, 1997). Further, orienting sensitivity, a subfactor of the HSPS (Aron & Aron, 1997; Evans & Rothbart, 2008) and the emotion-attention model of temperament (Evans & Rothbart, 2007, 2009), is a positive correlate of openness to experience (Evans & Rothbart, 2007), a trait associated with the neurotransmitter dopamine which mediates BAS-related approach behavior, positive affect and reward sensitivity (DeYoung et al., 2002, 2005). Openness (Li et al., 2015; Smits & Boeck, 2006) and orienting sensitivity factors of the HSP-AS/OS (Smolewska et al., 2006) have been shown to correlate positively with reward-responsiveness subfactors of BAS. Further, orienting sensitivity and openness (see Chapter 2) and also BAS (Dreu, Nijstad, & Baas, 2011) are each related to creative products/divergent thinking. Thus, attention studies exploring individual differences in

BIS/BAS provide a useful analogue to explore indirectly how orienting attention measured using spatial cueing paradigms may index cognitive processes associated with sensitivity and creativity.

Derryberry and Reed (1994) found, using a spatial cueing paradigm with motivationally salient locations, that temperament regulates orienting sub-functions involved with disengagement of attention from significant stimuli. At short SOAs, across both endogenous and exogenous cue types, introverts (weak BAS, strong BIS) were slower than extraverts (strong BAS, weak BIS) when disengaging from aversive cues, and extraverts were slower than introverts at disengaging from appetitive cues, and in both cases the effects were strongest when neuroticism was high (i.e., stronger non-specific arousal resulting in lower BIS/BAS thresholds). Other studies have shown how temperament and personality relate to cognitive functioning regardless of emotional valence. Looking at general cognitive mechanisms of attention could explain how the function of two modes of orienting attention may influence the detection and processing of threat and reward and thus determine motivation preferences (Poy et al., 2004) and outcomes of the sensitive temperament. For example, in exogenous cueing tasks, high versus low BIS and BAS is associated with stronger IOR (Avila, 1995). However, high versus low BIS is associated with greater costs when disengaging from invalid peripheral cues at short SOA following exogenous cues, whereas high versus low BAS is associated with a greater ability to disengage from invalid target locations at long SOA following endogenous cues (Poy et al., 2004).

Together, this evidence provides some support for the notion that temperament regulates attentional orienting processes involved with disengagement of attention from significant stimuli. Both introverts and extraverts are equally likely to notice, orient, attend to negative or positive events, but how they dwell in this information differs. Introverts are less able to disengage from negative events, or worrisome and ruminative thoughts, whereas extraverts are more prone to dwell

on positive events, but have greater cognitive flexibility to voluntarily disengage attention. Further, sensitivity to motivational cues determines how strongly these effects are observed. This effect is attributed to neuroticism and non-specific arousal, however an alternative explanation implicates the lower-sensory-thresholds and ease-of-excitation characteristics of the sensitive temperament (Aron & Aron, 1997; Smolewska et al., 2006). Stronger BIS and BAS are related to greater IOR, and recent evidence also links openness to experience, a personality trait associated with orienting sensitivity and creativity (see Chapter 2), with a broader distribution of IOR across the visual field (Wilson et al., 2016). These findings are each important, showing that personality traits with strong links to the sensitive temperament may be grounded in orienting attention systems. Further, the evidence suggests that orienting mechanisms involving disengagement of attention from significant stimuli relates to temperament and this is something not captured by the ANT, providing further justification for investigations of temperament and orienting attention using measures sensitive to both endogenous and exogenous orienting and sub-functions therein.

### **Sensitivity and Spatial Cueing Paradigms**

As definitions of sensitivity suggest individual differences in the exogenous orienting network (Evans & Rothbart, 2007), it is important that theoretical and empirical work supports an endogenous/exogenous taxonomy in order to justify further investigation beyond what has been found with existing measures, i.e., the ANT (see Chapter 4). Indeed, recent behavioural studies using spatial Stroop paradigms demonstrate qualitative differences representing a double dissociation between endogenous and exogenous orienting, wherein endogenous and exogenous cue types modulate spatial Stroop effects in opposite ways (Funes, Lupiáñez, & Milliken, 2007). Further, recent event-related transcranial magnetic stimulation studies have revealed a causal role for the temporoparietal junction in exogenous, but not endogenous attention (Chica, Bartolomeo,

et al., 2011), consistent with evidence identifying spatially distinct, functionally competitive but interactive neural networks that subservise endogenous and exogenous attention and internally and externally directed cognitions (Corbetta & Shulman, 2002; Dixon et al., 2014; Spreng et al., 2013). Thus, spatial cueing paradigms offer a useful tool to explore how individual differences in the sensitive temperament relate to efficiency of dissociated endogenous and exogenous attention networks.

## **Hypothesis**

Initially, using the spatial Stroop paradigm, we aim to replicate the dissociation of endogenous and exogenous tasks reported by Funes et al. (2007) wherein exogenous cues should reduce spatial Stroop interference, such that spatial congruency effects are smaller on valid versus invalid trials, whereas endogenous cues should either a) fail to reduce, or b) increase spatial congruency effects for valid versus invalid trials. Different SOAs are used in the spatial Stroop paradigm to observe maximal effects typically found for exogenous and endogenous cues at short (100ms) and long (850ms) SOA, respectively (Funes et al., 2007; Jonides, 1981; Posner & Cohen, 1984). This replication will provide evidence consistent with an endogenous/exogenous taxonomy, and thus provide further justification to investigate attention mechanisms beyond what has been found with existing measures, i.e., the ANT (see Chapter 4). Note, while Funes and colleagues manipulated attention task between subjects, the present study used a within-subject manipulation of task (see Appendix E).

Regarding individual differences, we predict ATQ-OS will relate to performance in the spatial Stroop task as both environmental sensitivity (Aron et al., 2012; Kantor-Martynuska, 2012) and orienting sensitivity (Evans & Rothbart, 2007) frameworks imply an attention mechanism, with ATQ-OS explicitly defined as “automatic” exogenous orienting. Findings

suggest that orienting is also affected by neuroticism (Derryberry & Reed, 1994) and as HSPS captures both negative and positive sides of sensitivity (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015), and ATQ-OS is a positive-affect-related vantage sensitivity (Sobocko & Zelenski, 2015), differences in performance between sensitivity measures may emerge. Thus, it will be important to understand whether sensitivity relates to orienting performance with negative affect controlled.

Based on evidence linking strong BIS and BAS to IOR (Avila, 1995) and openness to a broader distribution of IOR (Wilson et al., 2016), and considering the conceptual overlap of sensitivity measures with BIS/BAS and openness, we predict (i) ATQ-OS HSPs versus non-HSPs will have stronger IOR effects in exogenous tasks as ATQ-OS has a strong relationship with openness.

Further, based on the associations between BIS/BAS scales and the ATQ-OS, we predict (ii) HSPs versus non-HSPs would be associated with a greater ability to disengage from invalid target locations at long SOA using endogenous cues, as found with strong BAS (Poy et al., 2004). Note, whilst the ANT has already been used to investigate HSP versus non-HSP performance in endogenous orienting tasks, it does not have a cue validity condition to measure disengagement of attention from invalid cued locations, thus it is possible that endogenous task effects will be observed beyond what have been reported using the ANT (Chapter 4).

Regarding sensitivity and creativity, we hypothesize (iii) that orienting sensitivity and IOR to predict creativity, and if IOR underlies the relationship between sensitivity and creativity, then redundancy of the IOR variable should be observed when controlling for sensitivity. Further, evidence shows BAS is associated with greater flexibility when disengaging endogenously cued attention at late SOA (Poy et al., 2004) and BAS relates to creative products/divergent thinking

(Dreu et al., 2011). Indeed, higher cognitive flexibility is important for creative products/divergent thinking (Zabelina & Robinson, 2010). Thus, as orienting sensitivity correlates positively with reward–responsiveness subfactors of BAS (Smolewska et al., 2006) and creative products/divergent thinking (see Chapter 2), we predict that (iv) if hypothesis (ii) is supported and HSPs versus non-HSPs of the ATQ-OS have greater ability to disengage voluntary cued attention from invalid target locations at long SOA, then we expect this performance to predict creative products/divergent thinking. Further, if this subprocess of endogenous orienting underlies the relationship between sensitivity and creativity, then redundancy of this variable should be observed when controlling for sensitivity.

## **Method**

### **Participants**

A sample of 65 participants were recruited for the study (47 female, 18 male, aged between 18-28 years,  $M = 20.42$ ,  $SD = 2.34$ ). Participants were rewarded with course credit. This study was approved by Human Ethics Committee in the Faculty of Science and Environment at University of Plymouth. Participants gave informed consent before the study and were debriefed after completing the study.

### **Apparatus and Materials**

A computerized battery was developed on Survey Monkey to assess sensitivity, personality and creativity and administered in the lab. Each questionnaire was presented on a separate page within the software. For each item, the participant checked the blank in front of any item corresponding to the response that best applied to them.

Sensitivity was measured using two questionnaires. 1) The Highly Sensitive Person scale (HSPS) from Aron and Aron (1997) is a 27-item, modality general, self-report scale measuring

sensory processing sensitivity using items asking about tendencies to startle easily, become easily overwhelmed by sensory inputs but also awareness of subtleties in the environment, and enjoyment of fine and delicate scents, tastes, sounds, and works of art. Item responses ranged from 1 (not at all) to 7 (extremely). 2) The two HSPS factors of orienting sensitivity and negative affect were also measured using the Adult Temperament Questionnaire (ATQ)-short form (Evans & Rothbart, 2007). The ATQ is a self-report scale with 77 items measuring general constructs of orienting sensitivity (ATQ-OS), negative affect (ATQ NA), effortful control (ATQ EC), and extraversion/surgency (ATQ ES). Item responses ranged from 1 (extremely untrue) to 7 (extremely true) and “not applicable”.

The Big Five Inventory (BFI) assessed personality. This 44-item self-report questionnaire measures the Big Five dimensions of personality: Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Benet-Martinez & John, 1998; John et al., 1991; John et al., 2008; John & Srivastava, 1999). Item responses ranged from 1 (disagree strongly) to 5 (agree strongly).

Creativity was assessed using three of the most established and validated measures of creative processes. The Creative Achievement Questionnaire (CAQ; Carson et al., 2005) was chosen as an objective self-report measure of creative achievement across 10 domains of creativity. The Runco Ideational Behaviour Scale (RIBS; Runco et al., 2000-2001) is a 19-item questionnaire designed to measure creative ideation, which is thought to measure a single factor and has discriminant validity. Items probe behavioural tendencies and abilities regarding ideas and thinking, with many items emphasizing creative, unusual, or imaginative thought (e.g., “I have many wild ideas.”). The RIBS responses ranged from 1 (never) to 5 (very often). This study was lab-based in order to administer one pencil and paper creativity test: The Abbreviated



Torrance Test for Adults (ATTA; Goff & Torrance, 2002) consists of 3 timed (3-minute) tests of figural and verbal divergent thinking abilities thought to be critical for the creative process (Runco, 2014). The ATTA is a gold standard, objective measure of divergent thinking. The ATTA thus is the one test that independently verifies creative products/divergent thinking. The ATTA was presented in the lab in paper format with a pencil and eraser, not part of the Survey Monkey battery.

The experimental measures used in this experiment i.e., the spatial Stroop paradigm (Funes et al., 2007), and the presentation of stimuli, timing, and response collection was controlled using PsychoPy software (version 1.8; Peirce, 2007). Tasks were presented on a Viglen Windows 7 PC with Philips Brilliance LED monitor 221P3LPYES P-line 21.5" widescreen operating at 1920×1080 pixels with a 60hz refresh rate. Participants were sat in a cubicle with eyes at a distance of 60cm from the screen. On a black screen, the fixation point consisted of a white unfilled circle with a diameter of 3mm. The fixation was flanked by boxes on the left and right of the screen with a height and width of 24mm and 21mm respectively. The inner edge of each box measured 30mm from the centre of the fixation. In the exogenous task, the cue consisted of a brief and small increase in the line width of the box for 50ms, giving the impression of flicker. In the endogenous task, the cue consisted of a 50ms presentation of a red or green circle with a diameter of 7mm centred and overlaying the fixation.

## **Design**

Previously, Funes et al. (2007) manipulated Cue type/Task between-subjects. However, because this was intended as a group study of individual differences, all attention factors were manipulated within-subjects. In this task, we used a fully within-subjects design of the spatial Stroop task (Funes et al., 2007) which included 4 within-subjects factors: Cue type/Task

(endogenous cue, exogenous cue), SOA (100ms, 850ms), target location (valid or congruent with cue location, invalid or incongruent with cue location) and target direction (target direction congruent with target location, target direction incongruent with target location). The task presentation order was counterbalanced across participants such that there were equal numbers of times the exogenous and endogenous tasks were presented first. Each condition consisted of 7 blocks of 64 trials for a total of 448 trials per condition. For the endogenous condition the cue predicted target location 75% of the time with 336 valid trials and 112 invalid trials (48 valid trials and 16 invalid trials per block). For the exogenous condition the cue predicted target location 50% of the time with 224 valid trials and 224 invalid trials (32 valid trials and 32 invalid trials per block). SOA types and target directions were presented an equal number of times across valid and invalid conditions. Trials were presented in randomized order in each task. The practice block consisted of 32 trials randomly selected from a block of 64 trials. Endogenous and exogenous task order was counterbalanced across participants.

**Individual differences.** The HSPS may be a taxon consisting of HSP's (i.e., those high on HSPS) and non-HSP's, therefore Aron and Aron (2013) suggest dichotomizing the sample. As the sample majority consists of Psychology majors who may include a larger percentage of HSPs than the typical 20%, the break point was chosen to be 30% (high) HSP's and 70% (low) non-HSP's (Aron & Aron, 2013). For the ATQ-OS, the HSP group ( $n=20$ ,  $M = 5.63$ , 95% CI[5.41, 5.85]) have significantly higher ratings on the ATQ-OS,  $t(63)=11.32$ ,  $p<.001$ , than non-HSP groups ( $n=45$ ,  $M = 4.25$ , 95% CI[4.12, 4.37]).

For each creativity measures, groups were formed based on a median split, where high creativity groups  $>$  median score, and low creativity groups  $\leq$  median score. The medians for CAQ, RIBS and ATTA are  $Mdn=4$ ,  $Mdn=2.9$ , and  $Mdn=67$ , respectively. The CAQ scores for

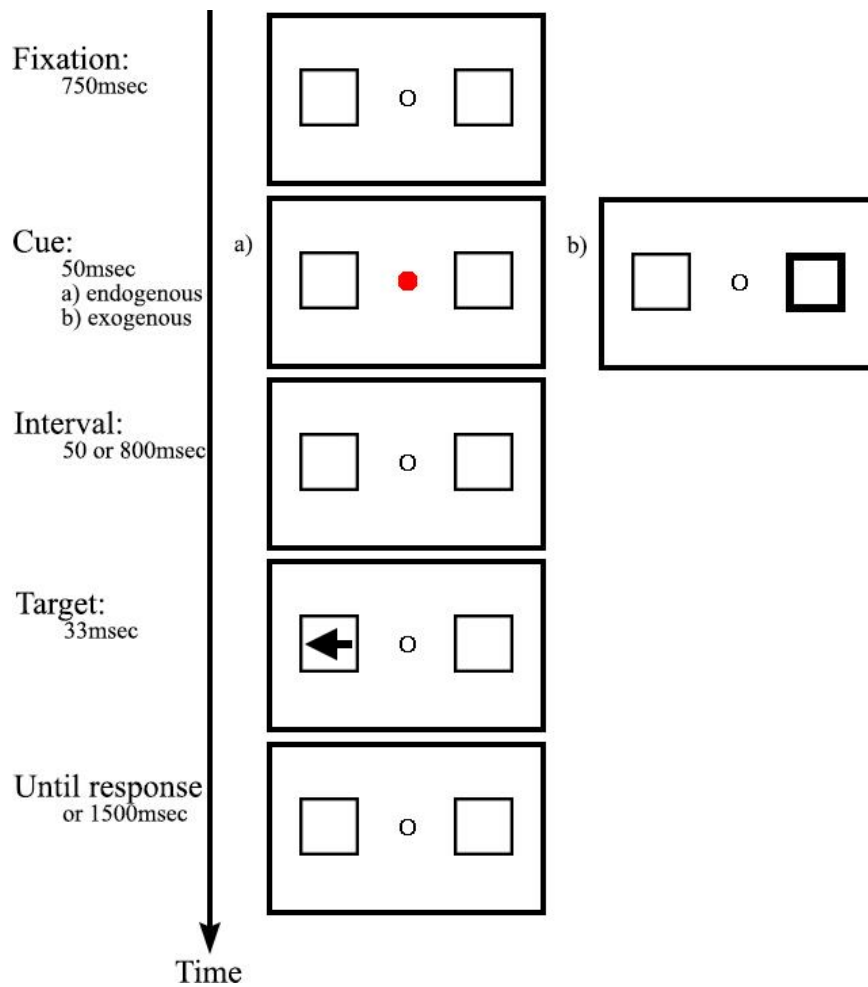
the high CAQ group ( $n=32$ ;  $M=13.41$ , 95% CI[10.42, 16.76]) are significantly higher than the low CAQ group ( $n=32$ ;  $M=13.41$ , 95% CI[10.42, 16.76]),  $t(63)=6.32$ ,  $p<.001$ . The RIBS scores for the high RIBS group ( $n=30$ ;  $M=3.39$ , 95% CI[3.26, 3.52]) are significantly higher than low the RIBS group ( $n=35$ ;  $M=2.54$ , 95% CI[2.44, 2.64]),  $t(63)=10.64$ ,  $p<.001$ . The ATTA scores for the high ATTA group ( $n=30$ ;  $M=72.23$ , 95% CI[71.11, 73.45]) are significantly higher than the low ATTA group ( $n=35$ ;  $M=59.97$ , 95% CI[56.02, 63.07]),  $t(63)=6.24$ ,  $p<.001$ . Note, all personality, temperament, and creativity measures are scaled between 0 and 1, see Chapter 2 for scaling. Max scores used for scaling CAQ are 49, and 82 for the ATTA in this chapter only.

### **Procedure**

Participants were first administered the spatial Stroop task using PsychoPy (Pierce, 2007). The stimulus events during each trial are presented in chronological order in Figure 5.1. At the beginning of each trial, a fixation point with two peripheral boxes was presented for 750ms, and then a cue appeared for 50ms. Following the cue, the fixation and peripheral boxes remained onscreen for a delay dictated by the SOA (50ms or 800ms). Following the SOA, a target arrow appeared in one peripheral box for 33ms. The fixation and peripheral boxes remained onscreen for 1500ms, or until a response was made. The inter-trial interval was a blank screen presented for a duration of 1000ms, but if the participant responded incorrectly they received a text of “Incorrect” as feedback for a 500ms duration, included at the beginning of the inter-trial interval.

For every trial, participants were instructed to keep their eyes centred on the fixation point. They were instructed to press the left control key if the arrow was pointing to the left, and the right control key if the arrow was pointing to the right, and to respond as quickly and accurately as possible. In the exogenous task, the cues appeared equally often in the left and right

peripheral boxes at random, and were not predictive about the location of the target. In the endogenous task, participants were told that the central cue was highly predictive about the location of the target arrow. For half of the participants a green central cue indicated that 75% of the targets would appear in the left peripheral box, and a red central cue indicated that 75% of the targets would appear in the right peripheral box. For the other half of participants the color indicators were switched, such that red central cues indicated that 75% of the targets would appear in the left peripheral box and green central cue indicated that 75% of the targets would appear in the right peripheral box. In both tasks, the peripheral or central cues did not predict the direction of the arrow, and the arrow pointed equally often to the left and right in all conditions. After given a practice block, participants took part in the main experiment and were given rest breaks after every block of 64 trials.



*Figure 5.1.* Schematic view of a trial sequence for both the endogenous (centre) and exogenous (peripheral) cue group. This example shows an invalid (cued target location), incongruent (target direction) trial for the exogenous condition, and for the endogenous condition when red (or counter-balanced green) centre dots direct attention rightwards. Time runs from top to bottom.

### Analyses

First analyses across all groups were conducted (Appendix E) to determine whether results from Funes et al. (2007) were replicated. Four factor repeated-measures ANOVA were conducted to analyze mean reaction times (RT) and error rate (ER) percentages (%). The ANOVA included **cue type / task** (endogenous vs. exogenous), **SOA** (100 vs. 850ms), **cue**

**validity** (valid vs. invalid), and spatial **congruity** (congruent vs. incongruent). Following this, a mixed ANOVA was used to explore ATQ-OS group differences in Spatial Stroop performance.

**Outlier detection.** For the spatial Stroop tasks, error rates were computed. Mean RTs for correct responses on each task were calculated following outlier removal using the MAD median method.

## **Results**

### **Sensitivity and Spatial Stroop Performance**

In this analysis, we explore the individual differences in endogenous and exogenous orienting and how this relates with two measures of the sensitive temperament, the ATQ-OS and the HSPS (Appendix E).

**Dichotomous samples in ATQ OS measures.** A 4-way mixed ANOVA was used to explore within-subjects factors SOA (100ms, 850ms), Validity (valid, invalid cue), and congruity (congruent, incongruent target) and between subjects factors of HSP group (HSP, non-HSP) for exogenous and endogenous task reaction times and error rates. ANOVAs were performed in order to look at ATQ-OS group differences. The ANOVAs were performed separately for exogenous and endogenous tasks, because the hypotheses regarding sensitivity relate specifically to automatic exogenous attention. See Table 5.2 for a summary of mixed ANOVA results for ATQ-OS groups, and see Table 5.1 for descriptive statistics of sensitivity measures.

### **ATQ-OS Mixed ANOVA for Reaction Times and Error Rates across Task**

**Mixed ANOVA with endogenous task reaction times for ATQ-OS.** No between-group effects or interactions were found for endogenous task RTs, see Table 5.2.

**Mixed ANOVA with exogenous task reaction times for ATQ-OS.** No between-group effects or interactions were found for exogenous task RTs, see Table 5.2.

**Mixed ANOVA with endogenous error rates for ATQ-OS.** No between-groups effects or interactions were found for exogenous task error rates, see Table 5.2

**Mixed ANOVA with exogenous error rates for ATQ-OS.** The mixed ANOVA revealed a significant SOA×Validity×Congruity×ATQ-OS group interaction (see Table 5.2). Figure 5.2 shows the interaction is the result of ATQ-OS group differences in spatial congruency effects across SOA for valid vs invalid conditions. The spatial congruency effects in the valid condition for HSP groups are larger for 850ms ( $M=5.63\%$ , 95% CI[3.3, 8.21]) versus 100ms SOA ( $M=1.61\%$ , 95% CI[.27, 2.86]),  $t(19)=3.15$ ,  $p<.01$ , and for non-HSP groups are numerically smaller for 850ms ( $M=3.81\%$ , 95% CI[2.46, 5.32]) versus 100ms SOA ( $M=4.05\%$ , 95% CI[2.86, 5.28]), but this difference is not significant ( $p=.76$ ). The spatial congruency effects in the invalid condition for HSP groups are not significantly larger ( $p=.27$ ) for 850ms ( $M=7.14\%$ , 95% CI[4.38, 10.09]) versus 100ms SOA ( $M=5.98\%$ , 95% CI[3.48, 8.57]), but for non-HSP groups are significantly larger for 850ms ( $M=7.06\%$ , 95% CI[5, 9.44]) versus 100ms SOA ( $M=5.12\%$ , 95% CI[3.65, 6.79]),  $t(44)=2.15$ ,  $p=.037$ . However, for HSP groups, the effect of SOA is larger for valid versus invalid conditions,  $t(44)=2.27$ ,  $p=.028$ , but for non-HSP groups the effect of SOA is larger for invalid versus valid conditions,  $t(44)=2.27$ ,  $p=.028$ . An independent samples t-test shows this group difference in spatial congruency effects across SOA and validity conditions explains the interaction,  $t(63)=3.19$ ,  $p=.003$ .

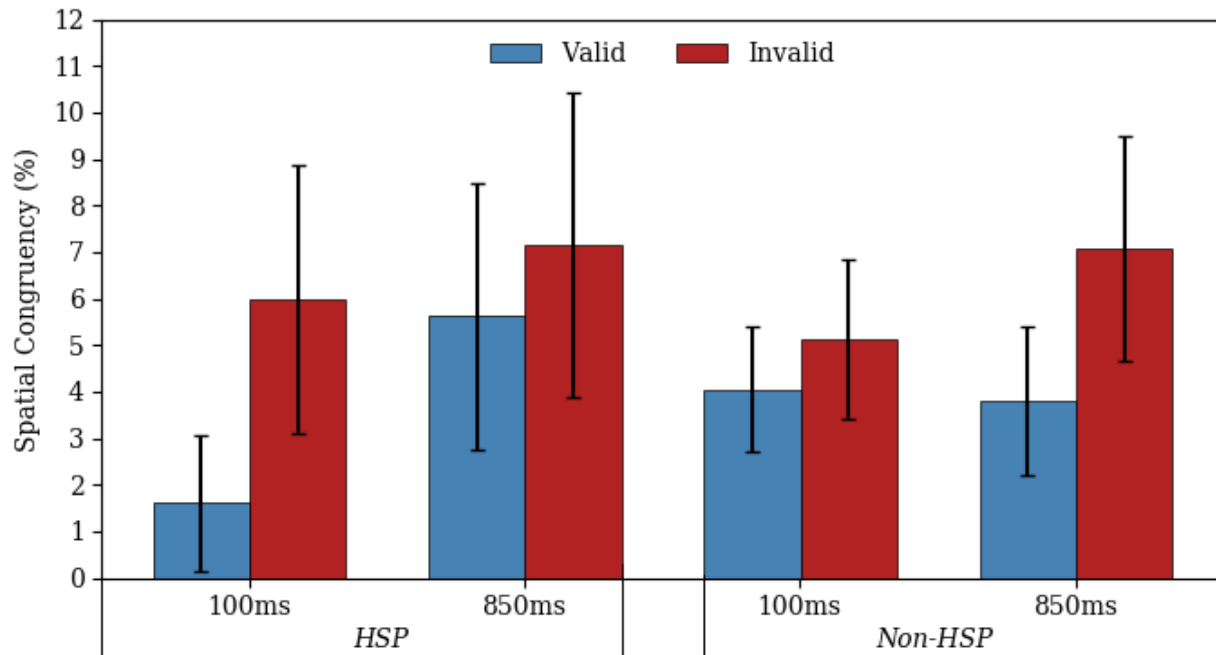


Figure 5.2. The SOA (100ms, 850ms) × Validity (Valid, Invalid) × Congruity × ATQ-OS (HSP, Non-HSP) group interaction for exogenous task error rates (%). Error bars show 95% confidence intervals.

The pattern of results (Figure 5.2) on valid trials shows that HSPs show the smallest congruency effect at the 100ms SOA compared to all other conditions, suggesting facilitation. Also, on valid trials, inhibition is suggested by the results that (a) the largest congruency effect at the 850ms SOA compared to all other conditions and (b) only HSPs show more errors at 850 than 100ms SOA. This pattern suggests that HSPs show both facilitation and inhibition effects on valid trials, but non-HSPs do not, thus suggesting greater IOR in HSP than non-HSP groups. In contrast, invalid trial results suggest that non-HSPs show greater interference effects on invalid trials than HSPs. However, spatial congruency effects do not enable a pure test of the IOR effect. Thus, while the 4-way interaction indicates that sensitivity affects inhibition-of-return effects, separate planned contrast of SOA×cue validity×ATQ-OS group for congruent and



incongruent trials were done to determine whether IOR effects can be observed in each congruency condition.

***SOA×cue validity×ATQ-OS for congruent conditions.*** The 3-way interaction was significant,  $F(1,63)=4.75$ ,  $p=.033$ ,  $\eta_p^2=.07$ . For HSPs, ER for valid cues are higher at 100ms ( $M=2.05\%$ , 95% CI[1.25,2.95]) versus 850ms ( $M=.89\%$ , 95% CI[.27,1.7]),  $t(19)=2.8$ ,  $p=.012$ , whereas ER for invalid cues are numerically fewer at 100ms ( $M=1.34\%$ , 95% CI[.63,2.23]) versus 850ms ( $M=1.61\%$ , 95% CI[.89,2.41]), but not significantly so ( $p=.64$ ). For non-HSPs, ER for valid cues are equal ( $p=1$ ) 100ms ( $M=.71\%$ , 95% CI[.32,1.19]) versus 850ms ( $M=.71\%$ , 95% CI[.4,1.11]), whereas ER for invalid cues are higher at 100ms ( $M=1.34\%$ , 95% CI[.87,1.91]) versus 850ms ( $M=1.23\%$ , 95% CI[.75,1.79]), but not significantly so ( $p=.69$ ).

***SOA×cue validity×ATQ-OS for incongruent conditions.*** The 3-way interaction was significant,  $F(1,63)=4.96$ ,  $p=.03$ ,  $\eta_p^2=.073$ . For HSPs, ER for valid cues are fewer at 100ms ( $M=3.66\%$ , 95% CI[2.41,5]) versus 850ms ( $M=6.52\%$ , 95% CI[4.2,9.11]),  $t(19)=2.63$ ,  $p=.017$ , and ER for invalid cues are numerically fewer at 100ms ( $M=7.32\%$ , 95% CI[5,9.73]) versus 850ms ( $M=8.75\%$ , 95% CI[5.98,11.88]), but not significantly so ( $p=.12$ ). For non-HSPs, ER for valid cues are numerically higher ( $p=.76$ ) for 100ms ( $M=4.76\%$ , 95% CI[3.49,6.11]) versus 850ms SOA ( $M=4.52\%$ , 95% CI[2.94,6.43]), whereas ER for invalid cues are higher at 100ms ( $M=6.47\%$ , 95% CI[4.76,8.33]) versus 850ms ( $M=8.29\%$ , 95% CI[5.91,11.07]),  $t(44)=1.97$ ,  $p=.056$ .

Overall, the planned ANOVAs show that only HSPs display facilitation effects for valid cues at 850ms versus 100ms SOA for congruent targets, but negative facilitation effects for 850ms versus 100ms SOA for incongruent targets. Thus, IOR in HSPs affects incongruent targets, but not congruent targets.

## **Interim Summary: Sensitivity and Spatial Stroop Performance**

**Sensitivity affects exogenous orienting.** ATQ-OS measures of sensitivity show group differences in spatial Stroop performance, however findings are mainly specific to the exogenous task error rates as ATQ-OS groups show no significant effects for exogenous task RTs. ATQ-OS results show SOA effects on spatial congruency are mediated primarily by interference with invalid cues for non-HSPs, but facilitation with valid cues for HSPs. With ATQ-OS, non-HSPs show larger congruency effects on errors at 850ms versus 100ms SOA for invalid cues, and so the SOA effect is larger for invalid versus valid conditions. In contrast, ATQ-OS HSPs show this pattern instead for valid targets, wherein larger congruency effects for errors are observed at 850ms versus 100ms SOA and so the SOA effect is larger for valid versus invalid conditions. Thus, while non-HSPs make more errors for incongruent targets at 850ms SOA and spatial congruency effects are mediated primarily by more interference for invalid cues, HSPs show no evidence for more errors for incongruent targets, and spatial congruency effects are mediated primarily by facilitation for valid for ATQ-OS HSPs. This supports the idea that exogenous orienting is better in HSP than non-HSP groups.

As ATQ-OS groups show no significant effects for endogenous or exogenous task RTs, no support was found for hypotheses (ii) which was developed based on links between BIS/BAS scales and the ATQ-OS, and results from Poy et al. (2004) which suggest ATQ-OS would relate to more flexible disengagement of attention across cue types. Overall, results so far suggest exogenous attention benefits for HSPs and endogenous attention benefits at the 100 ms SOA for HSPs (vs. at the 850 ms SOA for non-HSPs); this suggests a vantage sensitivity for HSPs regarding exogenous attention and differences in endogenous attention.

**Sensitivity and inhibition-of-return.** The remaining effects reported relate specifically to sensitivity group differences in how inhibition-of-return affects error rates. Recall, exogenous cue facilitation effects (i.e., faster RTs and greater accuracy) are observed with short cue-target SOAs of approximately 100ms, but not with cue-target SOAs greater than 250ms (Jonides, 1981; Muller & Rabbitt, 1989). Instead, at longer SOAs, both reaction times (Posner & Cohen, 1984) and accuracy (Klein & Dick, 2002) show negative facilitation effects (i.e., slower RTs and greater error rates) for target processing. This negative facilitation effect is known as inhibition-of-return (IOR; Lupiáñez et al., 2004; Posner & Cohen, 1984; Posner et al., 1985). In the spatial Stroop task, exogenous IOR is observed when the facilitation effects at short 100ms SOA invert to become negative facilitation effects at 850ms SOA (Funes et al., 2007).

For the ATQ-OS, a significant SOA×Validity×Congruity×ATQ-OS group interaction was observed for exogenous, but not endogenous, error rates. Post-hoc tests revealed this effect is the result of greater ATQ-OS group differences in spatial congruency effects between SOAs for valid versus invalid conditions. Specifically, for HSPs the SOA modulates spatial congruency effects more strongly for valid versus invalid conditions, but for non-HSPs the SOA modulates spatial congruency effects instead for invalid versus valid conditions (Figure 5.2). For the HSP group, the differences in spatial congruency effects across SOA for valid conditions could be the result of either greater a) negative facilitation of spatial congruency effects from inhibition-of-return at 850ms SOA, or b) positive facilitation of spatial congruency effects usually found at 100ms SOA for exogenous tasks (Jonides, 1981; Posner & Cohen, 1984), or c) both. Indeed, post-hoc ANOVAs revealed c) to be true, as only HSPs display facilitation effects for valid cues at 850ms versus 100ms SOA for congruent targets, but negative facilitation effects for 850ms versus 100ms SOA for incongruent targets. Thus, IOR in HSPs affects incongruent targets, but

not congruent targets. There are also group differences in how SOA modulates spatial congruency effects for invalid conditions, although the effects are in the same direction. The lack of SOA effects for invalid conditions in HSP groups are probably due to greater variance in the smaller sample size, as shown in Figure 5.6.

This evidence is consistent with hypothesis that (i) HSPs versus non-HSPs on the ATQ-OS will have stronger IOR effects in exogenous tasks, as ATQ-OS has a strong relationship with openness (see Chapter 2) and higher openness is associated with a broader distribution of IOR (Wilson et al., 2016). In this case, ATQ-OS was associated with IOR for error rates.

This study demonstrates that ATQ-OS measures of sensitivity show group differences in spatial Stroop performance, mainly in relation to exogenous task error rates, in line with the general hypothesis regarding the role of exogenous orienting attention in the sensitive temperament. In summary, for error rates in exogenous tasks, HSPs (for ATQ-OS groups) exhibit greater facilitation, or inhibition-of-return, for valid versus invalid cues depending on SOA.

Overall, these findings are consistent with the idea that exogenous orienting attention may be one process underlying the sensitive temperament. Further, whilst group differences in sensitivity were found, they tend to be specific to error rates in the exogenous tasks.

### **Sensitivity and Inhibition-of-Return as Predictors of Creativity**

Using hierarchical multiple regression we test the prediction that orienting sensitivity, and inhibition-of-return (SOA×Validity×Congruity) for reaction times and error rates for exogenous tasks, can account for unique variance in creativity scores. Note, no analysis is performed for endogenous inhibition-of-return variables as the IOR phenomenon is only observed in exogenous tasks (Jonides, 1981; Posner, 1980). The interaction term was condensed into a single value for each participant henceforth referred to as the inhibition-of-return, or 'IOR'

variable. The IOR term was created for reaction times and error rates by subtracting the differences of congruency conditions (incongruent – congruent) for each validity condition, and then subtracting validity conditions (invalid – valid) for each SOA, and finally subtracting SOA conditions from each other (long – short), separately for the exogenous task. In the regression, we use continuous variables to restore statistical power lost when using dichotomisation (MacCallum et al., 2002) and also dichotomous sensitivity variables, as recommended by Aron and Aron (2013). Regression analysis was also performed with the HSPS (Appendix E).

**Hierarchical multiple regression.** In the hierarchical multiple regression, Model 1 regressed IOR onto creativity scores. Model 2 added a sensitivity measure to Model 1. Model 3 added BFI-E and BFI-N variables to account for NA Adding NA measures to this hierarchical model allows the examination of sensitivity effects with and without NA controlled. Model 4 added BFI-O, a strong correlate of ATQ-OS (Evans & Rothbart, 2007), to examine whether IOR and sensitivity effects are redundant in the presence of BFI-O.

Assumptions of ordinary least squares regression were checked. Note, the minimum number of participants required for multiple regression is  $N \geq 50 + m$ , where  $m$  is the number of predictors. Regression equations with 6 or more predictor variables should aim for a minimum of  $N = 10m$  (VanVoorhis & Morgan, 2007). In this study,  $N = 65$  and regression models use 5 predictor variables, thus sample size requirements for multiple regression are satisfied. Scatterplots indicate linearity between variables, two outlier cases were observed for ATTA, but one unusual case was shared between CAQ and ATTA, with unusually high and low scores, respectively. Distributions were inspected using P-P plots and histograms which indicate non-normality for CAQ and ATTA scores, but not RIBS. Standardised residuals  $> 3$  were found for a single case in CAQ scores and two cases in ATTA scores, although Mahalanobis distance values

<15 indicate little influence with low leverage indicated by values less than  $(3[k + 1]/n)$  suggesting the outlier cases do not substantially influence the model parameters (Field, 2013).

Residual variance indicates that homoscedasticity cannot be assumed for CAQ and ATTA.

In no cases, for exogenous reaction times or error rates, did IOR account for unique variance in any of the creativity measures. IOR for exogenous reaction times do not account for significant variance in CAQ or RIBS ( $p > .57$ ), although they approach significance with the ATTA ( $p = .073$ ). IOR for exogenous error rates do not account for significant variance in CAQ, RIBS or ATTA scores ( $p > .37$ ). As Models 2, 3 and 4 are of no interest unless Model 1 accounts for unique variance they are not reported, but see Chapter 2.

In summary, IOR for exogenous reaction times and error rates do not account for unique variance in CAQ, RIBS or ATTA scores.

## **Discussion**

Overall, this study, manipulating task within-subjects, provides further support for a endogenous/exogenous taxonomy by partially replicating findings reported by Funes et al. (2007) in a between-subject design, which are not consistent with a unitary view of attention (e.g., Jonides, 1981) and thus shows the spatial Stroop paradigm is a useful tool to explore how the sensitive temperament may relate to endogenous and exogenous orienting of attention, and how those mechanisms relate to creativity (see Appendix E). Regarding sensitivity, ATQ-OS was observed to show reliable IOR effects in the exogenous task, as predicted based on the notion that ATQ-OS relates to “automatic” exogenous attention, extending the understanding of sensitivity beyond that reported in Chapter 4 using different measures of attention network efficiency. However, the hypothesis that exogenous orienting attention processes associated with the sensitive temperament may predict creativity was not supported, suggesting that exogenous

orienting mechanisms underlying the sensitive temperament are not implicated in higher creativity.

## Tables

Table 5.1

*Mean, standard deviation (SD), and lower (LCI) and upper (UCI) 95% confidence intervals for creativity, temperament and personality variables (n=65)*

	Mean	SD	LCI	UCI
<i>Creativity</i>				
CAQ	7.78	8.87	5.85	9.97
RIBS	2.93	.56	2.81	3.06
ATTA	65.63	10.00	62.95	67.95
<i>Temperament</i>				
ATQ_OS	4.67	.81	4.5	4.85
<i>Personality</i>				
B5_O	3.15	.56	3	3.29
B5_C	3.39	.64	3.23	3.55
B5_E	3.14	.81	2.95	3.32
B5_A	3.87	.56	3.73	4
B5_N	3.09	.89	2.89	3.29

*Note:* CAQ = Creative Achievement Questionnaire; RIBS = Runco Ideational Behaviour Scale; ATTA = Abbreviated Torrance Test for Adults; ATQ-OS = orienting sensitivity factor of the ATQ; BFI-O = openness to experience factor of the Big Five Inventory (BFI); BFI-C = conscientiousness factor of the BFI; BFI-E = extraversion factor of the BFI; BFI-A = agreeableness factor of the BFI; BFI-N = neuroticism factor of the BFI.



Table 5.2

*Summary of separate mixed ANOVA for endogenous and exogenous tasks using within-groups factors of SOA, Validity and Congruity, and between-groups factors of ATQ-OS group, for reaction time and error rate performance*

	<i>Reaction times</i>				<i>Error rates</i>			
	<i>Endogenous</i>		<i>Exogenous</i>		<i>Endogenous</i>		<i>Exogenous</i>	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
ATQ-OS	.44	.007	.03	0	.05	.001	.41	.006
<i>Interactions</i>								
ATQ-OS×SOA	.21	.003	.13	.002	0	0	.51	.008
ATQ-OS×Validity	.92	.014	2.83	.043	.64	.01	.11	.002
ATQ-OS×Congruity	.39	.006	.01	0	.04	.001	.95	0
ATQ-OS×SOA×Validity	.39	.006	2	.031	1.42	.022	.29	.018
ATQ-OS×SOA×Congruity	1.68	.026	.48	.008	1.78	.027	2	.031
ATQ-OS×Validity×Congruity	1.23	.019	.13	.002	.23	.004	.51	.007
ATQ-OS×SOA×Validity×Congruity	.01	0	2	.031	1.59	.002	9.54**	.131

*Note, \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ ; degrees of freedom = 1,64.*

## CHAPTER VI

### **Sensitivity and the Cognitive Unconscious**

#### Abstract

In this chapter, we employ the Serial Response Time Task (SRTT) task used by Schendan, Searl, Melrose, and Stern (2003b) to investigate how sensitivity and creativity relate to explicit and implicit learning and memory performance. The SRTT provides measurements of sequence-specific learning in both implicit and explicit tasks. Following implicit and explicit SRTT learning, explicit memory tasks were performed to measure awareness and explicit memory for implicit and explicit task sequences.

Performance on implicit and explicit SRTT did not differ significantly between orienting sensitivity groups. HSPs develop more explicit awareness of the exact repeating pattern following implicit tasks. However, explicit memory performance following implicit sequence learning does not predict creativity, and thus no evidence suggests this mechanism underlies the sensitive creator.



## **Introduction**

The ability to automatically and implicitly detect and learn critical covariations in the environment is a fundamental ability of unconscious cognition. Implicit learning takes place without intention or awareness and plays a significant role in structuring our conscious skills, perceptions and behaviours (Kaufman, DeYoung, et al., 2010; Kihlstrom, 1987; Reber, 1989, 1992). Sensitivity is a biologically-based personality trait associated with automatic information-gathering attention systems (Aron & Aron, 1997; Aron et al., 2012; Evans & Rothbart, 2008; Johnson, Posner, & Rothbart, 1991; Pluess, 2015a; Posner & Rothbart, 1980; Sokolov, 1963, 1990) necessary for implicit learning and memory (Nissen & Bullemer, 1987). In addition, sensitivity is thought to enhance the ability to enable minimally conscious or unconscious information, such as implicit memory, to be brought to conscious awareness and made explicit, potentially enhancing also explicit memory (Aron et al., 2012). Enhanced ability to bring nonconscious information into conscious awareness so that it can influence thinking is a hallmark of the creative process and higher creative ability (Bowers, Regehr, Balthazard, & Parker, 1990; Dijksterhuis & Meurs, 2006; Finke et al., 1992; Schooler & Melcher, 1995; Wallas, 1926). Thus, conceptualizations of sensitivity (Aron & Aron, 1997; Aron et al., 2012; Evans & Rothbart, 2007; Pluess, 2015a) are linked to individual differences in the unconscious cognitive processes underlying creative thought. In this chapter, we examine how individual differences in learning and memory abilities, especially implicit learning and memory and their relationship with explicit memory, define the sensitive creator.

### **Multiple Memory Systems**

According to multiple memory systems theory, different brain systems support different kinds of learning and memory. Explicit learning and memory encompasses two conscious types

of memory. Episodic memory refers to recollection, recognition, and feelings of familiarity about previous experiences within a specific spatiotemporal context, and semantic or knowledge memory, which refers to facts and concepts (e.g., word meanings) about the world independent of spatiotemporal context (Squire & Zola-Morgan, 1991; Tulving, 1972). In contrast, implicit learning and memory can influence stimulus, cognitive, and motor processing without conscious awareness, and is demonstrated by changes in performance as a result of prior experience, such as priming, skill-learning and habit formation (Cleeremans, Destrebecqz, & Boyer, 1998; Schacter, 1997; Schendan, 2012). Explicit memory depends on the medial temporal lobe (MTL) memory system consisting of the hippocampus and surrounding cortex, including the entorhinal, perirhinal, and parahippocampal cortex (Squire & Zola-Morgan, 1991). Adult neurological patients with amnesia due to damage to the MTL memory system demonstrate impaired explicit episodic memory encoding abilities, including the ability to acquire new semantic memory that depends on some MTL functions, while implicit learning and memory remain intact (e.g., Cohen & Squire, 1980; cf. Curran, 1997; Scoville & Milner, 1957). The observations of dissociated explicit episodic and implicit memory functions in MTL amnesia supports the theory of multiple memory systems and suggests that implicit memory depends on structures outside the MTL system, specifically neocortex and subcortical structures, such as the basal ganglia (Schendan, 2012).

The most established method for measuring implicit learning is the serial response time task (SRTT) developed by Nissen and Bullemer (1987), which measures learning abilities considered foundational to the acquisition of motor skills, such as typing, playing musical instruments, and route navigation (Destrebecqz & Cleeremans, 2001; Kaufman, DeYoung, et al., 2010; Schendan et al., 2003b; Shanks, 2005). In the SRTT, participants are typically asked to

push buttons in response to targets appearing at corresponding spatial locations on a computer screen over extended periods of time. Unbeknownst to the participant, the sequence of stimuli follow a structured pattern governed by a set of rules, and increased exposure to the structured pattern improves task response time and accuracy due to accumulating knowledge about the structure of the sequence in the structured condition relative to unstructured, pseudo-random locations. Crucially, many participants can be unaware of the structured pattern, as evidenced by failure to explicitly report awareness of the pattern and knowledge about the sequence during explicit memory tests (e.g., Schendan et al., 2003b).

Memory accounts of sequence learning (Schacter, 1997; Squire, 1992) argue that MTL activation during sequence learning varies as a function of awareness, with higher awareness resulting in greater MTL involvement. In contrast, relational accounts (Cohen & Eichenbaum, 1993) argue that MTL is involved whenever learning is more complex than simple pairwise associations between temporally adjacent stimuli, known as higher-order association learning (Curran, 1997). Indeed, fMRI neuroimaging studies using the SRTT paradigm lend support to relational accounts showing MTL involvement during higher-order association learning, regardless of sequence awareness (Schendan et al., 2003b; Schendan, Tinaz, Maher, & Stern, 2013).

Intriguingly, Schendan and colleagues (2013) also found that elderly people and people with Parkinson's disease show primarily implicit learning and far less evidence of becoming consciously aware of sequence information compared to young people who show more of both implicit and explicit learning and memory. Basal ganglia function, including dopamine function, decreases with aging and substantially so in Parkinson's disease. Altogether, this indicates that

dopamine dysfunction adversely affects implicit learning and the ability to develop explicit conscious awareness of memory about the structured sequence.

Dopamine function is controlled by plasticity genes implicated in sensitive and open personalities and creativity (Belsky & Pluess, 2009b; Chen et al., 2011; DeYoung et al., 2002, 2005). This predicts that changes in implicit and explicit sequence learning may be associated with sensitivity, openness, and creativity. To test this prediction and examine whether and how multiple memory systems vary with sensitivity, openness, and creativity, the SRTT paradigm that was used previously to demonstrate these dopamine-related changes (Schendan, et al., 2013) was adapted for this experiment. This paradigm enables sensitive assessment of multiple memory systems: implicit and explicit learning, implicit memory, explicit episodic memory, and sequence knowledge, including sensitive assessment of associated conscious awareness.

### **Implicit Learning and Plasticity as Core Mechanisms of Sensitivity**

Relational accounts of memory are consistent with evolutionary models (Reber, 2013) explaining implicit learning as an emergent property of general plasticity that permeates information-processing networks across the brain to adaptively improve function via experience, hence operating as a universal principle, as opposed to a single coherent memory system, and implicit memory is distinct from the explicit MTL memory system. Implicit learning as a plasticity principle applies well to understanding the neural changes in environmental sensitivity. Highly sensitive people are disproportionately shaped by their experiences (Aron & Aron, 1997; Pluess, 2015a), suggesting neurosensitivity results in changes in neuroplasticity. However, implicit learning is theorized to be an evolutionarily-old function, well-defined and distributed throughout the general population (Reber, 1992) because it is essential for survival. This may explain why individual differences in implicit learning are minimal (Reber, 1993).

However, evidence has emerged linking complex cognitive processes and personality to SRTT performance. Kaufman, DeYoung, et al. (2010) found that implicit learning in the SRTT predicts trait openness (cf. Norman, Price, & Duff, 2006; Norman, Price, Duff, & Mentzoni, 2007), and whilst explicit learning was moderately positively correlated with intelligence, the effects of implicit learning on personality are independent of intelligence, consistent with the idea that implicit learning is evolutionarily old and thus precedes higher cognitive functions of human intelligence (Reber, 1992). Openness to experience is a strong correlate of the orienting sensitivity subfactor of the sensitive temperament (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015) and subsumed under a broader meta-trait of plasticity defined as a dopamine-driven tendency towards exploration and novelty-seeking, which serves to encourage personal growth (DeYoung et al., 2002, 2005; Digman, 1997). Thus, implicit learning as a plasticity principle could be a core mechanism of vantage sensitivities (Pluess, 2015b) underlying the sensitive, open creator (see Chapter 2). Alternatively, negative-affect-related sensitivity resulting from childhood trauma (Aron & Aron, 1997; Aron et al., 2005) could negatively affect learning and memory. After all, (a) chronic stress damages the hippocampus, the core of the MTL memory system, in primates (Sapolsky, Uno, Rebert, & Finch, 1990), (b) vulnerability to psychological trauma is predicted by smaller hippocampal volume (Gilbertson et al., 2002), and (c) hippocampal dysfunction may be associated with memory impairments for neutral material, such as those in the SRTT task (for a review, see Pitman et al., 2012; Schendan, Searl, Melrose, & Stern, 2003a). Thus, negative-affect-related sensitivity could result in impaired unconscious cognitive processes relating to memory performance and creativity (cf. Deo & Singh, 1973). The purpose of this study is to understand how sensitivity and creativity manifest



as individual differences in plasticity as indexed by explicit and implicit learning and memory tasks.

## **Hypothesis**

In this study, we employ the SRTT task used by Schendan et al. (2003b) to investigate how sensitivity and creativity relate to explicit and implicit learning and memory performance. First, as a manipulation check, we aim to replicate findings of sequence-specific learning in both implicit and explicit tasks, where faster and more accurate responses are found for repeating versus random patterns. The sequences used allow analysis of higher-order associative learning related to complex associative learning across three or more locations that cannot be accounted for with simple item or bi-item frequencies. We aim to replicate higher-order associations demonstrated by a significant positive RT difference for transition pairs at all locations across runs and tasks (Schendan et al., 2003b). For explicit memory tasks, we aim to replicate the general finding that repeated versus random sequences are recognized more accurately, but that free generation of repeated sequences is higher in explicit than implicit conditions. For replication, see Appendix F.

Hypotheses and predictions are based on evidence that implicit learning depends on automatic versus voluntary attention (Nissen & Bullemer, 1987), and sensitivity has consequences for automatic exogenous attention which are related to creativity achievement and potential (see Chapter 1,2, 4 & 5; Evans & Rothbart, 2007, 2008). Overall, we predict sensitivity group differences in both implicit and explicit SRTT performance, but also higher-order associative learning independent of awareness, in line with relational accounts of memory (Cohen & Eichenbaum, 1993; Schendan et al., 2003b). (i) In particular, regarding sensitivity, emotion-attention temperament theory proposes that sensitivity reflects individual differences in

automatic information-gathering attention systems (Evans & Rothbart, 2007). This predicts that the ability to extract information incidentally during the implicit learning task will be greater in high than low sensitivity. Implicit learning will be demonstrated by faster RTs for repeated versus random sequences over the course of the implicit SRTT. (ii) Furthermore, temperament theories propose that higher sensitivity is associated with greater ability to bring non- or minimally- conscious information to conscious awareness (e.g., implicit knowledge). After all, the sensitive individual has been characterized as being more consciously aware of stimuli (Aron et al., 2012). This idea is also captured by the sensitivity measures that index exogenous attention ask about awareness (“aware”, “notice”, “detect”, and “consciously”) of subtle information from perceptual, emotional, and memory sources (Evans & Rothbart, 2007). Consequently, regarding explicit memory tests following explicit and implicit SRTT, this predicts sensitivity group differences in recall and recognition of repeating sequences across explicit memory tests. In particular, explicit memory will be greater in high than low sensitivity. (iii) Regarding creativity, this has been associated with greater capacity for global automatic attention and awareness of loose associations (for a review, see Förster & Dannenberg, 2010; Mendelsohn, 1976). This predicts a similar pattern as for sensitivity such that implicit learning and/or explicit knowledge will predict creativity.

## **Method**

### **Participants**

A sample of 80 participants were recruited, but 1 participant was excluded for not completing the tasks (55 female, 24 male, aged between 18-46 years,  $M=22.1$ ,  $SD=5.76$ ). Participants were rewarded with course credit or paid £8 per hour pro-rata. This study was approved by Human Ethics Committee in the Faculty of Science and Environment at University

of Plymouth. Participants gave informed consent before the study and were debriefed after completing the study.

### **Apparatus and Materials**

A computerized battery was developed on Survey Monkey to assess sensitivity, personality and creativity and administered in the lab. Each questionnaire was presented on a separate page within the software. For each item, the participant checked the blank in front of any item corresponding to the response that best applied to them.

Sensitivity was measured using two questionnaires. 1) The Highly Sensitive Person scale (HSPS) from Aron and Aron (1997) is a 27-item, modality general, self-report scale measuring sensory processing sensitivity using items asking about tendencies to startle easily, become easily overwhelmed by sensory inputs but also awareness of subtleties in the environment, and enjoyment of fine and delicate scents, tastes, sounds, and works of art. Item responses ranged from 1 (not at all) to 7 (extremely). 2) The two HSPS factors of orienting sensitivity and negative affect were also measured using the Adult Temperament Questionnaire (ATQ)-short form (Evans & Rothbart, 2007). The ATQ is a self-report scale with 77 items measuring general constructs of orienting sensitivity (ATQ-OS), negative affect (ATQ NA), effortful control (ATQ EC), and extraversion/surgency (ATQ ES). Item responses ranged from 1 (extremely untrue) to 7 (extremely true) and “not applicable”.

The Big Five Inventory (BFI) assessed personality. This 44-item self-report questionnaire measures the Big Five dimensions of personality: Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Benet-Martinez & John, 1998; John et al., 1991; John et al., 2008; John & Srivastava, 1999). Item responses ranged from 1 (disagree strongly) to 5 (agree strongly).

Creativity was assessed using three of the most established and validated measures of creative processes. The Creative Achievement Questionnaire (CAQ; Carson et al., 2005) was chosen as an objective self-report measure of creative achievement across 10 domains of creativity. The Runco Ideational Behaviour Scale (RIBS; Runco et al., 2000-2001) is a 19-item questionnaire designed to measure creative ideation, which is thought to measure a single factor and has discriminant validity. Items probe behavioural tendencies and abilities regarding ideas and thinking, with many items emphasizing creative, unusual, or imaginative thought (e.g., “I have many wild ideas.”). The RIBS responses ranged from 1 (never) to 5 (very often). This study was lab-based in order to administer one pencil and paper creativity test: The Abbreviated Torrance Test for Adults (ATTA; Goff & Torrance, 2002) consists of 3 timed (3-minute) tests of figural and verbal divergent thinking abilities thought to be critical for the creative process (Runco, 2014). The ATTA is a gold standard, objective measure of divergent thinking. The ATTA thus is the one test that independently verifies creative products/divergent thinking. The ATTA was presented in the lab in paper format with a pencil and eraser, not part of the Survey Monkey battery.

The experimental stimuli in the serial response time task (SRTT; Schendan et al., 2003b) were identical to those used by Schendan and colleagues (Schendan, et al., 2013), except for hardware and software for presentation. Stimuli were presented using a Viglen Windows 7 PC with Philips Brilliance LED monitor 221P3LPYES P-line 21.5" widescreen operating at 1920 × 1080 pixels with a 60hz refresh rate, and were programmed and controlled using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, [www.neurobs.com](http://www.neurobs.com)). Response cues were shown in second order conditional (SOC) sequences of 12 locations. All SOC sequences consisted of 3 instances of each of the 4 spatial locations and 1 instance of each

of the 12 possible transition pairs between locations (i.e., 1-2, 1-3, 1-4, 2-1, 2-3, etc.). In the sequence condition, one SOC sequence was shown repeatedly for implicit (1-2-1-4-2-3-4-1-3-2-4-3; Curran, 1997) and explicit SRTT (2-3-2-4-1-3-1-4-3-4-2-1; Reber & Squire, 1998); in the random condition, new SOC sequences of 12 locations each were presented once, each, across the entire experiment.

## **Procedure**

Participants sat in a testing room alone. The implicit SRTT and respective explicit memory tests always preceded the explicit SRTT and respective explicit memory tests.

**Implicit serial response time task.** Before the first run, naïve participants were given instructions on how to perform the task. Participants were told they will see 4 boxes on the screen, and press corresponding buttons as they light up. Participants were told the 4 boxes refer to each of the locations of the 4 response buttons and to push the relevant button as soon as the box lights up, as fast and accurately as possible. Participants were also told to relax their eyes on fixation crosses whenever they appeared. Participants were first given a practice run with one new SOC sequence of 12 locations. Participants were not informed about any repeating sequence. For the experiment, in each of the 4 runs, Sequence and Random blocks alternated. Each sequence block began at a random location in the sequence to ensure implicit learning, whilst avoiding the need for distractor tasks (Schendan et al., 2003b). The 12-location sequences repeated 4 times in each of the 3 Sequence blocks per run for a total of 144 trials per run. Random blocks had two lengths: (1) two short 24 trial random blocks (r) consisting of 2 novel 12-location sequences each and separated by Sequence blocks, and (2) two long 48 trial random blocks (R) consisting of 4 novel 12-location sequences each, starting or ending each run in order to equate the total number of trials across Sequence and Random conditions. For

counterbalancing purposes, the position of long Random blocks varied between 3 types of block ordering. In block order A, long Random blocks preceded all Sequence blocks (i.e., R-R-S-r-S-r-S), in block order B, a single long Random sequence preceded all sequences, and a single long Random sequence followed all sequences (i.e., R-S-r-S-r-S-R), and in block order C, both long Random blocks followed all sequences (i.e., S-r-S-r-S-R-R). Half of participants were presented with runs in order of ABBC, and the other half were presented with runs in order of BBBB. Fixation rests (3750ms) preceded some Random blocks. At the end of each run, participants were given a 10 second rest period. At the end of the rest period a countdown timer was presented, counting down from 3 (to 1) to indicate the start of the next run.

**Explicit serial response time task.** Before the first run, participants were instructed to perform the SRTT again. This time, participants were told to try and see chunks in a new repeating sequence and to use chunking to help them memorize the sequence. The first exposure to the explicit sequence was in three four-location chunks, given in the training phase before the first Sequence block. The run of the explicit SRTT consisted of 6 Sequence and 6 Random blocks in this order: 3 consecutive presentations of long Random blocks, followed by 6 consecutive presentations of 48 trial Sequence blocks with a rest in-between, followed by 3 consecutive presentations of long Random blocks (i.e., R-R-R-S-S-S-rest-S-S-S-R-R-R). Prior to each block, instructions were given. For Random blocks, participants were told that the following sequence was a button task with random locations. For the Sequence blocks, participants were told to memorize the repeating sequence in 3 chunks of 4 locations. After each Sequence block, participants performed the free generation test; they were then asked to report the repeating sequence by looking at the boxes, and pressing the buttons in the order of the repeating locations until “STOP” appeared on screen (after 20 seconds).

**Explicit memory tests.** For implicit SRTT, all explicit tests were given after all implicit SRTT runs were complete. For explicit SRTT, each Sequence block was followed by a free generation test, and, after the entire explicit SRTT was complete, participants did awareness and full recognition tasks, but not other explicit tests due to time. Tests which vary in sensitivity to conscious awareness are described in the order of presentation.

**Awareness.** Immediately following implicit and explicit memory tasks, participants pressed a key to respond (1) Yes, (2) Probably, (3) Unlikely, (4) No to four questions: “In the task you just performed, did you notice that (a) the boxes lit up at random locations the entire time; (b) some boxes lit up more often than other boxes; (c) the task was easier at times and harder at other times; (d) there was a repeating pattern of locations some of the time?”. Note, awareness is assumed in explicit tasks and thus no analyses are conducted on explicit awareness, but see Table 6.9 for descriptive statistics.

**Free generation.** Participants were informed that there was a repeating pattern in the SRTT, and to try and report the repeating sequence of locations. Following a 3750ms fixation point, participants were presented with empty response locations. They pressed buttons in the order of the repeating locations until “STOP” appeared onscreen. To complete the task, participants had 30 seconds for implicit SRTT and 20 seconds for explicit SRTT from the beginning; note, less time is needed when learning is explicit. For explicit SRTT, free generation followed each and every Sequence block.

**Cued generation.** Similar to the free generation, but each time participants pressed a key to generate the repeating implicit sequence, the corresponding square lit up on screen until the next key press. Participants were asked to keep pressing buttons in the sequence they remember

in the order of the repeating locations until “STOP” appeared onscreen, which only appeared after 96 button presses.

**Triplet generation.** Participants performed the SRTT on three locations, where half of the triplet sequences were in the repeating sequence, and half were novel sequences formed from two 12-item SOC sequences, none of which overlapped with the implicit sequence. After each triplet, participants were asked to rate how similar the sequence was to the repeating sequence on a scale of 1 (“certain I have seen this sequence before”) to 6 (“certain I have not seen this sequence before”).

**Full recognition.** Participants performed the SRTT with the entire implicit or explicit sequence, and four novel 12-item sequences. After each sequence, participants were asked to report how similar the sequence was to the repeating sequence on a scale of 10 (“exactly the same”) to 0 (“completely different”).

## **Analysis**

Median RTs with maximum cut-off of 1250ms (the total trial time) were calculated for each Sequence and Random blocks by run (Schendan et al., 2003b; Schendan et al., 2013). The two short Random blocks were analyzed together as one, as though they were one long Random block. Implicit and explicit performance data were analyzed separately as individual tasks.

Analysis of higher-order associative learning between 3 or more consecutive locations was conducted, where RTs for each pair of consecutive locations, or transition pairs, were compared between Sequence and Random conditions. For each transition pair, the median RT for the second location for each transition pair was determined, for Sequence and Random blocks, separately. The median RT was then averaged across blocks in each run, separately. Then, a difference score for each transition pair was calculated by subtracting the Sequence



mean RT from the Random mean RT, in each run. Note. A significant positive RT difference for one transition pair demonstrates higher-order associative learning among three consecutive locations, and for two or more transition pairs demonstrates higher-order associative learning amongst four or more locations (Schendan et al., 2003b).

For explicit memory tests common across task (i.e., free generation and full recognition) an omnibus ANOVA was performed to compare differences in conscious awareness between implicit and explicit SRTT tasks. Following this, performance on each explicit memory test was analyzed for the implicit and explicit SRTT task, separately. Note, for comparison of free generation between the implicit and explicit SRTT, mean performance was calculated across the six runs of free generation in the explicit SRTT condition.

Sensitivity may be a taxon consisting of HSPs (i.e., those high on HSPS) and non-HSPs, thus Aron and Aron (2013) suggest dichotomizing the sample with high-low break points somewhere between 15% for HSPs and 85% for non-HSPs, up to 30% for HSPs and 70% for non-HSPs. In this study a 30% HSP 70% non-HSP split was chosen. Between-groups factors of sensitivity were used to explore differences in SRTT performance between HSP ( $n=24$ ) and non-HSP groups ( $n=55$ ).

Group differences were explored using mixed ANOVA and  $t$ -test comparisons where appropriate using between-groups factors of ATQ-OS measures. See Appendix F for all analysis using the HSPS (Aron & Aron, 1997). For the ATQ-OS, the HSP groups ( $M=.76$ , 95% CI [.74,.79]) had significantly higher scores,  $t(78)=9.46$ ,  $p<.001$ , than non-HSPs ( $M=.52$ , 95% CI [.48,.55]). The same analysis was also performed for between-groups factors of creativity for CAQ, RIBS and ATTA, separately (Appendix F). Note, all personality, temperament, and

creativity measures are scaled between 0 and 1, see Chapter 2 for scaling. Max scores used for scaling CAQ are 94, and 83 for the ATTA in this chapter only.

## **Results**

### **Implicit SRTT performance and sensitivity**

A mixed ANOVA was run using within-groups factors of Run, Condition, and Block and between-groups factors of Sensitivity (HSP, non HSP). See Table 6.1 for the summary of results from the mixed ANOVA for ATQ-OS. No between-groups or interaction effects were found for the ATQ-OS groups ( $ps>.05$ ).

### **Explicit SRTT performance and sensitivity**

A mixed ANOVA was run using within-groups factors of Block and Condition and between-groups factors of Sensitivity (HSP, non HSP) group. Table 6.2 shows the output of the mixed ANOVA. No between-groups or interaction effects were found for the ATQ-OS groups ( $ps>.05$ ).

### **Implicit SRTT: higher-order associative learning and sensitivity**

Sensitivity group differences in higher-order association learning for RTs was analyzed with a mixed measures ANOVA using within-groups factors of Run (Run 1 to Run 4) and Transition Pair (12 pairs) and between-groups factors of Sensitivity (HSP, non HSP). Table 6.3 shows no significant effects were observed ( $ps>.05$ ).

### **Explicit Memory Tests: Awareness**

**Implicit SRTT: awareness and sensitivity.** An independent samples t-test was run to compare question ratings between sensitivity (HSP, non-HSP) groups. No between-groups differences in awareness ratings were observed between ATQ-OS groups ( $ps>.128$ ).

## **Explicit Memory Tests: Free Generation**

**Free generation omnibus task comparison and sensitivity.** Separate omnibus mixed ANOVA were performed to analyze group differences in performance on free generation across implicit and explicit SRTT task for a) maximum sequences generated, b) number of triplets generated, and c) ratio of triplets to keypresses between sensitivity (HSP, non-HSP) groups. The mixed ANOVA used within-groups factor of task (implicit, explicit) and between-groups variable of Sensitivity group. Table 6.4 shows the ANOVA revealed no 2-way, or between-groups main effects for ATQ-OS groups ( $ps>.05$ ).

**Implicit SRTT: free generation and sensitivity.** An independent samples t-test was run to compare maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses between sensitivity (HSP, non-HSP) groups. No between-groups differences were found for the ATQ-OS ( $ps>.413$ ) suggesting ATQ-OS groups do not differ in how they freely generate sequences, or recall triplet versus sequence inconsistent keypresses, following exposure to implicit sequences.

**Explicit SRTT: free generation and sensitivity.** Group differences in maximum sequences generated, number of sequence consistent triplets generated, and triplet ratios in free generation were analyzed separately with a mixed ANOVA using within-groups factor of Block (1 to 6) and between-groups factor of sensitivity (HSP, non-HSP) groups. See Table 6.5 for mixed ANOVA results.

## **Explicit Memory Tests: Cued Generation**

**Implicit SRTT: cued generation and sensitivity.** An independent samples t-test was run to compare maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses between sensitivity (HSP, non-HSP) groups. For ATQ-OS, a significant group

difference was found for maximum sequence generated,  $t(77)=2.31$ ,  $p=.024$ , where HSP groups ( $M=6.92$ , 95% CI [6.22,7.65]) showed longer mean maximum sequences generated in cued recall compared with non-HSP groups ( $M=6.02$ , 95% CI [5.64,6.42]). No between-groups effects were found for triplets generated, or ratio of triplets to keypresses for the ATQ-OS ( $ps>.55$ ).

### **Explicit Memory Tests: Triplet Recognition**

**Implicit SRTT: triplet recognition and sensitivity.** Ratings for Sequence and Random triplets were analyzed with a mixed ANOVA using within-subjects factors of sequence (Random [New], Sequence [Old]) and between-groups factors of sensitivity (HSP, non-HSP). No between-groups effects were significant ( $ps>.102$ ). Further, no sequence $\times$ sensitivity interactions emerged for any sensitivity measures ( $ps>.349$ ).

A comparison of new versus old triplet recognition on median RTs was performed using a mixed ANOVA using within-groups factors of Condition (Random, Sequence) and Location (1,2,3), and between-groups factor of Sensitivity (HSP, non-HSP) groups. See Table 6.6 for results of the mixed ANOVA.

A 3-way interaction was observed for the full ATQ-OS ( $p=.04$ ). Simple effects were used to determine whether RTs for each condition differed at Location 3. Paired samples t-tests showed that non-HSPs were faster to respond in old ( $M=372\text{ms}$ , 95% CI[356,388]) versus new ( $M=400\text{ms}$ , 95% CI[386,414]) conditions,  $t(49)=4.51$ ,  $p<.001$ , whereas HSPs show little difference in Location 3 for old ( $M=403\text{ms}$ , 95% CI[378,432]) versus new ( $M=402\text{ms}$ , 95% CI[379,426]) conditions ( $p=.9$ ). Further, the difference between conditions was significantly larger for non-HSPs versus HSPs,  $t(68)=2.6$ ,  $p=.011$ .

Overall, HSPs show less evidence than non-HSPs of implicit learning or motor fluency in higher-order associations measured with the triplets, but neither group shows evidence of motor fluency contamination of ratings (Appendix F).

### **Explicit Memory Tests: Full Recognition**

**Full recognition omnibus task comparison and sensitivity.** An omnibus mixed measures ANOVA was used to analyze group differences in recognition ratings of the full sequence between implicit and explicit tasks using within-group factors of task (implicit, explicit) and sequence (target, random), for between groups factors of sensitivity (HSP, non-HSP), separately. Table 6.7 shows the ANOVA revealed no 2-way, or between-groups main effects for ATQ-OS groups ( $ps > .05$ ).

**Implicit SRTT: full recognition and sensitivity.** Ratings for target sequences and mean ratings of the four Random sequences were compared across sensitivity groups with a mixed ANOVA using within-subjects factors of sequence (Target, Random) and between-groups factors of sensitivity (HSP, non-HSP). No between-groups effects ( $ps > .19$ ) of sequence $\times$ sensitivity interactions ( $ps > .21$ ) were found for ATQ-OS measures.

**Explicit SRTT: full recognition and sensitivity.** Ratings for target sequences and mean ratings of the four Random sequences were compared across sensitivity groups with a mixed ANOVA using within-subjects factors of sequence (Target, Random) and between-groups factors of sensitivity (HSP, non-HSP). No between-groups effects were found for ATQ-OS groups ( $ps > .5$ ) and no significant sequence $\times$ sensitivity interactions were found ( $ps > .14$ ).

## **Exploratory Regression: Explicit Memory of Implicit Sequences as a Predictor of Creativity**

Using hierarchical multiple regression we test the prediction that orienting sensitivity, and length of maximum sequence generated in cued generation tasks following implicit SRTT can account for unique variance in creativity scores.

**Hierarchical multiple regression.** In the hierarchical multiple regression, Model 1 regressed maximum sequence score (from cued generation task following implicit SRTT) onto creativity scores. Model 2 added a sensitivity measure to Model 1. Model 3 added BFI-E and BFI-N variables to account for NA Adding NA measures to this hierarchical model allows the examination of sensitivity effects with and without NA controlled. Model 4 added BFI-O, a strong correlate of ATQ-OS (Evans & Rothbart, 2007), to examine whether IOR and sensitivity effects are redundant in the presence of BFI-O.

In no cases did maximum sequence scores account for unique variance in any of the creativity measures ( $p > .36$ ). As Models 2, 3 and 4 are of no interest unless Model 1 accounts for unique variance they are not reported.

### **Discussion**

Overall, analysis in Appendix F shows this diverse group of young to middle-aged people showed similar patterns of sequence-specific, higher-order associative, implicit and explicit learning and evidence of explicit awareness found in prior work using these tasks (Curran, 1997; Reber & Squire, 1998; Schendan et al., 2003a; Schendan et al., 2013). New findings reported in this study have revealed how implicit learning and memory relate to concepts of sensitivity and creativity.

Overall, performance on implicit and explicit SRTT did not differ significantly between orienting sensitivity groups. However some group differences emerged in the explicit memory tasks following the implicit SRTT. Following implicit SRTT learning, explicit memory tasks were performed to measure awareness and explicit memory for implicit task sequences. Importantly, following implicit SRTT tasks, HSPs demonstrated more knowledge about the repeating sequence than non-HSPs. Specifically, the maximum sequence generated on the cued generation task of explicit knowledge was higher for HSPs than non-HSPs by the end of implicit SRTT learning. Thus, HSPs demonstrate more awareness and explicit knowledge of implicitly learned sequences than non-HSPs.

Interestingly, HSPs show less evidence than non-HSPs of implicit learning or motor-fluency in higher-order associations measured with the triplets. This finding is consistent with the conceptualization of sensitivity as a tendency towards the “pause and check” strategy (Aron & Aron, 1997). Indeed, HSPs have been shown to be slower, but no less accurate than non-HSPs in visual search tasks (Jagiellowicz et al., 2010). No support found for the 3<sup>rd</sup> hypothesis, that implicit learning and memory performance related to higher sensitivity will predict creativity. Overall, these findings for the implicit SRTT are particularly important because they provide key confirmation that sensitivity is associated with the ability to become more consciously aware of information automatically under implicit conditions, supporting the first and second hypotheses. Altogether, this consistent with conceptualizations of the sensitive individual as being more consciously aware of subtleties that others may not notice (Aron et al., 2012; Evans & Rothbart, 2007, 2008). Notably, implicit learning and memory tends to remain unaffected by neurological issues, whereas explicit learning and memory differs with many neurological changes. For example, aging (Schendan, et al., 2013), or mediotemporal lobe damage (Scoville & Milner,

1957) affect explicit learning but leave implicit learning unaffected or relatively spared. In contrast, implicit learning tends to be affected mainly by neurological issues affecting dopamine systems in the basal ganglia, such as Parkinson's disease (Schendan, et al., 2013). Given the association between implicit learning, dopamine, and the basal ganglia, sensitivity effects on conscious sequence knowledge following implicit learning suggests the dopamine system implicated in sensitivity could underlie these effects. This is consistent with the evidence that dopamine changes underlie changes in implicit and explicit learning and memory with aging and Parkinson's disease (Schendan et al., 2013), as suggested above. For an alternative interpretation of the findings that take into account a greater range of sensitivity measures and analysis, please see Appendix F.

## **Conclusions**

Overall, this study shows that sensitivity is associated with a greater ability to incidentally acquire and exploit information during the implicit learning task, consistent with conceptualizations of the sensitive individual as being more consciously aware resulting from more sensitive exogenous attention systems (Aron et al., 2012; Evans & Rothbart, 2007, 2008). However, explicit memory performance following implicit sequence learning does not predict creativity, and thus no evidence suggests this mechanism underlies the sensitive creator.



## Tables

Table 6.1

*Mixed ANOVA using within-groups factors of Run, Condition and Block with between-groups factors of Sensitivity for implicit SRTT performance*

	ATQ-OS	
	<i>F</i>	$\eta_p^2$
<i>Main effects</i>		
Sensitivity	0	0
<i>2-way interactions</i>		
Sensitivity×Run	.61	.008
Sensitivity×Condition	.69	.009
Sensitivity×Block	.88	.011
<i>3-way interactions</i>		
Sensitivity×Run×Condition	.56	.007
Sensitivity×Run×Block	1.33	.017
Sensitivity×Condition×Block	0	0
<i>4-way interactions</i>		
Sensitivity×Run×Condition×Block	1.32	.017

*Note.* ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.

Table 6.2

*Summary output of mixed ANOVA showing main effects and interactions for within-groups factors of run and condition with between-groups factors of sensitivity for explicit SRTT performance*

	ATQ-OS	
	<i>F</i>	$\eta_p^2$
<i>Main effects</i>		
Sensitivity	1.77	.03
<i>2-way interactions</i>		
Sensitivity×Condition	1.96	.033
Sensitivity×Block	1.07	.018
<i>3-way interactions</i>		
Sensitivity×Condition×Block	.47	.008

*Note.* \* $p < .05$ . ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.

Table 6.3

*Summary output of mixed ANOVA showing main effects and interactions for within-groups*

*factors of Run and Transition Pair with between-groups factors of sensitivity for implicit SRTT*

	ATQ-OS	
	<i>F</i>	$\eta_p^2$
<i>Main effects</i>		
Sensitivity	.71	.009
<i>2-way interactions</i>		
Sensitivity×Run	.59	.008
Sensitivity×Pair	.83	.011
<i>3-way interactions</i>		
Sensitivity×Run×Pair	1.18	.015

*Note.* ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.

Table 6.4

*Summary of separate omnibus mixed ANOVA for free generation, including maximum sequences*

*generated, number of triplets generated, and ratio of triplets to keypresses for between-groups*

*factor of sensitivity*

		ATQ-OS	
		<i>F</i>	$\eta_p^2$
Maximum sequence	Main effects	.02	0
	Interaction	0	0
Number of triplets	Main effects	.06	.001
	Interaction	1.87	.024
Triplet ratio	Main effects	.35	.004
	Interaction	.02	0

*Note.* ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.

Table 6.5

*Summary of separate mixed ANOVA for explicit SRTT free generation, including maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses for between-groups factor of sensitivity*

		ATQ-OS	
		<i>F</i>	$\eta_p^2$
Maximum sequence	Main effect	.01	0
	Interaction	1.59	.02
Number of triplets	Main effect	.79	.01
	Interaction	1.72	.022
Triplet ratio	Main effect	.1	.001
	Interaction	1.18	.015

*Note.* ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.

Table 6.6

*Summary output of mixed ANOVA showing group effects and interactions for within-groups factors of Condition and Location and between-groups variables of sensitivity for implicit SRTT triplet recognition response times*

		ATQ-OS	
		<i>F</i>	$\eta_p^2$
<i>Main effects</i>			
Sensitivity		.83	.012
<i>Two way interactions</i>			
Sensitivity×Condition		1.93	.028
Sensitivity×Location (Loc)		.74	.011
<i>Three way interactions</i>			
Sensitivity×Condition×Loc		3.29*	.046

*Note.* \* $p < .05$ . ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.

Table 6.7

*Summary output of mixed ANOVA of full recognition ratings for factors of Task and Sequence and between-groups factor of sensitivity*

	ATQ-OS	
	<i>F</i>	$\eta_p^2$
<i>Main effects</i>		
Sensitivity	.08	.001
<i>Two-way interactions</i>		
Sensitivity×Task	.47	.006
Sensitivity×Sequence	.65	.008
<i>Three-way interactions</i>		
Sensitivity×Task×Sequence	.01	0

*Note.* ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ);  $\eta_p^2$ =partial eta squared effect size.



## CHAPTER VII

### **Latent Inhibition in the Sensitive Creator**

#### Abstract

In this chapter we employ an instrumental learning-to-criterion measure of latent inhibition (LI) using a within-subjects design (Evans et al., 2007; Granger et al., 2016) to examine how individual differences in LI may be one explanatory mechanism underlying higher creative potential and achievement in the sensitive, open creator (see Chapter 2). Latent inhibition was measured using a) response times for correct trials conditions, and b) number of correct predictive trials.

No sensitivity group differences in LI response times (RT) or number of correct predictive responses (CPR) were found. Hierarchical multiple regression analysis provides no evidence that LI (RT and CPR) can account for unique variance in creativity measures used, nor did the LI measures create redundancy of sensitivity and openness coefficients accounting for unique variance in creativity scores, providing no support for the hypothesis that LI is an underlying mechanism of the sensitive, open creator.



## **Introduction**

In the previous chapters, we show that higher sensitivity is associated with higher creative potential and achievement (Chapter 2), and as a construct separate from openness to experience personality (Chapter 3) has some basis in unconscious cognitive processes, including automatic attention (Chapters 4 & 5), and learning with conscious awareness and retrieval of memory (Chapter 6). Unconscious cognitive processes are critical for the creative process (Finke et al., 1992; Schooler & Melcher, 1995; Wallas, 1926) and are implicated in theories of creative cognition, including the cognitive disinhibition hypothesis which explains that original, useful and surprising ideas are more probable when normal inhibitory mechanisms that limit novel associations break down (Eysenck, 1995; Kaufman, Kornilov, et al., 2010; Martindale, 1999). Latent inhibition (LI) describes a phenomenon grounded in automatic attention and memory retrieval mechanisms wherein casually familiar stimuli (i.e., stimuli experienced without consequence) enter into new associations more slowly than novel stimuli. When latent inhibition breaks down, attention, learning and memory improve for previously irrelevant stimuli (Lubow & Gewirtz, 1995; Lubow & Kaplan, 2005), and when something deemed irrelevant turns out to be highly relevant, surprising, insightful ideas can emerge (Schmajuk et al., 2009; Simonton, 2012b). The aim of this study is to examine LI as an explanatory mechanism underlying higher creative potential and achievement in the sensitive, open creator (see Chapter 2).

### **Latent Inhibition and Attention**

LI in humans is most commonly measured using instrumental learning-to-criterion tasks, with response time and number of trials to reach learning criterion as the dependent variable (Evans et al., 2007; Lubow, 1997; Lubow & Gewirtz, 1995). The procedure to obtain LI involves two phases. In the pre-exposure stage, an irrelevant to-be-conditioned stimulus is repeatedly



presented without consequence. During the test phase, an association between that stimulus and a new event or target must be learned. When comparing associative learning of the pre-exposed stimulus (PE) to learning in a non pre-exposed (NPE) control condition that did not receive stimulus pre-exposure, reduced learning in the PE versus NPE condition is observed (Braunstein-Bercovitz & Lubow, 1998b; Lubow & Gewirtz, 1995). Attentional-associative models (for a review, see Lubow, 1989) explain that LI results from a stimulus-specific decline in attention as a function of repeated, inconsequential exposure during the pre-exposure stage. That is, LI can only occur under conditions of diminished voluntary, controlled attention in the pre-exposure stage but with sufficient cognitive resources available for automatic/involuntary attentional processing (Braunstein-Bercovitz & Lubow, 1998a, 1998b). In the test stage, learned associations with the pre-exposed stimulus only occur when conditioned attention decrements are overcome. Critically, any attention manipulations or individual differences, such as personality trait or neuropathology, that restore or maintain the attention to the pre-exposed stimulus reduce the magnitude of LI (Lubow, 2005b).

As LI is presumed to be modulated by attentional processes (Lubow, 1989), LI tasks have been used to study disorders characterized by attentional deficits, such as attention deficit hyperactivity disorder (Lubow & Josman, 1993) and schizophrenia (Baruch, Hemsley, & Gray, 1988). One of the most salient features of schizophrenia is the inability to ignore, or screen out, irrelevant information (Braff, 1993). Consistent with this, Baruch et al. (1988) report that acute schizophrenia is associated with diminished latent inhibition due to overattention towards irrelevant stimuli in the pre-exposure stage. The dopamine hypothesis of schizophrenia states that schizophrenia is related to excessive dopamine-related neuronal activity (Meltzer & Stahl, 1976), and low LI in schizophrenia has been explained by evidence linking individual

differences in LI to dopamine variation. For example, dopamine agonists (i.e., increased available dopamine) abolish latent inhibition in the rat (Solomon et al., 1981), whereas dopamine antagonists normalize LI in acute schizophrenia patients under treatment with anti-psychotic medication (Baruch et al., 1988; Dunn, Atwater, & Kilts, 1993) and create super-LI effects in rodents (Solomon et al., 1981). LI and its mediation by the dopaminergic system may be one mechanism linking sensitivity, openness and creativity.

### **Latent Inhibition, Personality and Creativity**

Disorders of attention and dopamine variation underlie individual differences in LI. However, dopamine variation is also related to creativity (Jauk et al., 2015; Takeuchi et al., 2010), and both sensitivity and openness are associated with variations in DRD4 dopaminergic ‘plasticity’ genes which play a role in attention (Deyoung, 2013; Deyoung et al., 2011; Jauk et al., 2015; Pluess, 2015a, 2017). Lower LI is associated with higher openness to experience (Peterson & Carson, 2000), the Big-Five personality trait with the strongest association higher creativity (Feist, 2010; Kaufman et al., 2016; Runco, 2014; Sawyer, 2012), and higher creative achievement, especially in highly intelligent people, suggesting creative people are more open to environmental stimuli (Carson et al., 2003; Chirila & Feldman, 2012; Keri, 2011). Low LI is proposed to be a form of cognitive disinhibition that enables awareness of more information for creative association (Carson, 2011). According to the cognitive disinhibition hypothesis of creativity (Eysenck, 1995; Kaufman, Kornilov, et al., 2010; Martindale, 1999), highly creative people have lower cognitive inhibition due to frontal lobe de-activation, with greater disinhibition in the right hemisphere. This theory is consistent with evidence implicating anti-correlated attention networks for internally and externally directed cognition (Dixon et al., 2014) in creativity and studies linking ‘disinhibition’ (Takeuchi et al., 2011), increased grey matter

volume (Jauk et al., 2015), density (Fink et al., 2014) and function (Fink & Benedek, 2014) of areas of the DMN with divergent thinking. Also, variation in ideational originality on divergent thinking tasks (e.g., ATTA) is related to structural variation and activity in the DMN and the basal ganglia dopaminergic system (Andreasen, 2005; Jauk et al., 2015; Takeuchi et al., 2011; Takeuchi et al., 2010).

**Latent inhibition and creativity.** The attentional-associative model of classical conditioning can explain how low LI enhances creativity (Schmajuk et al., 2009) and suggests neural mechanisms for linking LI and creativity with sensitivity, openness, dopamine, and the DMN. In the model, an increase in dopaminergic activity enhances effects of novelty on attention, thereby increasing attention and reducing LI. Low LI is thus associated with increased attention to previously-experienced irrelevant stimuli (i.e., as if they are more novel), and this manifests as a lower attentional gating threshold for sensory stimulation (Schmajuk et al., 2009). Consequently, with low LI, learning and memory improves, as well as creativity processes that involve these novelty, attention, and memory mechanisms, such as the remote associates task and divergent thinking (Schmajuk et al., 2009). LI is due to processes within a "default automatic processing mode" that stands in contrast to a controlled top-down mode of processing (Lubow & Gewirtz, 1995). Consistent with this, neurophysiology (i.e., a P50) suggest that stronger, very early automatic attentional capture by an external stimulus ("sensory gating"), which is thought to be related to low LI, is associated with higher creativity (Zabelina et al., 2015; Zabelina, Saporta, et al., 2016). Early sensory gating and later automatic attention involve different processes (Wan, Crawford, & Boutros, 2007), although both may be part of the default automatic processing mode associated with LI. For example, low LI associated with low, early automatic attentional gating would enable more stimuli to reach later processing stages. In turn, low LI

associated with later automatic attention (e.g., exogenous orienting in the DMN) would further reduce selection and filtering. Altogether, this ensures that more stimuli reach awareness. While an attentional-associative model of LI and creativity (Schmajuk et al., 2009) fits an emotion-attention temperament framework (Evans & Rothbart, 2007) most readily, the environmental sensitivity framework (Pluess, 2015a) can also accommodate a link with LI because neurosensitivity can affect attention, learning and memory systems (e.g., see Chapter 6).

**Latent inhibition and sensitivity.** While there are no known direct links between LI and sensitive temperament, evidence is suggestive. The sensitive temperament is characterized by a behavioural profile that suggests low LI, as people high in sensory-processing sensitivity (SPS) seem to have a nonconscious tendency to attend irrelevant stimuli, having trouble ignoring or filtering them out (Eby, 2015; Rizzo-Sierra et al., 2011). Early evidence suggests that creativity is associated with higher sensitivity, which was defined as less ability to learn to habituate to repeated sensory stimulation, and this is associated with a higher orienting response (OR; Martindale et al., 1996). Higher OR means greater automatic attention to irrelevant stimulation (and greater novelty detection), as in low LI (Schmajuk et al., 2009). This pattern suggests that high sensitivity is related to low LI.

## **Aims**

The aim of this study is to examine how individual differences in LI may be one explanatory mechanism underlying higher creative potential and achievement in the sensitive, open creator (see Chapter 2). In this study we employ an instrumental learning-to-criterion measure of LI using a within-subjects design (Evans et al., 2007; Granger et al., 2016). Between-subjects designs are most common in human LI studies, in which participants are split into separate PE and NPE conditions, giving the greatest magnitude of effects. However, within-

subjects designs provide power to detect effects using fewer participants, and eliminate the need for matching groups based on important demographics (Gray, Snowden, Peoples, Hemsley, & Gray, 2003). The within-subjects design used in this study is sensitive to individual differences and has previously shown that high scores on the schizotypy personality dimension are associated with low LI (Evans et al., 2007; Granger et al., 2016; cf. Gray et al., 2003), consistent with the continuum approach wherein schizotypy personality may index psychosis-proneness in the general population (Claridge, 1994), which is linked to low LI (Baruch et al., 1988; Lubow & Gewirtz, 1995). This suggests the within-subjects LI task design can detect group differences in LI between sensitivity and creativity groups from the general population.

In this within-subjects LI task, the PE stage exposes participants to a PE stimulus letter amongst filler letters without consequence. In the test stage, participants see PE and novel NPE cues preceding target letters appearing on screen, and must either respond to, or predict, the target onset with a key press. Participants attempt to learn to associate the cues with the target letters in order to predict the target as early as possible. Learning associations between cues and targets will decrease response time, and increase correct predictive responses to targets. Correct predictive responses are defined as anticipatory responses recorded during PE or NPE stimuli presentations which precede target onset, demonstrating a learned association, rather than a simple response to an event (Granger et al., 2016). As a manipulation check (see Appendix G), we expect to observe LI effects where PE-target associations are learned more slowly than NPE-target associations, resulting in slower RTs and lower correct predictive responses for PE versus NPE cue-target pairs. Intelligence is not usually considered in human LI experiments or literature reviews (e.g., Lubow & Gewirtz, 1995), but we included a short-form Ravens Advanced

Progressive Matrices test (Arthur Jr & Day, 1994) because attention deficits associated with LI can instil a creative advantage in the presence of high IQ (Carson et al., 2003).

## **Hypothesis**

Creative achievement is associated with low LI (Carson et al., 2003; Chirila & Feldman, 2012; Keri, 2011; Schmajuk et al., 2009), and behavioural profiles of the sensitive temperament suggest low LI (Eby, 2015; Rizzo-Sierra et al., 2011). The overall hypothesis is that LI will be lower in high sensitive groups relative to low sensitive groups. This predicts group differences in response times and number of correct predictive responses between PE and NPE conditions (i.e., different LI effects between groups). Specifically, in the test phase i) high sensitive groups (who have lower LI) should be faster to learn associations with the PE stimuli than low sensitive groups (who have stronger LI). Consequently, a) differences in response times and b) correct predictive responses between PE versus NPE conditions (i.e., the LI effects) should be smaller for high versus low sensitive groups.

Regarding the relationship between intelligence, LI and creativity (Carson et al., 2003), between sensitivity and creativity (Chapter 2), and considering that higher intelligence may even infer an advantage in the presence of attention deficits associated with psychosis-proneness (Carson et al., 2003), we expect that ii) high sensitivity and high intelligence will be associated with the lower LI effects.

Considering sensitivity as a continuous variable, if LI effects represent a shared underlying mechanism between sensitivity, creativity and openness to experience, iii) we expect that inclusion of those variables together in the hierarchical multiple regression models will result in some redundancy of those LI regression coefficients.

## Method

### Participants

A sample of 80 participants were recruited for the study (55 female, 25 male, aged between 18-46 years,  $M=22.29$ ,  $SD=5.88$ ). Participants were rewarded with course credit or paid £8 per hour pro-rata. This study was approved by Human Ethics Committee in the Faculty of Science and Environment at University of Plymouth. Participants gave informed consent before the study and were debriefed after completing the study.

### Apparatus and Materials

A computerized battery was developed on Survey Monkey to assess sensitivity, Big-Five personality and creativity and administered in the lab. Each questionnaire was presented on a separate page within the software. For each item, the participant checked the blank in front of any item corresponding to the response that best applied to them.

Sensitivity was measured using two questionnaires. 1) The Highly Sensitive Person scale (HSPS) from Aron and Aron (1997) is a 27-item, modality general, self-report scale measuring sensory processing sensitivity using items asking about tendencies to startle easily, become easily overwhelmed by sensory inputs but also awareness of subtleties in the environment, and enjoyment of fine and delicate scents, tastes, sounds, and works of art. Item responses ranged from 1 (not at all) to 7 (extremely). 2) The two HSPS factors of orienting sensitivity and negative affect were also measured using the Adult Temperament Questionnaire (ATQ)-short form (Evans & Rothbart, 2007). The ATQ is a self-report scale with 77 items measuring general constructs of orienting sensitivity (ATQ-OS), negative affect (ATQ NA), effortful control (ATQ EC), and extraversion/surgency (ATQ ES). Item responses ranged from 1 (extremely untrue) to 7 (extremely true) and “not applicable”.

The Big Five Inventory (BFI) assessed personality. This 44-item self-report questionnaire measures the Big Five dimensions of personality: Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Benet-Martinez & John, 1998; John et al., 1991; John et al., 2008; John & Srivastava, 1999). Item responses ranged from 1 (disagree strongly) to 5 (agree strongly).

Creativity was assessed using three of the most established and validated measures of creative processes. The Creative Achievement Questionnaire (CAQ; Carson et al., 2005) was chosen as an objective self-report measure of creative achievement across 10 domains of creativity. The Runco Ideational Behaviour Scale (RIBS; Runco et al., 2000-2001) is a 19-item questionnaire designed to measure creative ideation, which is thought to measure a single factor and has discriminant validity. Items probe behavioural tendencies and abilities regarding ideas and thinking, with many items emphasizing creative, unusual, or imaginative thought (e.g., “I have many wild ideas.”). The RIBS responses ranged from 1 (never) to 5 (very often). This study was lab-based in order to administer one pencil and paper creativity test: The Abbreviated Torrance Test for Adults (ATTA; Goff & Torrance, 2002) consists of 3 timed (3-minute) tests of figural and verbal divergent thinking abilities thought to be critical for the creative process (Runco, 2014). The ATTA is a gold standard, objective measure of divergent thinking. The ATTA thus is the one test that independently verifies creative products/divergent thinking. The ATTA was presented in the lab in paper format with a pencil and eraser, not part of the Survey Monkey battery.

A measure of higher order cognitive ability (*g* or analytical ‘fluid’ intelligence) was assessed using the 12-item short-form of the Ravens Advanced Progressive Matrices Test. The short form Ravens test demonstrates similar psychometric properties to the long form, but with a



substantially shorter mean administration time of 15 minutes versus 35-45 minutes of the long form version (Arthur Jr & Day, 1994). The task consists of 12 matrix or design problems arranged in ascending order of difficulty. Participants were administered pencils, erasers, and multiple choice response sheets corresponding to the 12-item test presented as a booklet. After brief demonstration of how to perform the test using 2 practice items from the Ravens Advanced Progressive Matrices Test, participants were informed they have 15 minutes to complete the task, timed by the experimenter using a stopwatch. After 15 minutes, participants were asked to put their pencil down and stop working, and the experimenter collected the response sheets and test booklets. Ravens scores for each participant were calculated by summing the number of problems correctly solved, the same as that for the long-form (Arthur Jr & Day, 1994).

The experimental stimuli were presented on a Viglen Windows 7 PC with Philips Brilliance LED monitor 221P3LPYES P-line 21.5" widescreen operating at 1920 × 1080 pixels with a 60hz refresh rate, and were programmed and presented using PsychoPy (Peirce, 2007). Stimuli were white capital letters in Arial font (7mm x 5mm; h × w) presented on a grey background. The pre-exposed and non pre-exposed letter stimuli were “S” and “H”, respectively, but counterbalanced across participants so that equal numbers of participants saw “S” as the pre-exposed stimuli and “H” as the non pre-exposed stimuli, and vice versa for the other half of participants. For all participants, the letter “X” was the target stimulus, and letters “D”, “M”, “T” and “V” were filler stimuli. See Figure 7.1 for stimuli frequency in pre-exposure and test phases.

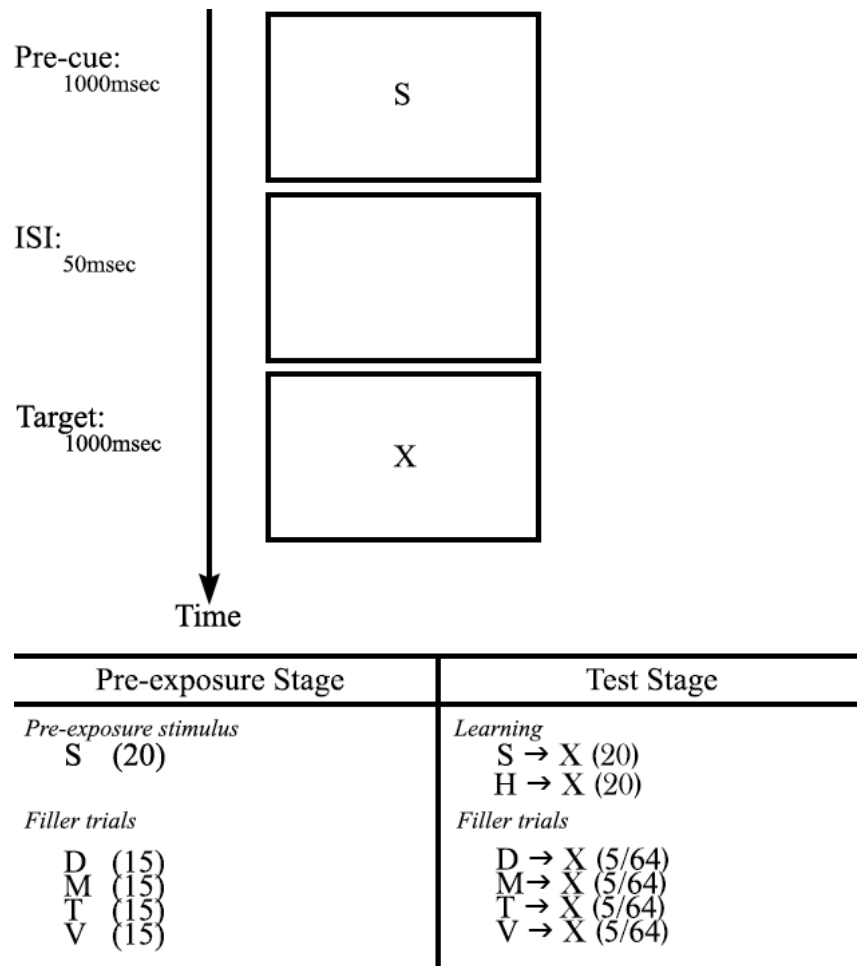


Figure 7.1. Experiment design and example of a pre-exposed stimuli predicting target letter ‘X’ in the test stage of the latent inhibition task (Evans et al., 2007; Granger et al., 2016). For pre-exposure stage, letters in parenthesis reflect stimuli frequency. For test stage, letters in parenthesis reflect number of times stimuli predicts target letter ‘X’, where numbers in parenthesis for filler trials reflect probability of predicting target letter ‘X’. Note, learning stimuli always precede target stimuli in the test stage.

### Procedure

The latent inhibition task consists of two stages, a pre-exposure stage and a test stage. In the pre-exposure stage, participants were first presented with instructions for the task. The

instructions informed participants that they would be presented with letters, one after the other, and their task was to read the letter out loud to themselves. When the participants had read and understood the instructions, they were told to push the space bar to begin. In the pre-exposure stage, each participant was presented with a random sequence of letters in which the inter-mixed pre-exposed stimulus (i.e., S or H) appeared 20 times and four filler letters (D, M, T, V) appeared 15 times each. Each letter was presented for 1000ms with a 50ms inter-stimulus interval with 80 trials taking approximately 2 minutes to complete. The non pre-exposed and target letter stimuli were not presented during the pre-exposure stage.

The test stage followed the pre-exposure stage. When the pre-exposure stage was complete, the participants were given the following instructions for the test phase, taken verbatim from Granger et al. (2016):

“In this task, I want you to watch the sequence of letters appearing on the screen. Your task is to try and predict when a letter ‘X’ is going to appear. If you think you know when the ‘X’ will appear then you can press the space bar early in the sequence, that is before the ‘X’ appears on screen. Alternatively, if you are unable to do this please press the spacebar as quickly as possible when you see the letter ‘X.’ There may be more than one rule that predicts the ‘X.’ Please try to be as accurate as you can, but do not worry about making the occasional error. If you understand your task and are ready to start press the spacebar to begin.”.

In the test stage, each participant was presented with a random sequence of letters in which the inter-mixed pre-exposed and non pre-exposed predictive stimuli appeared 20 times each. The target letter followed every presentation of the pre-exposed and non pre-exposed predictive stimuli (100% predictive probability). Filler letters appeared 64 times each and, within those presentations, the target appeared 5 times following each of the filler stimuli (7.82% predictive probability). Thus due to the much higher probability of the pre-exposed and non pre-exposed predictive stimuli relative to the filler stimuli, learning of the association with the target should occur much more strongly for the predictive than the filler stimuli. The extent to which learning is less for the pre-exposed relative to non-pre-exposed predictive stimuli is the measure of latent inhibition of learning. Each letter was presented for 1000ms with a 50ms inter-stimulus interval. The presentation of 356 total trials took approximately 7 minutes to complete.

### **Analysis**

Errors of omission (miss) and errors of commission (false alarm) across all trials were used to determine participant engagement with the task, because excessive errors of omission and commission suggest poor engagement in the task (Evans et al., 2007). Median or mean absolute deviation was used to detect outliers and reject participants with outstanding errors of omission and commission based on the assumption they were not engaging with the task (cf. Evans et al., 2007).

Latent inhibition was measured using a) response times for correct trials conditions, and b) number of correct predictive trials, both for PE and NPE conditions only. Note, correct predictive trials were categorized as predictive on the condition that the response preceded target onset during presentation of predictive stimuli or during the 50ms pre-target interval. Within-groups task factors of interest were exposure condition (pre-exposed and non pre-exposed predictive stimuli), and trial

block (10 trial blocks), wherein each trial block measure is the mean response times over 2 consecutive trials, with no trials overlapping between blocks (see Granger et al., 2016). A between-groups factor of pre-exposure stimuli (Order) was included in the main analysis as a stimulus counter-balance factor. In this study, participants were either exposed to “S” or “H” as the pre-exposed stimuli, thus an Order factor determines whether “S” or “H” as the pre-exposed stimulus affects latent inhibition. Another between-groups factor included the median-split Ravens short-form (Arthur Jr & Day, 1994) intelligence scores (high, low), used to examine whether general cognitive ability interacts with latent inhibition. Note, only effects relating to the manipulation of exposure condition are reported.

The HSPS may be a taxon consisting of HSPs (i.e., those high on HSPS) and non-HSPs, thus Aron and Aron (2013) suggest dichotomizing the sample with high-low break points somewhere between 15% for HSPs and 85% for non-HSPs, up to 30% for HSPs and 70% for non-HSPs. In this study a 30% HSP 70% non-HSP split was chosen. Between-groups factors of sensitivity were used to explore differences in LI performance between HSP ( $n=22$ ) and non-HSP groups ( $n=51$ ).

Sensitivity group differences were explored using mixed ANOVA and t-test comparisons using between-groups factors of ATQ-OS. For the ATQ-OS, the HSP groups ( $M=.76$ , 95% CI [.73,.78]) had higher scores than non-HSPs ( $M=.51$ , 95% CI [.48,.54]). See Appendix G for HSPS and CAQ, RIBS, ATTA and Ravens group splits. Note, all personality, temperament, and creativity measures are scaled between 0 and 1, see Chapter 2 for scaling. Max scores used for scaling in this study are CAQ are 94, and 83 for the ATTA in this study only.

For sensitivity measures considered as continuous variables and analyzed with regression analysis, single variables for latent inhibition response times (LI RT) were created by collapsed

response times across trials and subtracting mean response times of non pre-exposed (NPE) from the pre-exposed (PE) condition (PE minus NPE). For latent inhibition correct predictive responses (LI CPR), a variable for total correct predictive responses was calculated for each condition and subtracted (NPE minus PE). Positive values for LI RT and LI CPR indicate latent inhibition was present, whereas zero or negative scores indicate an absence of latent inhibition (Evans et al., 2007).

### **Missing Data**

Only 2 participants included in the analysis had a missing data in the control condition, each missing a single trial. Therefore, in order to minimize loss of data during the analysis, missing data was replaced using the group mean RT for those trials with missing data.

## **Results**

### **Task Accuracy and Participant Exclusion**

Overall, 39 participants made errors of omission (miss) at least once across 60 target presentations, ranging between 0 and 14 omissions ( $M=1.1$ ,  $SD=2.05$ ). 77 participants made errors of commission (false alarm) across all trials ranging between 0 and 37 commissions ( $M=7.93$ ,  $SD=7.46$ ). Using the median absolute deviation method of outlier detection, 5 participants were detected as outliers with errors of commission  $\geq 24$ . For errors of omission, more than 50% of error values were zero and thus median absolute deviation was not applicable. Using the mean absolute deviation method of outlier detection, 2 participants were detected as outliers with errors of omission  $\geq 9$ . Therefore, 7 participants were rejected ( $n=5$  via errors of commission &  $n=2$  via errors of omission), leaving  $n=73$  participants for further analysis. See Appendix G for analysis collapsed across groups.

### **Individual Differences in Latent Inhibition using Dichotomous Measures**

Individual differences in response times and correct predictive responses were analyzed

separately for sensitivity groups defined using ATQ-OS. To analyze individual differences in LI response times, a mixed ANOVA used within-groups factors of test condition (pre-exposed [PE], non pre-exposed [NPE]) and trial (trial block 1:10) and between-groups factors of Ravens group (high, low) and Sensitivity (HSP, non-HSP). To analyze individual differences in latent inhibition using numbers of correct predictive responses, a mixed ANOVA used within-groups factors of test condition (PE, NPE) and between-groups factor of Ravens group (high, low) and Sensitivity (HSP, non-HSP). See Appendix G for analysis with the HSPS and with all creativity measures.

### **Latent Inhibition and Sensitivity**

**Response times.** Sensitivity group differences in latent inhibition were not observed for ATQ-OS ( $ps > .17$ ).

**Correct predictive responses.** The mixed ANOVA did not reveal any significant between-groups effects ( $ps > .16$ ), 2-way ( $ps > .23$ ) or 3-way ( $ps > .1$ ) interactions for the sensitivity measure.

### **Latent Inhibition and Continuous Individual Differences Measures**

Dichotomous splits used for sensitivity measures reduce statistical power to detect effects (MacCallum et al., 2002). To assess LI effects based on continuous sensitivity measures with greater power, single variables for LI response times (RT; PE minus NPE) and LI correct predictive response (CPR; NPE minus PE) were calculated using mean scores for each condition collapsed across trials.

**Latent inhibition, intelligence and sensitivity as predictors of creativity.** The hypothesis (iii) asks whether latent inhibition is one underlying mechanism of the sensitive, open creator. A hierarchical regression model will demonstrate whether sensitivity and latent inhibition can account for unique variance in creativity, measured using the CAQ, RIBS, and ATTA. In the hierarchical multiple regression, Model 1 regressed either LI RTs or LI CPR onto CAQ, RIBS

and ATTA variables, separately. Model 2 added Ravens short-form scores in order to assess whether LI predicts creativity independent of intelligence (Carson et al., 2003). Model 3 adds ATQ-OS as a sensitivity measure. Model 4 added BFI-E and BFI-N variables to account for NA. Adding NA to this hierarchical model allows the examination of sensitivity effects with and without NA controlled. Model 5 added BFI-O, a strong correlate of ATQ-OS (Evans & Rothbart, 2007), to examine whether latent inhibition and sensitivity coefficients are redundant in the presence of BFI-O.

Assumptions of ordinary least squares regression were checked. Note, the minimum number of participants required for multiple regression is  $N \geq 50 + m$ , where  $m$  is the number of predictors. Regression equations with 6 or more predictor variables should aim for a minimum of  $N = 10m$  (VanVoorhis & Morgan, 2007). In this study,  $N = 73$  and regression models use 6 predictor variables, thus sample size requirements for multiple regression are satisfied. Scatterplots indicate linearity between variables. Distributions were inspected using P-P plots and histograms revealed that LI RT and LI CPR are positively skewed. Although no assumptions are made regarding independent variables in regression models, it is useful to find whether influential cases or outliers exist. Standardised residuals  $> 3$  were found for a five cases over creativity measures ( $n = 2$ ,  $n = 1$  and  $n = 2$  for CAQ, RIBS and ATTA, respectively), although Mahalanobis distance values  $< 15$  indicate little influence with low leverage indicated by values  $< 3[k + 1]/n$  suggesting the outlier cases do not substantially influence the model parameters (Field, 2013). Homoscedasticity cannot be assumed for CAQ or ATTA, as variance is not evenly dispersed. Violation of this assumption may limit the generalisability of the findings beyond the sample.

Table 7.1 and Table 7.2 show the results of the hierarchical multiple regressions. In no models did LI RT or LI CPR account for unique variance for creativity measures. For LI RT and



LI CPR, Model 1 was not significant across CAQ, RIBS or ATTA measures, and did not account for unique variance together with Ravens short-form measures in Model 2, or with ATQ-OS variables in Model 3, or with Big-Five Neuroticism, Extraversion (Model 4) and Openness (Model 5) controlled. Note, Ravens scores accounts for significant unique CAQ variance in Models 2, 3, and 4 but not with openness to experience controlled in Model 5.

### **Discussion**

In this study, a latent inhibition effect was found (see Appendix G) where responses were slower and less predictive in PE versus NPE conditions, although order effects were also found for response times, suggesting that the manipulation did not work when “S” was the pre-exposed stimulus. Further, intelligence measured with the Ravens short-form measure (Arthur Jr & Day, 1994) did not interact with the LI effects, or correlate with LI variables, suggesting LI in this within-subjects task is not directly influenced by general intellectual ability.

The purpose of the study was to understand how individual differences in sensitivity manifest in measures of latent inhibition. We tested the hypothesis that sensitivity relates to LI RT and LI CPR, treating sensitivity as dichotomous and continuous variables with respective ANOVA and regression analysis. Considering the sensitivity as dichotomous, no sensitivity group differences in LI response times or number of correct predictive responses were found, providing no support for the hypothesis that high sensitivity would be associated with low latent inhibition. Thus, ANOVA using dichotomous orienting sensitivity measures provide no evidence that higher sensitivity is associated with low LI.

Considering sensitivity as a continuous variable with greater power to detect effects (MacCallum et al., 2002), hierarchical multiple regression analysis was used test the hypothesis that latent inhibition is one shared underlying mechanism of the sensitive, open creator that can

account for unique variance in models predicting creativity, but in the presence of sensitivity and openness measures is made redundant. No effects relating to LI were found. In particular, LI RT or LI CPR did not account for unique variance in any creativity measures, nor did LI measures create redundancy of sensitivity and openness coefficients accounting for unique variance in creativity scores (see Chapter 2 for relationship between sensitivity and creativity, including data from this study). Overall, findings provide no evidence that LI is a common mechanism underlying sensitivity, openness, and creativity.

## **Conclusions**

The key findings from this within-subjects LI task are that a) LI is normal across high and low orienting sensitivity groups, when sensitivity is considered as a dichotomous variable, and b) LI does not appear to be a unifying mechanism in the relationship between sensitivity, openness and creativity.

One explanation for the lack of evidence for low LI in sensitivity includes the possibility that within-subjects designs of the LI task lack sensitivity to detect individual differences in LI. Consistent with this, Gray et al. (2003) show that within-subjects LI tasks are insensitive to LI effects between high and low schizotypy personality groups which are observed with between-groups LI tasks, wherein the magnitude of effects are larger. In addition, the lack of task sensitivity could be explained by order effects, as LI effects were only observed in half of the participants pre-exposed to “H” stimuli, thus larger group differences would be diminished through averaging across all participants, including those pre-exposed to “S” stimuli (see Appendix G). Finally, lack of group differences in the direction predicted could also be explained by inadequate sample sizes per group ( $ns < 30$ ) in the ANOVA analysis (cf. Carson et al., 2003) and overall sample size ( $N < 250$ ) in the regression analysis (Schönbrodt & Perugini, 2013). Thus, the null hypothesis of normal LI

in the sensitive, open creator cannot be rejected in this study using either a) a within-subjects task, or b) inadequate sample sizes.

## Tables

Table 7.1

*Hierarchical multiple regression with LI response times, intelligence, sensitivity and personality predicting creativity for CAQ, RIBS and ATTA*

	ATQ-OS		
	CAQ	RIBS	ATTA
<b>Model 1</b>			
LI RT	0	0	0
<b>Model 2</b>			
LI RT	0	0	0
Ravens	.217*	.019	.114
<b>Model 3</b>			
LI RT	0	0	0
Ravens	.185*	-.03	.104
Sensitivity	.386***	.588***	.116
<b>Model 4</b>			
LI RT	0	0	0
Ravens	.193**	-.04	.107
Sensitivity	.381**	.512***	.092
BFI-E	-.096	.159*	-.027
BFI-N	0	.175*	.074
<b>Model 5</b>			
LI RT	0	0	0
Ravens	.118	-.073	.106
Sensitivity	-.035	.33*	.086
BFI-E	-.097	.158*	-.027
BFI-N	.042	.177**	.074
BFI-O	.487**	.214	.008
<b>Model fit (<math>R^2</math>)</b>			
Model 1	.005	-.01	-.014
Model 2	.058*	-.024	.002
Model 3	.177*	.343***	.008
Model 4	.174	.401*	.001
Model 5	.248***	.413	-.014

*Note.* \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; LI RT=Latent inhibition response times (mean PE – mean NPE); ATQ-OS=orienting sensitivity factor of the ATQ; BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory;  $R^2$ =adjusted  $R^2$  for change in model fit.

Table 7.2

*Hierarchical multiple regression with LI correct predictive response, intelligence, sensitivity and personality predicting creativity for CAQ, RIBS and ATTA*

	ATQ-OS		
	CAQ	RIBS	ATTA
<b>Model 1</b>			
LI CPR	.005	-.001	0
<b>Model 2</b>			
LI CPR	.005	-.001	0
Ravens	.224*	.019	.114
<b>Model 3</b>			
LI CPR	.004	-.002	0
Ravens	.191*	-.031	.104
Sensitivity	.389***	.592***	.116
<b>Model 4</b>			
LI CPR	.005	-.002	0
Ravens	.199*	-.042	.107
Sensitivity	.383***	.515***	.093
BFI-E	-.091	.164*	-.026
BFI-N	.041	.173*	.074
<b>Model 5</b>			
LI CPR	.004	-.003	0
Ravens	.122	-.078	.106
Sensitivity	-.032	.321***	.086
BFI-E	-.093	.162*	-.026
BFI-N	.045	.175**	.074
BFI-O	.486**	.227	.008
<b>Model fit (R<sup>2</sup>)</b>			
Model 1	-.001	-.013	-.014
Model 2	.056*	-.027	.002
Model 3	.177***	.346***	.008
Model 4	.174	.405*	.001
Model 5	.247**	.42	-.015

*Note.* \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; LI CPR=Latent inhibition correct predictive responses (NPE-PE); ATQ-OS=orienting sensitivity factor of the ATQ; BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory;  $R^2$ =adjusted  $R^2$  for change in model fit.

CHAPTER VIII  
**General Discussion**



## **Introduction**

In this thesis, we established relationships between temperament, personality, creative potential and achievement using state-of-the-art subjective and objective measures. We focused specifically on orienting sensitivity (Evans & Rothbart, 2007) also captured by environmental sensitivity (Aron & Aron, 1997; Pluess, 2015a) and sensory-processing sensitivity frameworks (Aron & Aron, 1997). Orienting sensitivity is the positive-affect-related sensitivity dimension of the emotion-attention temperament model most important for creativity (see Chapter 1 and 2). Orienting sensitivity can be measured using the Adult Temperament Questionnaire (Evans & Rothbart, 2007, 2008) or the Highly Sensitive Person Scale (Aron & Aron, 1997; Smolewska et al., 2006; Sobocko & Zelenski, 2015). Cognitive implications of trait sensitivity are suggested through mechanisms of sensory-processing sensitivity (SPS; Aron & Aron, 1997), neurosensitivity (Pluess, 2015a) and automatic attention orienting processes (Evans & Rothbart, 2007), thus we aim to establish objective measures of those cognitive processes, and how they explain the relationships between temperament, personality and creativity. Findings relating to sensitivity and creativity are interpreted in light of a new sensitivity framework explaining the sensitive, open creator, which aligns with the cognitive disinhibition and hemispheric asymmetry hypothesis of creativity (Eysenck, 1995; Kaufman, Kornilov, et al., 2010; Martindale, 1999), and models of the creative process (Lubart, 2001; Wallas, 1926).

### **Establishing Links between Sensitivity and Creativity**

In Chapter 2, findings strongly link orienting sensitivity (OS), openness and diverse creative processes. We found that OS and openness are highly correlated traits that have independent roles in creative ideation and achievement but interactive roles in divergent thinking (DT) and achievement, because openness increases DT and achievement in people with higher



OS. Some argue that sensitivity is subsumed under openness (Shiner et al., 2012b; Shiner & DeYoung, 2013a), suggesting that any relationship between sensitivity and creativity is explained by openness. Factor analysis in Chapter 3 indicates that OS and openness are highly correlated, but distinct factors with discriminant validity (see also Aron & Aron, 1997; Evans & Rothbart, 2007) consistent with theoretical accounts describing OS as the biological substrate of openness (Evans & Rothbart, 2007) and the proposition that OS is a dimension of openness (Shiner et al., 2012b; Shiner & DeYoung, 2013a). However, factor analysis cannot provide clarity regarding hierarchical relationships between constructs, thus we cannot conclude that OS is a higher-order openness dimension. Further, in this thesis our conclusions regarding the relationship between OS and openness, and the incremental predictive validity of OS over openness when accounting for variance in creativity measures, are limited because short-form versions of the openness scale were used. However, if openness is to subsume OS, then short-form measures of openness require more OS questions to capture sensitivity more completely. Nevertheless, we show sensitivity is a broad, higher-order personality dimension with implications beyond the single trait of openness. For example, the factor analysis shows evidence of an NA component in the sensitivity construct, consistent with previous reports (Evans & Rothbart, 2008; Smolewska et al., 2006; Sobocko & Zelenski, 2015) and environmental sensitivity frameworks (Aron & Aron, 1997; Aron et al., 2005; Pluess, 2015a; Pluess & Boniwell, 2015b) wherein manifestations of sensitivity change depending on experience; people who are disproportionately susceptible to positive or negative life events may have different outcomes in the relative strengths of positive-affect-related OS and negative-affect-related (NA) dimensions of sensitivity, respectively. The HSPS captures multiple outcomes of the sensitive temperament (Evans & Rothbart, 2008; Smolewska et al., 2006), although given the importance

of the OS dimension in regards to vantage sensitivity, and the ratio of OS to NA items on the HSPS, future work may want to consider the benefits of increasing OS items on the HSPS scale to capture OS more completely. Nevertheless, the sensitivity frameworks described in this project capture a missing link with personality development by defining core constitutional mechanisms which “grow” personality through social and environmental interaction, and shape cognition.

### **Sensitivity, Cognition and Creativity**

The conceptualisations of sensory-processing sensitivity (Aron & Aron, 1997), neurosensitivity (Pluess, 2015a) and orienting attention sensitivity (Evans & Rothbart, 2007) suggest a neuro-cognitive basis of this higher-order trait. Thus, we hypothesized that sensitivity will have broad implications for perception, attention, learning and memory. Indeed, these cognitive mechanisms are suggested in the highly sensitive person, who experiences greater awareness of internal and external events (Evans & Rothbart, 2007), such that subtleties are noted and processed more deeply, driven by either stronger emotional reactions (Aron et al., 2012), or neurosensitivity (Pluess, 2015a), which may facilitate learning and memory.

In Chapter 4 we showed that OS is characterized by individual differences in change detection and sensitivity of the alerting and executive attention networks. HSPs have a harder time filtering out (inhibiting) distracting information (i.e., more sensitive to irrelevant information) when attention is alert and diffused. As alerting networks support visual orienting and other attention processes (Posner & Petersen, 1990) and share common brain anatomy with exogenous attention networks, including the temporal-parietal junction (Corbetta & Shulman, 2002; Fan et al., 2005), this evidence is consistent with OS defined as sensitive exogenous attention. However, the tasks used in Chapter 4 measure endogenous, goal-driven attention, and

therefore cannot fully account for sensitive exogenous orienting mechanisms that may be related to ATQ-OS measures. Thus, Chapter 5 examines individual differences in both endogenous and exogenous attention, and whether those cognitive processes can explain the relationship between sensitivity and creativity.

Key findings in Chapter 5 demonstrate that ATQ-OS was associated with exogenous task-related inhibition-of-return (IOR) effects, consistent with the definition of OS as exogenous attention. However, no sensitivity effects were specific to orienting processes per se. Further, as no links were made between IOR and creativity, this suggests that exogenous IOR mechanisms do not explain the relationship between sensitivity and creativity.

The findings across Chapter 4 and Chapter 5 suggest that sensitivity relates to attention processes more generally, including alerting mechanisms associated with defocused attention and disinhibited states (Callejas et al., 2004; Posner, 1994), rather than the orienting processes themselves. The observations of defocused, disinhibited states in higher sensitivity and higher creative ideation are consistent with accounts suggesting that creative inspirations emerge in states of lower cognitive inhibition due to frontal lobe de-activation, with greater disinhibition in the right hemisphere (Eysenck, 1995; Kaufman, Kornilov, et al., 2010; Martindale, 1999). High sensitive groups show differences in alerting efficiency associated with right lateralised attention networks important for global processing (Fan et al., 2005; Ivry & Robertson, 1998), and show greater (disinhibited) activity in those networks during change detection tasks (Jagiellowicz et al., 2011). Defocused and disinhibited global processing styles observed in highly sensitive people may enhance creativity by facilitating access to remotely associated content in conceptual memory (for a review, see Förster & Dannenberg, 2010; Mendelsohn, 1976) which may be useful during global problem restructuring and creative insight processes (Schooler & Melcher,

1995), and divergent thinking (Förster & Dannenberg, 2010; Friedman et al., 2003; Friedman & Förster, 2001), which is essential for creative ideation (Runco et al., 2000-2001).

In Chapter 6 we move beyond the implications of sensitivity on attention to investigate the possibility that neurosensitivity may have implications for conscious and unconscious cognitive processes associated with learning and memory. Findings show that higher sensitivity is associated with greater ability to incidentally acquire and exploit covariations in the environment, and greater awareness of unconscious memories. Higher awareness of unconscious memories observed in higher sensitivity is consistent with greater awareness in the sensitive personality (Aron & Aron, 1997; Aron et al., 2012; Evans & Rothbart, 2007) and states of cognitive disinhibition that facilitate creative ideation through greater awareness of unconsciously generated associations (Carson, 2011; Martindale, 1999).

Latent inhibition (LI) is a mechanism which inhibits irrelevant information from consciousness in order to help prioritize information relevant to survival, and to protect limited attention resources from information overload (Lubow, 2005a; Lubow & Gewirtz, 1995). Based on evidence that higher creative achievement and intelligence (Carson et al., 2003; Chirila & Feldman, 2012; Keri, 2011; Schmajuk et al., 2009), and higher openness (Peterson & Carson, 2000) are associated with low LI, and behavioural profiles of the sensitive temperament suggest low LI (Eby, 2015; Martindale et al., 1996; Rizzo-Sierra et al., 2011), the overall hypothesis was that LI will be lower in high than low sensitive groups. We found no support for the hypothesis that high sensitivity would be associated with low latent inhibition, and no evidence that LI is a unifying mechanism in the relationship between sensitivity, openness and creativity.

## **A New Sensitivity Framework for the Sensitive, Open Creator**

In order to understand the implications that sensitivity may have for cognition and creativity, it is important to integrate existing knowledge of sensitivity into a single framework that can be used to explain the findings from this project.

**A synthesis of existing sensitivity frameworks.** Each of the major sensitivity frameworks reviewed in Chapter 1 (Aron & Aron, 1997; Evans & Rothbart, 2007; Pluess, 2015a) and others not reviewed that include sensitivity dimensions, including the Regulatory Theory of Temperament (Strelau & Zawadzki, 1993) and the Functional Ensemble of Temperament framework (Trofimova & Robbins, 2016), share a core definition of sensitivity as reactivity to environmental stimuli (for a review, see Bridges & Schendan, 2018). In these theories, reactivity thresholds are defined by the interaction of the magnitude of both trait sensitivity and environmental stimuli with the emotional-motivational systems, which trigger appropriate, adaptive behaviours (i.e., approach or avoid) depending on the valence of the affective response to the environment (Moore & Depue, 2016). Overstimulation, often experienced by highly sensitive people (Aron & Aron, 1997) resulting in part from neuronal disinhibition (Homborg et al., 2016), can lead to positive or negative-affect-related life outcomes, depending on the developmental context (Pluess, 2015a; Trofimova, 2018). It is the perceived capacity of an organism that determines the affective valence associated with overstimulation, and whether to explore, or withdraw (Trofimova, 2018). If the needs of an organism outweigh capacity, then negative affect is experienced, however if capacity is sufficient, then positive affect is experienced. This is particularly important in how an organism responds to novelty, a core component of creativity (Runco & Jaeger, 2012), because novelty presents potential for unpreparedness, uncertainty and incapacity to cope. Overstimulation from novelty experienced

by high sensitives may signal lack of capacity to handle situations, resulting in behavioural inhibition and withdrawal (Aron & Aron, 1997). However, this tendency is mediated by developmental experiences, since positive, enriching environments develop tendencies towards positive-affect, openness and resilience (Pluess, 2015b), which are important for creativity (Csikszentmihalyi, 1996). The capacity to cope with overstimulation may have important implications for creative cognition, since capacity determines whether the upregulation of alerting and orienting attention systems (i.e., higher orienting sensitivity) are used for a) coping with negative affect, or b) challenging existing capacities that enable further sensation (or information) seeking (Bridges & Schendan, 2018; Trofimova, 2018), which itself is part of the creative process (Wallas, 1926).

**The Sensitive, Open Creator (SOC) model.** Based on the literature review in Chapter 1, the findings of this project, and the integration of sensitivity frameworks from the previous section, a new model of the sensitive creator emerges, abbreviated to the SOC model. As noted above, and in Chapter 1, the mechanisms underlying sensitivity are the same in either positive or negative-affect-related sensitivity (i.e., disinhibition, attention networks), but how those mechanisms are expressed is determined by the developmental context. Thus, the sensitivity  $\times$  environment interaction determines the sensitive, open creator.

*SOC.* Developmental environments interacting with sensitivity mechanisms shape the outcome of the sensitive temperament. Positive, enriching environments interact with attention mechanisms (i.e., orienting sensitivity) to promote resilience to overstimulation experienced with novelty, and develop a Big-5 personality profile with high openness, and normal to low neuroticism. This profile is most strongly related to vantage sensitivity (Pluess, 2015b) and most adequately captured by measures of orienting sensitivity (Aron & Aron, 1997; Evans & Rothbart,

2007). Conversely, trauma and adversity during childhood decrease the capacity to cope and thus decrease resilience to novelty, and develop a Big-5 personality profile with high neuroticism and introversion. This profile is most strongly related to the negative-affect-related sensitivity and most adequately captured with the HSPS or ATQ-NA component.

It is vantage sensitivity that offers the greatest potential for creativity, because vantage sensitivity enables greater tolerances for disinhibited thought, exploration, curiosity and openness towards novelty that are important for creativity (e.g., Chapter 2). The SOC model is consistent with the cognitive disinhibition and hemispheric asymmetry hypotheses of creativity (Kaufman, Kornilov, et al., 2010; Martindale, 1999) which posit a strong role of disinhibition and right-hemisphere exogenous attention processes in the creative process. Further, one of the paradoxical characteristics of the creative person is the openness to experience life, but with the resilience so as not to suffer (Csikszentmihalyi, 1996). The resilience and openness of vantage sensitivity offers a greater range of stimulation and information extraction that play an important role in the creative process (Lubart, 2001; Wallas, 1926).

**Empirical support for the Sensitive, Open Creator model.** The new SOC framework developed in this chapter assumes identical sensitivity mechanisms across sensitivity subtypes, but differential expression of those mechanisms depending on the developmental context. Using the evidence accumulated from this project, the validity of the new SOC framework can be verified.

We present new evidence that creativity is a vantage sensitivity associated with positive-affect-related dimensions of OS, distinct from, but interactive with, the Big-Five openness trait, and has consequences for cognition that may facilitate creativity. This general summary of evidence provides support for the SOC model overall. However, the SOC model suggests that upregulation of attention orienting mechanisms are characteristic of all sensitive people, and that highly sensitive

people with vantage sensitivity should display different orienting than those with high negative-affect-related sensitivity. Interestingly, we find no evidence that sensitivity is characterized by differences in orienting attention mechanisms, as would be expected considering definitions of OS and evidence linking higher sensitivity to greater activation of orienting brain networks in change detection tasks (Jagiellowicz et al., 2011). Instead, positive-affect-related sensitivity is characterized by attention states related to global, defocused and disinhibited processing styles that predict creativity (Chapter 4). Further, high orienting sensitivity is characterized by stronger inhibition-of-return, an exogenous attention process, however no evidence was found to suggest exogenous IOR mechanisms associated with orienting sensitivity are implicated in higher creativity by any creativity measure used in this study.

Chapter 6 provides some evidence that sensitivity has positive implications for unconscious learning and memory processes implicated in the sensitive, open creator, where the ease of memory retrieval of implicit sequences observed in high sensitivity may be grounded in cognitive disinhibition and sensitive exogenous orienting mechanisms explained in the SOC model. This is feasible because low threshold memories could be more easily accessed in consciousness through mechanisms of disinhibition and exogenous orienting, as in the attention to memory model (Cabeza et al., 2011). Sensitivity of attention, learning and memory processes and greater awareness during disinhibited states are beneficial for the creative process, because novel associations developed during preparation and incubation stages may only emerge as creative insights with a level of sensitivity and awareness that is receptive to those unconsciously generated ideas (Wallas, 1926). Chapter 7 provides no evidence that low latent inhibition is characteristic of the sensitive, open creator. As low latent inhibition is proposed to be a form of cognitive disinhibition that enables awareness of more information for creative association (Carson, 2011), this evidence contradicts



the idea that cognitive disinhibition may be one mechanism defining the sensitive, open creator defined in the SOC model. However, the within-subjects design weaknesses in Chapter 7 means that further work is required.

In summary, this thesis proposes a new framework showing the sensitive, open creator emerging as a result of positive enriching environments that promote resilience to novelty (Bridges & Schendan, 2018). The SOC model assumes that underlying sensitivity mechanisms (e.g., disinhibition, sensitive exogenous orienting) are shared across subtypes of sensitivity, but are expressed differently depending on their interaction with the developmental context. This framework and supporting evidence is consistent with existing theories that explain individual differences in creativity originate from cognitive disinhibition and right hemisphere mechanisms (Kaufman, Kornilov, et al., 2010; Martindale, 1999).

### **Future Directions**

This thesis provides a broad analysis of the cognitive implications of sensitivity, and how they relate to diverse creative processes, although more work is required. Finding an LI effect with sensitivity groups was important to understand whether dopamine variation provides an explanatory mechanism underlying sensitivity, openness, creativity and DMN function. The failure to reject the null hypothesis may be the result of choosing an LI task using within-subjects design (see Chapter 7). Thus, future work can address these problems by considering the use of between-subjects LI designs for exploring LI in the sensitive creator.

This project focuses on the impact of positive-affect-related sensitivity on creativity, as these vantage sensitivity benefits are not observed in negative-affect-related sensitivity. Thus, an interesting question emerges whether interventions in high negative-affect-related sensitivity can be used to develop vantage sensitivities, such as creativity, thus helping highly sensitive

individuals with traumatic backgrounds achieve more positive life outcomes and realise their creative potential. This would provide greater understanding how deterministic environmental interactions are on the outcomes of sensitivity, and whether neurosensitivity creates conditions of greater dynamism in the brain, such that, under favourable conditions, disproportionate susceptibility results in greater recovery following trauma, and ultimately the reformation of cognition and personality.

Finally, future work should consider the nature of sensitivity based on the theory and empirical findings presented in this thesis as a motivation for updating current measures of environmental sensitivity. We show the HSPS is multidimensional, consistent with previous work (Evans & Rothbart, 2007; Smolewska et al., 2006), and recent literature identifying multiple factors of sensory-processing sensitivity that the HSPS was not designed to capture (Aron et al., 2012). The different dimensions of sensitivity have different outcomes for creative cognition, but scales differ in how those sub-dimensions are measured. We suggest that current sensitivity measures are updated to provide a balanced ratio of NA and OS sensitivity dimension, whilst also taking into consideration the nature of sensitivity in relation the Big-Five personality traits, especially openness. Until new measures are created, we recommend the use of long-form personality measures when employing measures of sensitivity in order to observe pure sensitivity effects beyond what is observed with personality measures, whilst also providing the opportunity to consider how sensitivity may interact with personality, as observed in the sensitive, open creator (see Chapter 2). These suggestions could help future work address the limitations of this study regarding the use of short-form measures in making solid conclusions regarding the relationship between temperament, personality and creativity. Without evidence that sensitivity provides additional, valuable information beyond what is provided by long-form Big-Five

measures, then measures of temperament, including the HSPS and ATQ-OS, may struggle to find their relevance in a personality-oriented literature.

### **Concluding Remarks**

Western society tends to favour “tough warriors and kings” in families, social groups, and the workplace, such that sensitivity is perceived as flaw, and is thus penalized (Aron, 1999). In this thesis, we demonstrate the uniqueness of the sensitive person should be valued, and nurtured throughout child development and adulthood, because through positive, enriching environments, vantage sensitivities emerge that are beneficial for the self, and for the cultural advancement of humanity through cognitive innovation.

# Appendices



## Appendix A

### Theories and Perspectives on Creativity

Operational definitions of creativity are necessary for experimental work. Definitions of “creativity” are both ambiguous, and elusive with an abundance of definitions in the past literature offering little consistency regarding what creativity actually means (Plucker et al., 2004; Runco & Jaeger, 2012; Simonton, 2012a). However, the general consensus, or “standard definition” defines creativity as something demanding both originality and effectiveness (Runco & Jaeger, 2012; cf. Simonton, 2016). Originality is essential for something to be novel, whereas effectiveness determines the usefulness of an idea or product. Neither term alone is sufficient for creativity to emerge. For example, original ideas can stem from psychopathology, or randomness, but may lack value. On the other hand, effective or useful ideas lacking originality are not new, and so already exist. The relationship between the two terms has not been thoroughly investigated, however evidence suggests that novelty may be considered as more important than usefulness (Diedrich, Benedek, Jauk, & Neubauer, 2015). Others argue the standard definition conflates originality with “surprise” (i.e., nonobvious), as something can be novel and effective, but not surprising (Simonton, 2012b). The three-criterion definition of creativity is a modified version of the criteria used by the United States Patent Office to determine whether an invention can be patent protected, wherein an invention must be new, useful and nonobvious (surprising) to be accepted (see <https://www.uspto.gov/help/patent-help>). In the three-criterion definition of creativity (Simonton, 2012b), originality, value and surprise are scaled variables (valued between 0 to 1) which are multiplicative, rather than additive, wherein ideas lacking originality, value or surprise cannot amount to creativity. Hence there is

one way for an idea to be maximally creative, and multiple ways in which an idea can lack creativity.

The standard definition of creativity is a core component of many theories of creativity, for example, those exploring how novelty and effectiveness emerges as a function of product, place, process and person (for a review of the Four P's of creativity, see Kozbelt, Beghetto, & Runco, 2010). Creativity theories can take an objective approach by looking at works or products regarded as creative, the environments, or places, in which creativity may flourish, or may seek to understand the subjective experience of the individual by exploring the creative process or person. Cognitive theories of creativity place emphasis on the creative process and person and the idea that normative human cognition forms the basis of creative capacity (Smith et al., 1995). Such theories can focus on universal cognitive capacities (e.g., attention, memory) to explain the creative process, or how those processes relate to creative potential (Kozbelt et al., 2010). Creative cognition approaches (e.g., Finke et al., 1992; Smith et al., 1995) recognize individual differences and a continuity between products or ideas that emerge at different levels of creative magnitude, arguing that cognitive processes involved in uncommon “Big-C” creative achievements of eminent Genius creators, whose influential works stand the test of time, are not fundamentally different to those involved in the subjective, everyday “little-c” creativity normally distributed throughout the general population (for sub-divisions of little-c, see Kaufman & Beghetto, 2009).

To address the aims of this thesis, we take an individual differences and creative cognition approach in order to understand how temperament, personality, and cognition relate to creativity at various magnitudes. The three-criterion definition of creativity is adopted because additional criterion of surprise may be dependent on personality types associated with individual

differences in cognition (Peterson & Carson, 2000; Simonton, 2012b). Nested within the three-criteria definition is the widely accepted standard definition of creativity (Runco & Jaeger, 2012), which is useful because this allows cross-comparison across the greatest number of studies, and also because this operationalization allows for objective measures of novelty and effectiveness, using scoring and ratings, and holistic approaches using judges to evaluate the perceived creativity of a given product or idea (Diedrich et al., 2015). One problem emerging with the standard definition of creativity is that socio-cultural influences are not explicitly defined. Confluence or “systems” approaches (Csikszentmihalyi, 1996; Plucker et al., 2004; Sternberg & Lubart, 1991, 1999) explain creativity very broadly as “the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context.” (Plucker et al., 2004, p. 90). No “creative trait” exists, and one is not creative unless their work is judged as important by an appropriate field of expertise. Confluence theories acknowledge the standard definition of creativity (Runco & Jaeger, 2012), but go further with the additional role of social context, thus explaining why works of great artists of the past (e.g., van Gogh, J. S. Bach) were not considered as creative until years later; contemporaries in the field did not judge their work as important at the time. This helps to dispel debilitating myths of creativity that people are born creative/uncreative but provides the means by which aptitude (e.g., skill-set in a domain) and environment as dynamic characteristics allow for individual differences acquired through experience (Plucker et al., 2004). Further, the social context criterion suggests that creativity is relative, and thus creative magnitude exists on a continuum (cf. Csikszentmihalyi, 1996), i.e., a child’s drawing can be considered as creative relative to the context of their home environment, rather than all works in the entirety of human history. Confluence theories thus provide a holistic



definition of creativity, and the context for exploring individual differences in the creative process and person at various magnitudes of creativity. However, the qualitative nature of many aspects of confluence models (e.g., Csikszentmihalyi, 1996) make it difficult to test hypothesis unambiguously, and the multiple, diverse levels of systems models create problems grounding experimentation in particular methodologies (Kozbelt et al., 2010), thus the three-criterion definition with nested standard definition is preferred in this thesis.

### **Creativity: Concepts and Measurement**

Different conceptualizations of creativity tend to be associated with different measurements. One important distinction to make is that between creative potential and creative achievement, as the two concepts may not actually be related (Runco, 2014). Creative potential is a normally distributed, person-oriented little-c creativity and refers to an ability to produce new and useful ideas, whereas creative achievement is a positively skewed, product-oriented dimension referring to tangible big-C achievements, such as awards, patents, or publications (Carson et al., 2005; Jauk et al., 2013; Runco, 2014). In this project, we investigate how individual differences in temperament, personality and cognition relate to both creative potential and achievement, considered as two measures on a single continuum of creative magnitude.

Psychometric approaches characterize individual differences associated with creative potential and creative achievement and have been useful in providing researchers with valid creativity measurement tools, in particular those with predictive validity and discriminant validity. Discriminant validity is of particular importance, as it indicates whether measures of creativity are distinct from other constructs, such as intelligence/IQ, thus warranting its own field of investigation (Kozbelt et al., 2010).

The term 'intelligence' can have several meanings. Intelligence can be something measured by intelligence quotient (IQ) tests, can be the entire domain of human cognitive ability, or observable behaviours or performances (Barron & Harrington, 1981). Many once believed that creative talents can be accounted for by high levels of intelligence, but the conceptualization that intelligence and creativity are the same has been considered both inadequate and detrimental to our understanding of creativity (Guilford, 1950). In the early 20<sup>th</sup> century, psychometric measures showing weak positive correlations between intelligence and creativity suggested the two constructs were not identical (for reviews, see Barron & Harrington, 1981; Batey & Furnham, 2006). Indeed, recent meta-analyses (Kim, 2005, 2008) indicate that the mean correlation coefficient between creativity test scores (including ideation and creative achievement) and intelligence are negligible ( $r \leq .174$ ). However, the relationship may be more complex than a linear correlation. Threshold theories of intelligence (Guilford, 1967) suggests a curvi-linear relationship between IQ and creativity, where the correlation between the two is moderately positive, but only up to a certain level of intellectual ability, when  $IQ < 120$  (cf. Kim, 2005; Runco & Albert, 1985, 1986). However, recent reviews conclude little or no support overall for threshold theories (Sawyer, 2010). An alternative explanation involves fractionating intelligence into separate factors, because a single IQ general ability score may be too coarse to represent multiple intelligences inherent in domain-specific abilities and achievements (Gardner, 2011b; Hampshire, Highfield, Parkin, & Owen, 2012). Indeed, longitudinal studies of intellectually talented individuals show that variable intellectual configurations of spatial, mathematical, and verbal ability partially determine creative outcomes (Kell, Lubinski, Benbow, & Steiger, 2013). When combined, three cognitive measures of mathematical, verbal and spatial ability account for 18.4% in creative achievements across several domains, consistent with

correlations between IQ and creative ideation and achievement (Kim, 2005, 2008). However, spatial abilities, required for spatial judgement and mental imagery (Gardner, 2011b), incrementally predict 7.6% of variance in creative achievements over verbal and mathematical abilities, which themselves account for 10.8% variance together (Kell et al., 2013). This evidence is consistent with the idea that general indicators of intelligence are not adequately capturing the individual variations in multiple cognitive abilities which have unique relations with relevant domain-specific creative potential and/or achievements.

### **Measurement of Creative Potential**

Creative potential can be observed by measuring divergent thinking (DT) abilities. It was Guilford (1950) who linked divergent production (i.e., thinking) to creative potential. DT has been defined as the ability to give a diversity of responses to open-ended problems and, through ideation, this often leads to originality, a central feature of creativity (Runco & Acar, 2012). In the Structure of Intellect theory (Guilford, 1967), divergent thinking was defined as a major operation of the human intellect and something distinct from convergent thinking. Convergent thinking typically leads to a conventional, correct response to a clearly defined question and is more often associated with intelligence (Gardner, 2011a). Although seemingly distinct, divergent and convergent thinking are thought to exist on a single divergence-convergence continuum (Eysenck, 1993; Runco, 2014), in which both styles of thinking are important for creativity (Cropley, 2006). Indicators of divergent thinking measure cognitive abilities such as fluency, flexibility, originality and elaboration, and whilst not considered the same as creative thinking, can be seen as an indicator of creative potential (Runco, 2014).

Divergent thinking tasks generally have adequate reliability (Runco & Acar, 2012), although reliability estimates of originality differ across verbal and figural DT tasks and may be

over-inflated due to high correlations with the fluency factor. Fluency contaminates originality in verbal DT tasks (Hocevar, 1979b), but originality is reliable in figural DT tasks at certain levels of achievement (Runco & Albert, 1985). To counteract this problem, alternative scoring methods which control for the effect of fluency on originality are used (e.g., Benedek et al., 2013).

The discriminant validity of DT tasks is questionable. For example, Wallach and Kogan (1965) show the relation between DT and intelligence depends on the task instructions given. That is, under test-like conditions, the discriminant validity is affected by low correlations between IQ and DT, but under game-like conditions there is no correlation. A re-analysis of Wallach and Kogan's (1965) data suggests that, whilst fluency is strongly related to originality, it also has a significantly modest positive relation with IQ (Silvia, 2008). The discriminant validity of DT measures is further complicated by the divergence-convergence continuum which suggests overlap between the two processes of divergent and convergent thinking (Runco & Acar, 2012).

Regarding convergent validity, DT tasks are positively correlated with various indexes of creative ability (for reviews, see Barron & Harrington, 1981; Batey & Furnham, 2006), including measures of real world creative achievements ( $r = .47$ ) across several domains (Carson et al., 2005), although a recent meta-analysis by Kim (2008) suggest the correlation is weak ( $r = .216$ ). Scores in DT tasks have also been shown to be three times better than intelligence measures at predicting creative achievements (Plucker, 1999). However, the predictive validity of DT tasks is unstable and influenced by testing conditions (e.g., game-like vs. test-like, timed vs. untimed, instructions to "be creative" vs. generic instructions) and may also be susceptible to training effects (Plucker & Makel, 2010).

While this seems to cast doubt on the validity of DT tasks as measures of creative potential, the use of creative achievements as criterion measures of divergent thinking have been criticised. Runco et al. (2000-2001) argue that DT is a measure of ideation and the potential for problem solving, rather than past creative achievements. As such, DT tests are improperly validated when past creative accomplishments are used as the criterion measure, which may explain the moderate or low predictive validity found in studies of divergent thinking (Kim, 2008). The evidence of discriminant, convergent and predictive validity presented is therefore adequate considering DT tasks are not considered as synonymous with creativity, but rather as indicators of ideation and creative potential (Runco & Acar, 2012).

The Runco Ideational Behavioural Scale (RIBS; (Runco et al., 2000-2001) was designed to address the need for a more appropriate criterion measure when looking at the predictive validity of divergent thinking/creative ideation. The RIBS is based on the notion that ideas are products of original, divergent and creative thinking. The scale is a self-report measure of overt behaviours that clearly reflect an individual's use, appreciation and skill with ideation. The RIBS shows good reliability (Cronbach's  $\alpha > .9$ ) and discriminant validity with estimates of intellectual ability and other self-report measures of creative thinking. The short form RIBS-S has good reliability (Cronbach's  $\alpha = .84$ ) and correlates highly with long form RIBS-V ( $r = .94$ ). In addition, RIBS-V offers no incremental predictive validity over RIBS-S, which itself shows concurrent validity with measures of creative activities and achievement, accounting for 22% variance in scores. RIBS is positively correlated with openness to experience (Batey et al., 2010; Von Stumm et al., 2011), the Big-Five trait with the strongest relationship with creativity (Feist, 2010; Kaufman et al., 2016; Runco, 2014; Sawyer, 2012) and shows weak positive correlations with DT tasks (Ames & Runco, 2005; Plucker et al., 2006; Von Stumm et al., 2011). Weak

correlations between DT and RIBS are consistent with the ambiguous construct validity of the RIBS (Runco et al., 2000-2001), which suggests creative potential may be more adequately captured with both objective divergent thinking tasks and subjective, self-report measures of creative ideation.

Together, DT tasks and self-report creative ideation can be used to measure creative potential, the little-c creativity differing only in magnitude to Big-C creativity (Finke et al., 1992; Smith et al., 1995). As both measures capture little-c creativity, they are useful indicators of everyday creative ideation, problem-solving and insight which is normally distributed throughout the population (Kaufman & Beghetto, 2009) making any findings highly generalizable. Whilst DT tasks and creative ideation are not synonymous with creativity (Runco, 2014), they will help fulfil the aims of this thesis by providing insights into specific cognitive processes responsible for any magnitude of creative achievement (Finke et al., 1992; Smith et al., 1995) which may differ across temperament and personality traits.

### **Measurement of Creative Achievement**

The best predictor of creative behavior may be past creative behavior (Colangelo et al., 1992). For example, greater engagement in everyday creative activities (e.g., wrote a poem, designed a piece of music, made a present) predicts real world creative achievement (Jauk et al., 2014b). Self-report measures of creative achievement can focus on creative behavior, achievement and self-perception (for reviews, see Plucker & Makel, 2010; Silvia et al., 2012). The Creative Achievements Questionnaire (CAQ; Carson et al., 2005) is a recent self-report measure that captures creative achievements across 10 domains, focusing on observable but uncommon big-C creative accomplishments. The CAQ has adequate reliability and validity; the internal consistency of the CAQ is high ( $\alpha = .96$ ); the predictive validity is evident with CAQ

scores strongly positively correlated with ratings of creative products ( $r = .59$ ); convergent validity is demonstrated through moderate positive correlations with divergent thinking tests ( $r = .47$ ) and openness to experience ( $r = .33$ ), a personality trait associated with higher creativity (Carson et al., 2005). The CAQ also covaries well with other measures of self-reported creative behavior, achievement and self-perception (Silvia et al., 2012). CAQ has discriminant validity but shows weak positive correlations with IQ (Carson et al., 2005; Keri, 2011). The focus on capturing big-C creativity means that CAQ scores are severely skewed with most scores piling up at the lower end of the scale and relatively few scores indicating significant creative achievements. CAQ scores also tend to be over-dispersed with variances larger than the mean resulting from excessive zero scores. The nature of CAQ distributions mean that researchers should pay attention to the assumptions of common statistical analysis techniques, and use robust methods or data transformations where appropriate (Silvia et al., 2012).

The Creative Behaviour Inventory (Hocevar, 1979a) also measures big-C creative accomplishments and was recently revised to capture little-c accomplishments, although the revision lacks domain specificity (Silvia et al., 2012). Other self-report measures are available to assess everyday little-c creativity, including the Revised Creative Domain Questionnaire (CDQ-R; (Kaufman, Waterstreet, et al., 2010). The CDQ-R is a reliable measure of the subjective belief people have about their own level of creativity across four domains which combined have moderate positive correlations with openness to experience ( $r = .43$ ). It is recommended that in order to gain accurate measurement of big-C and little-c creative achievements, as many measures as possible should be employed, given the time and resources available (Silvia et al., 2012).

## Neurobiological Theories of Creative Cognition

Neurobiological theories of creativity aim to explain how the brain achieves creative cognition and what biological and neurogenetic factors are involved. Colin Martindale's work builds on early theories of creativity including primary process cognition (Kris, 1952), associative hierarchies (Mednick, 1962), and defocused attention (Mendelsohn, 1976), which themselves are thought to be cognitive "building blocks" in the overall creative process (Kaufman, Kornilov, et al., 2010; Martindale, 1999). Martindale (1999) theorized that creative inspirations are the result of a combined mental state in which attention is defocused, thought is associative and a large number of mental representations are simultaneously activated, occurring together in a state of cognitive disinhibition with comparatively more right than left hemisphere activation. Specifically, highly creative people have lower cognitive inhibition due to frontal lobe de-activation, with greater disinhibition in the right hemisphere, but only when engaged in the creative process. Martindale (1999) thus integrates the cognitive disinhibition and hemispheric asymmetry hypotheses of creativity under one theory.

The cognitive disinhibition and hemispheric asymmetry hypothesis are major theories of creativity and Martindale's (1999) insights (see also Kaufman, Kornilov, et al., 2010) are consistent with evidence linking anti-correlated active and default mode brain networks (Buckner et al., 2008) responsible for internally and externally directed cognitions (Dixon et al., 2014) with the creative process. For example, studies link cognitive disinhibition (Takeuchi et al., 2011), increased grey matter volume (Jauk et al., 2015), density (Fink et al., 2013) and function (Fink et al., 2012) of areas of the DMN with divergent thinking. Also, variation in ideational originality on divergent thinking tasks, such as the Abbreviated Torrance Test for Adults (ATTA; Goff & Torrance, 2002), is related to structural variation and activity in the



DMN and the basal ganglia dopaminergic system (Andreasen, 2005; Jauk et al., 2015; Takeuchi et al., 2011; Takeuchi et al., 2010). Kris (1952) presciently argued that ability to switch between internally and externally directed cognition, or to “regress in the service of the ego”, was a defining characteristic of highly creative individuals (Martindale, 1999). Indeed, neuroimaging studies have also shown that creative thought processes, including spontaneous mind wandering, benefit from the dynamic interaction of the DMN with frontoparietal control and dorsal attention/salience networks (Beaty et al., 2015; Beaty, Benedek, et al., 2016; Fox et al., 2015) which are also involved with internally and externally directed cognition (Dixon et al., 2014).

The default mode network includes the strongly right lateralized ventral exogenous orienting attention network which aligns attention either with incoming bottom-up processing of sensory stimulation (Corbetta & Shulman, 2002; Posner & Rothbart, 2007) or explicit memory (Binder & Desai, 2011; Buckner et al., 2008), as described in the attention to memory model (Cabeza et al., 2011; Daselaar et al., 2013). Attention to memory provides a mechanism for the detection and orientation towards internally generated novelty. Consistent with the hemispheric asymmetry hypothesis of creativity, the ventral network includes a temporal parietal junction (TPJ) component that is strongly right lateralized and implicated in global hierarchical pattern perception, and orienting attention to global versus local levels of processing (Ivry & Robertson, 1998). The hemispheric asymmetry hypothesis of creativity capitalizes on the idea that the right hemisphere is dominant for global processing, whereas the left hemisphere is dominant for local processing (Ivry & Robertson, 1998). Global processing has a role in holistic, diffuse, insight and integrative creative processes, whereas local processing has a role in analytical creative processes (Kaufman, Kornilov, et al., 2010). Creativity may benefit from a global processing style as a broader more global attentional scope may facilitate access to remotely associated

content in conceptual memory (for a review, see Förster & Dannenberg, 2010; Mendelsohn, 1976) which may be useful during global problem restructuring and creative insight processes (Schooler & Melcher, 1995), cognitive flexibility (Nijstad et al., 2010) and divergent thinking (Förster & Dannenberg, 2010; Friedman et al., 2003; Friedman & Förster, 2001).

Building on Martindale's integration, Kaufman, Kornilov, et al. (2010) suggests that cognitive disinhibition and hemispheric asymmetry reflect two separate stages of creative cognition. Cognitive disinhibition facilitates internally directed thought processes, such as day-dreaming, fantasy and ideation, and the exogenous attention network monitors, detects and signals the mind to orient towards novelty. Martindale's work is of particular interest because of the role of that cortical arousal plays in creative cognition. In a series of experiments, Martindale found that highly creative people were over-sensitive and more physiologically reactive than people low in creativity (for a review, see Martindale, 1999). Sensitivity is considered as an enduring higher-order personality or temperament trait anecdotally linked to higher creativity (Aron & Aron, 1997) and may reflect individual differences in universal cognitive functions of attention (Evans & Rothbart, 2007), and cognition more generally through the mechanism of sensory-processing sensitivity (Aron & Aron, 1997), or neurosensitivity (Pluess, 2015a). The relationship between creativity and cognitive processes that should reflect sensitive neural processing have not been investigated prior to this project, thus we address these major gaps in understanding individual differences in creativity by focusing on sensitivity and its cognitive implications, providing a possible neurocognitive basis for creativity

### **Temperament, Personality and Creativity**

Openness to experience is the factor among the Big-Five personality dimensions that has the strongest relationship with creativity (Feist, 2010; Kaufman et al., 2016; Runco, 2014;

Sawyer, 2012). Openness to experience is a universal dimension of personality characterized as "the breadth, depth, and permeability of consciousness, and in the recurrent need to enlarge and examine experience" (McCrae & Costa, 1997, p. 826), the tendency to be imaginative, curious, perceptive, creative, artistic, thoughtful and intellectual, all subsumed under the overarching explanation of cognitive exploration (DeYoung et al., 2011). Openness is commonly referred to as Openness/Intellect, although openness and intellect labels capture core but distinct elements of the trait, referring to engagement with perceptual and abstract information, respectively (DeYoung et al., 2011). The inclusion of intelligence within the Openness/Intellect factor is controversial, as is the suggestion that creativity is synonymous with Openness/Intellect (DeYoung, 2013; Johnson, 1994). Indeed, self-reports and ratings of openness are weakly positively correlated with divergent thinking (McCrae, 1987; Silvia, Nusbaum, Berg, Martin, & O'Connor, 2009), and moderately positively so with real world creative achievements (Carson et al., 2005; Hirsh & Peterson, 2008; Silvia, Kaufman, Reiter-Palmon, & Wigert, 2011; Silvia et al., 2009), although the correlations are not strong enough to support the inclusion of creativity into the more general Openness/Intellect factor as discriminant validity is suggested ( $r_s < .85$ ; Kline, 2015). Openness, however, may interact with a range of other creative characteristics, including autonomy, unconventionality and sensitivity (Runco, 2014); notably, sensitivity is defined in this thesis as sensory-processing sensitivity (Aron & Aron, 1997), or neurosensitivity (Pluess, 2015a), an environmental sensitivity framework explaining the basis for individual differences in the responsiveness to environmental factors.

The neurotransmitter dopamine is thought to play a key role in the biological substrate of both Openness/Intellect (DeYoung et al., 2002, 2005) and Extraversion (Depue & Collins, 1999). Indeed, variation in both D4 (DRD4) and catechol-O-methyltransferase (COMT) genes involved

with prefrontal dopaminergic function predict Openness/Intellect, and DRD4 also predicts Extraversion (DeYoung et al., 2011). Extraversion is a behavioural manifestation of exploratory, approach behaviours and reward seeking and is considered distinct from the more cerebral cognitive exploration of Openness/Intellect. However, the commonalities can be explained by the influence of dopamine forming a biological substrate for both openness and extraversion (DeYoung et al., 2011; DeYoung et al., 2002, 2005). These traits, and other Big-Five traits converge to form higher-order meta-traits of “plasticity” and “stability”, provide a missing link with personality development by defining core constitutional mechanisms which “grow” personality through social and environmental interaction (DeYoung et al., 2002, 2005; Digman, 1997; see also Evans & Rothbart, 2009; Rothbart, 2007). The higher-order trait of plasticity is loaded with extraversion and openness traits related to dopamine variation. The higher-order trait of stability is loaded with neuroticism (reversed), conscientiousness, agreeableness and has a basis in the serotonergic system related to emotional government and motivation regulation, and controlled, organized behavior needed for achieving various goals (DeYoung et al., 2006). Plasticity and stability are related to, but have opposing effects (pos/neg relationship, respectively), on measures of divergent thinking (Silvia et al., 2008) and creative achievement (Silvia et al., 2009).

The personality approach to creativity looks for stable characteristics (i.e., traits) associated with creativity. Personality approaches cannot aim to explain creativity in terms of a single trait because creativity exists in a constellation of traits interacting with cognitive and environmental factors that may facilitate creativity (Runco, 2014). The personality of the creative person is complex, and paradoxical. For example, creative people may have higher levels of intelligence but the naivety to question, the extraversion to exchange ideas but the solitary

introversion to work, the ability to engage in imagination/fantasy but keep ideas rooted in reality, and an openness and sensitivity to experience consciousness but a resilience so as not to suffer (Csikszentmihalyi, 1996). A quantitative meta-analysis shows the most creative individuals are more likely to be higher in openness, introversion, impulsivity, and display higher sensitivity to internal affective states compared with less creative people, but this differs between artists and scientists (Feist, 1998); see also Batey and Furnham (2006).

In spite of the evidence, the existence of a relationship between creativity and personality traits remains controversial (Necka & Hlawacz, 2013; Sawyer, 2012), and the scarce links between personality and creativity may relate to something not explicitly captured by psychometric personality assessments; the notion of temperament (Necka & Hlawacz, 2013). It is widely believed that temperaments are the foundations of global personality traits (Aron et al., 2012; Davis, Panksepp, & Normansell, 2003; McCrae et al., 2000). Temperament refers to ones “real nature” (Necka & Hlawacz, 2013), the early emerging basic dispositions in activity, affectivity, attention and self-regulation that are product of a complex interaction of genetic, biological and environmental factors which influence the development of personality (Goldsmith et al., 1987; Rothbart et al., 2000; Shiner et al., 2012b; Zentner & Bates, 2008). However, there is some debate regarding the distinction between personality and temperament. Some argue that temperament and personality are different ways of describing the same trait separated only by the age of manifestation, with temperament relating to childhood and personality relating to adulthood. In this view, individual differences in temperament are subsumed under the Big-Five traits (Shiner et al., 2012b; Shiner & DeYoung, 2013a). An alternative view is that temperament and personality remain separable in that personality includes specific cognitions, beliefs and values, whereas temperament includes dispositional cognitive processes (e.g., effortful/orienting

attention), which may influence, but do not include, specific cognitions themselves (Evans & Rothbart, 2007). Temperament has received little attention in creativity literature and is not explicitly included in recent influential reviews and books (Hennessey & Amabile, 2010; Kaufman & Sternberg, 2010; Sawyer, 2012) and models of the creative personality (Feist, 2010), though it is indirectly included by acknowledging genetic and epigenetic influences on creativity and has recently been identified as a major critical gap in creativity research (Feist, 2010; Necka & Hlawacz, 2013; Runco, 2014). In this project, the terms “temperament” and “higher-order personality trait” are synonymous.



## Appendix B







Table B1

*Non-Parametric Spearman's Rho ( $r_s$ ) correlations between creativity, personality and higher-order factors (N=288)*

	<i>Creativity</i>			<i>Higher-order factors</i>						<i>Big-Five</i>							
	CAQ	RIBS_S	ATTA	HSPS	HSP-OS	HSP-NA	HSP-OS/AS	HSP-EOE	HSP-LST	ATQ-OS	ATQ-NA	ATQ-EC	ATQ-ES	BFI-O	BFI-C	BFI-E	BFI-A
<i>Creativity</i>																	
CAQ	-																
RIBS_S	.343***	-															
ATTA	.153**	.279***	-														
<i>Higher-order factors</i>																	
HSPS	.247***	.300***	.083	-													
HSP-OS	.410***	.489***	.201***	.673***	-												
HSP-NA	.153**	.186**	.019	.956***	.463***	-											
HSP-OS	.459***	.555***	.236***	.553***	.897***	.347***	-										
HSP-EOE	.093	.171**	-.007	.882***	.487***	.906***	.292***	-									
HSP-LST	.185**	.187***	.072	.892***	.477***	.895***	.380***	.693***	-								
ATQ-OS	.442***	.561***	.201***	.351***	.584***	.215***	.664***	.166**	.227***	-							
ATQ-NA	.072	.095	.031	.704***	.324***	.751***	.175**	.708***	.671***	.166**	-						
ATQ-EC	-.112	-.177**	.105	-.297***	-.203***	-.295***	-.159**	-.295***	-.238***	-.170**	-.284***	-					
ATQ-ES	.100	.064	-.075	-.402***	-.130*	-.444***	-.042	-.332***	-.457***	.004	-.479***	.036	-				
<i>Big-Five</i>																	
BFI-O	.456***	.530***	.253***	.231***	.533***	.093	.620***	.023	.146*	.603***	-.012	-.080	.008	-			
BFI-C	-.109	-.117*	.084	-.064	-.122*	-.045	-.103	-.016	-.066	-.129*	-.067	.639***	.065	-.144*	-		
BFI-E	.123*	.103	.046	-.386***	-.178**	-.420***	-.012	-.420***	-.378***	.008	-.404***	.122*	.573***	.110	.129*	-	
BFI-A	.010	-.058	-.158**	-.100	.021	-.131*	-.004	-.021	-.149*	.008	-.157**	.118*	.254***	-.020	.241***	.090	-
BFI-N	.086	.113	.083	.675***	.365***	.689***	.219***	.716***	.559***	.200***	.703***	-.250***	-.417***	.020	-.134*	-.460***	-.131*

*Note.* 2-tailed significance: \*  $p < 0.05$  level, \*\*  $p < .01$ , \*\*\*  $p < .001$ . CAQ = Creative Achievement Questionnaire; RIBS = Runco Ideational Behaviour Scale; ATTA = Abbreviated Torrance Test for Adults; HSPS = Highly-Sensitive Person Scale (full); HSP-OS = orienting-sensitivity factor of the HSPS; HSP-NA = negative-affect factor of the HSPS; HSP-OS = orienting/ aesthetic sensitivity factor of the HSPS; HSP-EOE = ease of excitation factor of the HSPS; HSP-LST = low sensory threshold factor of the HSPS; ATQ-OS = orienting-sensitivity factor of the ATQ; ATQ-NA = negative-affect factor of the ATQ; ATQ-EC = effortful-control factor of the ATQ; ATQ-ES = extraversion/surgency factor of the ATQ; BFI-O = openness factor of the Big-Five Inventory (BFI); BFI-C = conscientiousness factor of the BFI; BFI-E = extraversion factor of the BFI; BFI-A = agreeableness factor of the BFI; BFI-N = neuroticism factor of the Big-Five Inventory.



## Appendix C



## Individual Differences in CDT Performance

**HSPS, HSPS sub factors and CDT reaction time correlations.** The HSPS weakly positively correlates with location and size RTs. HSP-NA weakly positively correlates with location RTs, and size RTs ( $p=.051$ ). HSP-EOE has a weak positive correlation with overall, location and size RTs. HSP-LST has a weak positive correlation with location RTs ( $p=.052$ ). HSP-OS or HSP-AES does not correlate with any CDT RTs, thus only NA factors of the HSPS correlate with the CDT RT performance. Note, the correlation between HSPS (N,E) residuals and location or size RTs was not significant, suggesting the HSPS correlations with location and size RTs are specific to NA.

**Big-Five personality and CDT reaction time correlations.** BFI-E (introversion inverted) weakly negatively correlates with location RTs. BFI-N weakly positively correlates with location and size RTs. No other correlations with personality variables emerged.

**Dichotomous samples in HSPS.** Using one-way ANOVA, we explored group differences in CDT performance by HSPS, as well as HSPS (E, N) residuals. Note, no effects for accuracy were observed and thus not reported further.

**ANOVA comparison of CDT condition across HSPS groups.** Group differences expected with location RTs based on correlation data (see Table 4.2) were not found ( $p=.101$ ). However, the ANOVA revealed a significant group difference in size RTs between HSPS groups,  $F(1,95)=4.22$ ,  $p=.043$ , where HSPs ( $M=13623$ ms, 95% CI [11990, 15256]) were slower when detecting size changes than non-HSP groups ( $M=11677$ ms, 95% CI [10645, 12709]). However, the group difference becomes non-significant when negative affect (BFI-E and BFI-N) is partialled out of HSPS scores,  $F(1,95)=1.01$ ,  $p=.317$ . Additional effects were found when negative affect was partialled out of HSPS scores. The ANOVA revealed a significant group difference in colour RTs between HSPS (E, N) residual groups,  $F(1,95)=5.11$ ,  $p=.026$ . For the HSPS (E, N) residuals group analysis, HSP groups

( $M=23301\text{ms}$ , 95% CI [18558, 28044]) were slower when detecting colour changes than non-HSP groups ( $M=18420\text{ms}$ , 95% CI [16402, 20439]).

**Minor versus major group comparison.** A mixed ANOVA compared HSPS group differences in the detection of minor versus major changes, using within-groups factor of difference (major RTs, minor RTs) and between-groups factor of group (HSPs, non-HSPs). No between-groups effects were found for HSPS groups ( $p=.361$ ), and difference RTs did not interact with HSPS groups ( $p=.917$ ). For the HSPS (E, N) residual groups, the ANOVA revealed a marginally significant difference  $\times$  group interaction,  $F(1,95)=3.44$ ,  $p=.067$ ,  $\eta_p^2=.035$ , where HSP groups ( $M=23301\text{ms}$ , 95% CI [18558, 28044]) show slower RTs than non-HSP groups ( $M=18420\text{ms}$ , 95% CI [16402, 20439]) for minor,  $t(95)=2.26$ ,  $p=.026$ , but not major RTs ( $p>.05$ ). A significant between-groups effect was found,  $F(1,95)=6.31$ ,  $p=.014$ ,  $\eta_p^2=.062$ , where HSP groups were slower ( $M=16668\text{ms}$ , 95% CI [14774, 18562]) than non-HSPs ( $M=13804\text{ms}$ , 95% CI [12567, 15042]) overall.

**Dichotomous samples in ATQ-OS.** The same dichotomy used for the HSPS was applied to the ATQ-OS. The high sensitive (HSP) ATQ-OS groups consisted of  $n=29$  participants and the low-sensitive (non-HSP) ATQ-OS groups consisted of  $n=68$  participants. The HSP group ( $M=5.37$ , 95% CI [5.26, 5.49]) have significantly higher ratings on the ATQ-OS,  $t(95)=10.82$ ,  $p<.001$ , than non-HSP groups ( $M=4.18$ , 95% CI [4.05, 4.31]). Using a one-way ANOVA, we explored group differences in CDT performance by ATQ-OS, as well as ATQ-OS (E, N) residuals. However, no group differences were found by condition (colour, size, presence, location) for ATQ-OS or ATQ-OS (E, N) groups. A mixed ANOVA compared HSP groups differences in performance detecting minor versus major changes, using within-groups factor of difference (major RTs, minor RTs) and between-groups factor of ATQ-OS group (HSPs, non-HSPs). However, no between-groups effects ( $ps>.407$ ) or interactions ( $ps>.317$ ) were found for ATQ-OS, or ATQ-OS (E, N).



### **Hierarchical multiple regression: Sensitivity, personality and change detection as predictors of creative ideation.**

**HSPS.** The hierarchical multiple regression models 1-4 were repeated using HSPS in place of ATQ-OS. Model 1 accounting for 5.2% variance shows that minor versus major RTs account for unique variance in RIBS scores. Model 2 accounts for 4.8 % variance and does not provide a better fit for the data ( $p=.424$ ). In Model 2, HSPS does not account for unique variance and minor versus major RT performance remains significant. Model 3 accounts for 5.8% but does not give a significantly better fit for the data ( $p=.234$ ), and neither BFI-N, BFI-E or HSPS account for unique variance, nor do they reduce the capacity of minor versus major RTs to account for unique variance. Model 4 accounts for 26.7% and gives a significantly better fit for the data. In Model 4, only BFI-O accounts for unique variance in RIBS scores. The interpretation of the main results does not change depending on whether HSPS is treated as dichotomous, see Table 4.3 and Table 4.4. The final regression equation for Model 4:  $\hat{Y}(\text{RIBS}) = .593 + .121(\text{minor vs. major RT}) + .043(\text{HSPS}) + .127(\text{BFI-N}) + .158(\text{BFI-E}) + .487(\text{BFI-O})$ .

### **Summary of Individual Differences in CDT Performance**

The HSPS does not exhibit this pattern of correlations as the ATQ-OS. The HSPS and NA-related factors of the HSPS, ATQ (NA and ES inverted introversion), and personality (i.e., BFI-N and BFI-E inverted) all positively correlate with location and size RTs suggesting an NA factor relates to performance in those CDT conditions, which show no association with creativity.

When HSPS is treated as dichotomous variable, group differences reflect the correlations found with size RT (see Table 4.2) with HSPs performing more slowly than non-HSPs. However, when negative affect is partialled out using BFI-E and BFI-N, the group

differences in size RT disappear, further suggesting this correlation and group difference relates to NA. Additional findings emerged when controlling NA in HSPS scores, showing HSPs to have slower colour RTs than non-HSPs. This finding may reflect orienting sensitivity (OS) factors within the HSPS (Evans & Rothbart, 2007, 2008; Smolewska et al., 2006). However, when ATQ-OS is treated as dichotomous or when NA is controlled, no group differences emerge, probably because dichotomous splits reduce power to detect effects (MacCallum et al., 2002).

Table C4.1

Mean, standard deviation (SD) and lower (LCI) and upper (UCI) 95% confidence intervals

for creativity, temperament, personality variables (N=97)

	Mean	SD	LCI	UCI
<i>Creativity</i>				
CAQ	8.32	6.62	7.08	9.66
RIBS	2.85	.53	2.75	2.96
ATTA	68.09	8.62	66.2	69.79
<i>Temperament</i>				
HSPS	4.21	.76	4.06	4.36
HSPS-OS	4.43	.81	4.28	4.59
HSPS-NA	4.15	.97	3.96	4.34
HSPS-AES	4.37	.84	4.21	4.53
HSPS-EOE	4.67	.9	4.5	4.85
HSPS-LST	3.27	1.16	3.05	3.51
ATQ-OS	4.53	.74	4.39	4.68
ATQ-EC	3.98	.75	3.83	4.14
ATQ-NA	4.2	.69	4.07	4.34
ATQ-ES	4.67	.83	4.51	4.83
<i>Personality</i>				
BFI-O	3.16	.57	3.05	3.28
BFI-C	3.46	.68	3.33	3.6
BFI-E	3.22	.78	3.07	3.38
BFI-A	3.81	.66	3.68	3.94
BFI-N	3.36	.8	3.21	3.52

Note: CAQ=Creative Achievement Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults; HSPS=Highly Sensitive Person Scale (full); HSP-OS=orienting sensitivity factor of the HSPS; HSP-NA=negative affect factor of the HSPS; HSP-AES=aesthetic sensitivity factor of the HSPS; HSP-EOE=ease of excitation factor of the HSPS; HSP-LST=low sensory threshold factor of the HSPS; ATQ-OS=orienting sensitivity factor of the ATQ; ATQ-EC=effortful control factor of the ATQ; ATQ-NA=negative affect factor of the ATQ; ATQ-ES=extraversion/surgency factor of the ATQ; BFI-O=openness to experience factor of the Big Five Inventory (BFI); BFI-C=conscientiousness factor of the BFI; BFI-E=extraversion factor of the BFI; BFI-A=agreeableness factor of the BFI; BFI-N=neuroticism factor of the Big Five Inventory.

Table C4.2

*Spearman's correlations for creativity, temperament and personality measures and the reaction time and error rates for the CDT task*

	Reaction Times						Error Rates					
	Overall	Location	Presence	Color	Size	Mi-Ma	Overall	Location	Presence	Color	Size	Mi-Ma
<i>Creativity</i>												
CAQ	.057	-.005	-.106	.135	.019	.154	-.024	.009	-.017	-.003	.018	.028
RIBS	.114	.036	-.109	.204*	.091	.211*	-.007	-.06	.04	.031	-.018	.044
ATTA	.105	.015	.156	.061	.074	.042	-.076	-.196	-.088	-.041	-.089	-.005
<i>Temperament</i>												
HSPS	.185	.241*	.132	.021	.221*	-.043	-.084	-.058	-.159	-.159	.069	-.149
HSPS (E, N)	.122	.049	.089	.094	.088	.053	-.117	-.04	-.157	-.117	-.001	-.087
HSP OS	.055	.06	-.091	.051	.109	.055	-.14	-.165	-.086	-.136	-.039	-.099
HSP NA	.168	.285**	.145	-.004	.199	-.074	-.056	-.019	-.161	-.136	.081	-.134
HSP EOE	.233*	.266**	.149	.044	.273**	-.022	-.065	-.05	-.151	-.154	.061	-.161
HSP AES	.075	.018	-.025	.08	.121	.072	-.106	-.144	-.062	-.102	-.002	-.059
HSP LST	.021	.198	.005	-.04	.001	-.067	-.081	-.013	-.158	-.119	.044	-.104
ATQ OS	.111	.009	-.125	.202*	.003	.215*	-.086	-.088	-.116	-.049	-.101	-.012
ATQ OS (E, N)	.087	-.025	-.128	.194	-.03	.211*	-.076	-.071	-.105	-.026	-.114	.011
ATQ EC	-.19	-.126	-.181	-.119	-.074	-.071	.149	.157	.041	.176	.104	.168
ATQ NA	-.02	.281**	.027	-.143	.001	-.155	.034	.081	-.042	-.008	.08	-.029
ATQ ES	-.01	-.266**	.023	.088	-.018	.107	-.008	-.048	.073	.033	-.052	.046
<i>Personality</i>												
BFI O	-.012	-.098	-.193	.1	-.045	.158	-.132	-.008	-.002	-.144	-.032	-.146
BFI C	-.126	-.109	-.171	-.03	-.053	.005	.121	.136	-.068	.178	.06	.191
BFI E	-.015	-.221*	.043	.124	-.115	.148	.024	-.027	.077	.113	-.021	.132
BFI A	-.087	-.104	-.165	-.064	.005	-.025	-.059	.031	-.04	-.037	-.107	-.053
BFI N	.135	.241*	.044	-.012	.239*	-.034	-.056	-.065	-.095	-.142	.083	-.143

*Note.* \*  $p < 0.05$  level, \*\*  $p < .01$  (2-tailed). *Note:* CAQ=Creative Achievement Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults; HSPS=Highly Sensitive Person Scale (full); HSPS (E, N)=HSPS with BFI extraversion and neuroticism partialled out; HSP OS=orienting sensitivity factor of the HSPS; HSP NA=negative affect factor of the HSPS; HSP AES=aesthetic sensitivity factor of the HSPS; HSP EOE=ease of excitation factor of the HSPS; HSP LST=low sensory threshold factor of the HSPS; ATQ-OS=orienting sensitivity factor of the ATQ; ATQ OS (E, N)=ATQ OS with BFI extraversion and neuroticism partialled out; ATQ-EC=effortful control factor of the ATQ; ATQ-NA=negative affect factor of the ATQ; ATQ-ES=extraversion/surgency factor of the ATQ; BFI O=openness to experience factor of the Big Five Inventory (BFI); BFI C=conscientiousness factor of the BFI; BFI E=extraversion factor of the BFI; BFI A=agreeableness factor of the BFI; BFI N=neuroticism factor of the Big Five

Table C4.3

*Hierarchical multiple regression – Continuous sensitivity, personality and change detection as predictors of creative ideation*

	RIBS					
	ATQ-OS			HSPS		
	Beta	SE	<i>t</i>	Beta	SE	<i>t</i>
<b>Model 1</b>						
Mi-Ma RT	.248	0	2.5*	.248	0	2.5*
<b>Model 2</b>						
Mi-Ma RT	.159	0	1.68	.248	0	2.49*
Sensitivity	.386	.068	4.08***	.08	.069	.8
<b>Model 3</b>						
Mi-Ma RT	.121	0	1.249	.209	0	2.04*
Sensitivity	.407	.069	4.246***	.218	.099	1.52
BFI-N	.045	.081	.369	-.026	.1	-.17
BFI-E	.181	.083	1.476	.205	.093	1.49
<b>Model 4</b>						
Mi-Ma RT	.077	0	.862	.121	0	1.32
Sensitivity	.258	.068	2.739**	.043	.09	.33
BFI-N	.111	.074	.989	.127	.091	.93
BFI-E	.168	.076	1.491	.158	.082	1.3
BFI-O	.402	.087	4.321***	.487	.087	5.23***
<b>Model fit</b>						
	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>
Model 1	6.23*	1,95	.052	6.23*	1,95	.052
Model 2	16.66***	1,94	.186	.65	1,94	.048
Model 3	1.37	2,92	.192	1.47	2,92	.058
Model 4	18.67***	1,91	.322	27.33***	1,91	.267

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; Mi-Ma RT=Major – Minor RT; ATQ-OS=orienting sensitivity factor of the ATQ; HSPS=Highly Sensitive Person Scale (full); BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory; *F*=*f*-change in model fit; *df*=degrees of freedom; *R*<sup>2</sup>=adjusted *R*<sup>2</sup>.

Table C4.4

*Hierarchical Multiple Regression – Dichotomous sensitivity, personality and change detection as predictors of creative ideation*

	RIBS					
	ATQ-OS			HSPS		
	Beta	SE	<i>t</i>	Beta	SE	<i>t</i>
<b>Model 1</b>						
Mi-Ma RT	.248	0	2.5*	.248	0	2.5*
<b>Model 2</b>						
Mi-Ma RT	.207	0	2.26*	.248	0	2.48*
Sensitivity	.402	.105	4.4***	.053	.115	.53
<b>Model 3</b>						
Mi-Ma RT	.174	0	1.85*	.215	0	2.09*
Sensitivity	.413	.106	4.49***	.104	.134	.9
BFI-N	.068	.079	.57	.059	.09	.43
BFI-E	.176	.082	1.45	.177	.093	1.29
<b>Model 4</b>						
Mi-Ma RT	.114	0	1.29	.121	0	1.32
Sensitivity	.258	.107	2.78**	.021	.118	.2
BFI-N	.124	.074	1.12	.144	.08	1.2
BFI-E	.164	.076	1.46	.153	.081	1.27
BFI-O	.388	.088	4.1***	.492	.085	5.4***
<b>Model fit</b>						
	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>
Model 1	6.23*	1,95	.052	6.23*	1,95	.052
Model 2	19.34***	1,94	.205	.28	1,94	.044
Model 3	1.16	2,92	.208	.89	2,92	.042
Model 4	16.78***	1,91	.324	29.17***	1,91	.267

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; Mi-Ma RT=Major – Minor RT; ATQ-OS=orienting sensitivity factor of the ATQ; HSPS=Highly Sensitive Person Scale (full); BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory; *F*=*f*-change in model fit; *df*=degrees of freedom; *R*<sup>2</sup>=adjusted *R*<sup>2</sup>.



**Appendix D**





### The Attention Network Task: Overall Performance

Table 4.1 shows the mean reaction times (RT) and error rates (ER) with standard deviations for flanker conditions across cue types. To replicate Fan et al. (2002) we carried out a 4 (cue condition: no cue, centre cue, double cue, spatial/direction cue)  $\times$  3 (flanker type: neutral, congruent, incongruent) factor cue  $\times$  flanker ANOVA using RT and ER data. Note, spatial and direction cues are synonymous terms used to describe endogenously cued targets. Sphericity was not assumed for any factors or interactions so Greenhouse-Geisser correction was applied.

Table D4.1

*Mean and standard deviations in parenthesis for reaction times (msec) and error rates (%) for cue (columns) and flanker (row) types*

	Cue Type								Overall	
	None		Centre		Double		Direction			
<i>Reaction times</i>										
Congruent	584	(81)	539	(78)	537	(75)	500	(72)	540	(77)
Incongruent	656	(87)	643	(90)	629	(88)	567	(85)	624	(88)
Neutral	571	(75)	535	(78)	530	(72)	493	(71)	532	(74)
Overall	604	(81)	572	(82)	565	(78)	520	(76)	565	(79)
<i>Error rates</i>										
Congruent	0.45	(.14)	0.92	(.24)	0.58	(.17)	0.59	(.25)	.63	(.2)
Incongruent	3.16	(.47)	5.94	(.88)	5.15	(.84)	2.13	(.40)	4.1	(.65)
Neutral	1.03	(.20)	1.03	(.22)	0.58	(.14)	0.37	(.14)	.75	(.18)
Overall	1.55	(.27)	2.63	(.45)	2.10	(.38)	1.03	(.26)	1.83	(.34)

The ANOVA revealed significant main effects of cue and flanker conditions, as well as cue  $\times$  flanker interactions, see Table 4.2 for summary of repeated-measures ANOVA.

Table D4.2

*Repeated measures ANOVA looking at main effects and interactions for cue and flanker conditions for reaction times and error rates*

	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>Reaction times</i>			
Cue	392.43***	3,258	.803
Flanker	693.19***	2,151	.878
Cue × Flanker	21.51***	5,454	.183
<i>Error rates</i>			
Cue	15.86***	3,242	.142
Flanker	48.46***	1,104	.335
Cue × Flanker	9.14***	3,321	.087

*Note.* \*\*\*  $p < .001$ . *F*=ANOVA *F*-ratio; *df*=degrees of freedom;  $\eta_p^2$ =partial eta squared

For visualization of main effects for cue and flanker, see Figure 4.1 and Figure 4.2 for RTs and ERs, respectively. For visualization of the interaction, see Figure 4.3 (main text) for both RTs and ERs. Post-hoc tests using the Bonferroni correction examined main effects for RT and ER between conditions for each factor. Simple contrasts were used to explore the nature of the interactions, where “no cue” and neutral flanker conditions were selected as baseline categories for cue and flanker factors, respectively.

**Main effects for reaction times.** Post-hoc tests using the Bonferroni correction revealed that all mean RTs across cue conditions were significantly different from each other ( $ps < .01$ ) and from baseline no cue conditions ( $ps < .001$ ). The largest differences in mean RTs is found between the spatial orienting ( $M=520\text{ms}$ , 95% CI [505, 535]) and no cue condition ( $M=604\text{ms}$ , 95% CI [588,619]) and the smallest mean difference is found between centre ( $M=572\text{ms}$ , 95% CI [556, 588]) and double ( $M=565\text{ms}$ , 95% CI [550, 581]) alerting cues, see Figure 4.1.

All mean RTs across flanker conditions were significantly different from each other ( $ps < .001$ ) and from baseline neutral flanker conditions ( $ps < .001$ ). The largest differences in RTs

is found between incongruent ( $M=624\text{ms}$ , 95% CI [607, 641]) and neutral ( $M=532\text{ms}$ , 95% CI [517, 546]) flankers and the smallest difference is found between congruent ( $M=540\text{ms}$ , 95% CI [525, 555]) and neutral ( $M=532\text{ms}$ , 95% CI [517, 546]) flankers, see Figure 4.3.

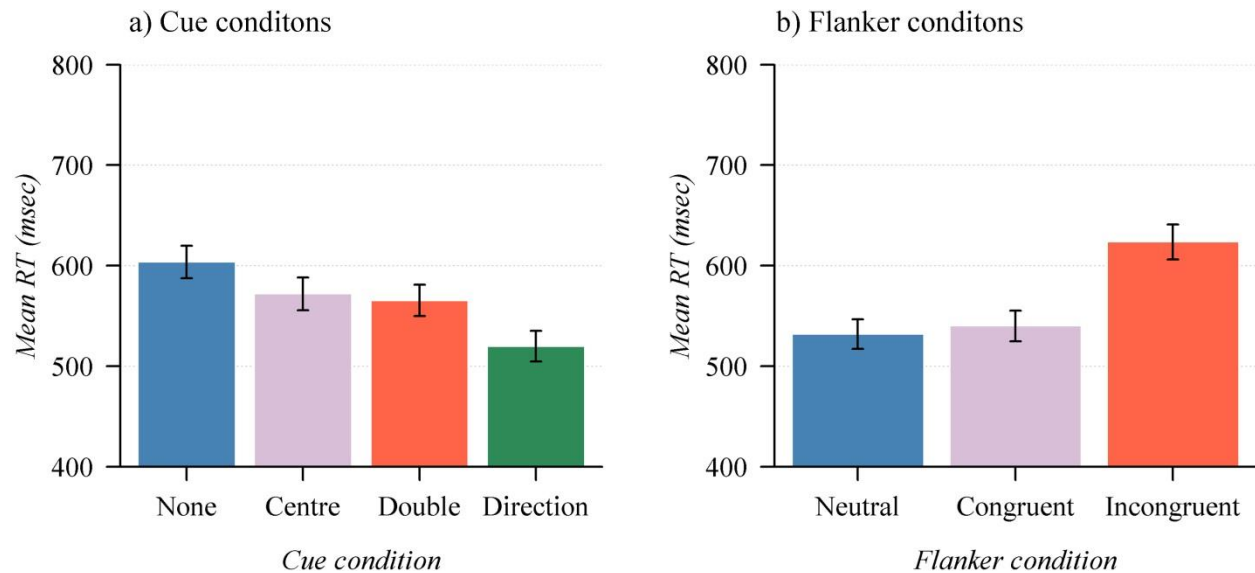


Figure D4.1. Mean RTs with 95% confidence intervals for a) cue conditions and b) flanker conditions.

**Main effects for error rates.** Post-hoc tests using the Bonferroni correction revealed that mean ER across cue conditions were significantly different between centre cues and spatial cues ( $p < .001$ ), and double cues and spatial cues ( $p < .001$ ). All conditions were significantly different from baseline no cue conditions ( $p < .05$ ). The largest difference in ER was observed between centre ( $M=2.63\%$ , 95% CI [1.95, 3.31]) and direction cues ( $M=1.03\%$ , 95% CI [.65, 1.41]) and the smallest difference is observed between centre ( $M=2.63\%$ , 95% CI [1.95, 3.31]) and double alerting cues ( $M=2.1\%$ , 95% CI [1.47, 2.74]), see Figure 4.2.

Mean ER across flanker conditions were significantly different between incongruent and congruent flankers, and incongruent and neutral flankers ( $p < .001$ ), but not between congruent and neutral flankers ( $p = .931$ ). The largest differences in ER was found between incongruent

( $M=4.1\%$ , 95% CI [3.03, 5.17]) and congruent flankers ( $M=.63\%$ , 95% CI [.38, .89]), and the smallest difference was found between congruent and neutral flankers ( $M=.75$ , 95% CI [.51, 1.0]), see Figure 4.2.

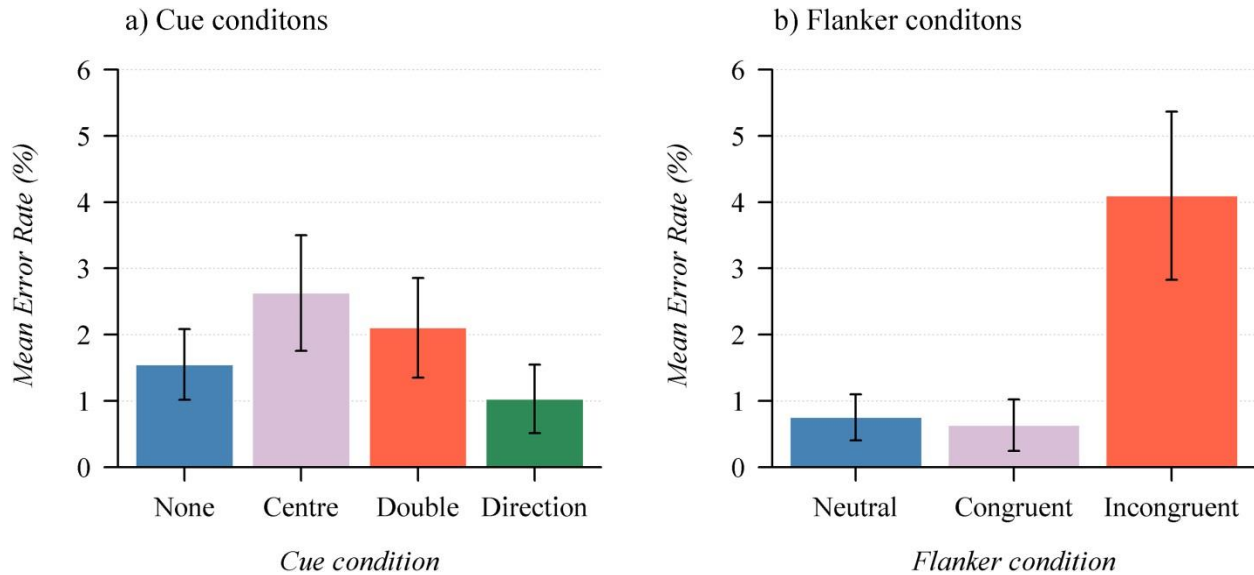


Figure D4.2. Mean error rate (%) with 95% confidence intervals for a) cue conditions and b) flanker conditions.

**Cue × flanker interactions for reaction times.** The cue × flanker interaction was significant (see Table 4.2). Simple contrasts revealed that effects of centre cue (vs. no cue) on targets with incongruent (vs. neutral) flankers are significant,  $F(1,96)=21.67$ ,  $p<.001$ ,  $\eta_p.^2=.184$ . Table 4.1 and Figure 4.5 (main text) show the RT differences between targets with neutral and incongruent flankers are larger for centre (108msec) versus no cue (85msec) conditions. This effect shows that alerting centre cues modulate the incongruency effect. Specifically, when alerting centre cues precede a target with incongruent (vs. neutral) flankers, RTs increase compared with no cue conditions, replicating Fan et al. (2002). The effects of centre cue (vs. no cue) on targets surrounded by congruent (vs. neutral) flankers was significant,  $F(1,96)=9.04$ ,  $p=.003$ ,  $\eta_p.^2=.086$ . Table 4.1 and Figure 4.5 (main text) show the RT differences between targets

with neutral and congruent flankers are larger for no cue (13ms) versus centre (4ms) conditions. Thus, alerting centre cues are associated with faster RTs for targets with congruent (vs. neutral) flankers, compared with no cue conditions. This effect was not reported by Fan et al. (2002).

The effects of double cue (vs. no cue) on targets with incongruent (vs. neutral) flankers was significant,  $F(1,96)=14.49$ ,  $p<.001$ ,  $\eta_p^2=.131$ . Table 4.1 and Figure 4.5 (main text) show the RT differences between targets with neutral and incongruent flankers are larger for double (99ms) versus no cue (85ms) conditions. This effect shows that alerting double cues modulate the incongruency effect. Specifically, when alerting double cues precede a target with incongruent (vs. neutral) flankers, RTs increase compared with no cue conditions, replicating Fan et al. (2002). The effects of double cue (vs. no cue) on congruent (vs. neutral) flankers was not significant,  $F(1,96)=3.13$ ,  $p=.08$ .

The effects of direction cue (vs. no cue) on targets with incongruent (vs. neutral) flankers was significant,  $F(1,96)=4.79$ ,  $p=.031$ ,  $\eta_p^2=.047$ . Table 4.1 and Figure 4.5 (main text) show the RT differences between targets with neutral and incongruent flankers are larger for no cue (85ms) versus direction cue conditions (74ms). This effect shows that direction cues modulate the incongruency effect. Specifically, when direction cues precede a target with incongruent (vs. neutral) flankers, RTs decrease compared with no cue conditions. This effect was not reported by Fan et al. (2002). The effects of direction cue (vs. no cue) on congruent (vs. neutral) flankers was not significant,  $F(1,96)=3.28$ ,  $p=.073$ .

For completeness, we also used contrasts to explore differences between alerting and spatial orienting conditions. The effects of direction cues compared to centre cues,  $F(1,96)=64.42$ ,  $p <.001$ ,  $\eta_p^2=.401$ , and double cues,  $F(1,96)=40.31$ ,  $p <.001$ ,  $\eta_p^2=.296$ , on targets RTs with incongruent (vs. neutral) flankers were significant. When alerting cues precede a

target with incongruent (vs. neutral) flankers, RTs increase compared with direction cue conditions. The RT effects of direction cue (vs. centre or double cue) on congruent (vs. neutral) flankers were not significant ( $p > .469$ ).

**Cue × flanker interactions for error rates.** The cue × flanker interaction was significant (see Table 4.2). Simple contrasts revealed that the effects of centre cue (vs. no cue) on targets with incongruent (vs. neutral) flankers was significant,  $F(1,96)=11.87$ ,  $p < .001$ ,  $\eta_p^2=.110$ . Table 4.1 and Figure 4.5 (main text) show ER differences between targets with neutral and incongruent flankers are larger for centre (4.91%) versus no cue (2.13%) conditions. This effect shows that alerting centre cues modulate the incongruency effect. Specifically, when alerting centre cues precede a target with incongruent (vs. neutral) flankers, ERs increase compared with no cue conditions. The effects of centre cue (vs. no cue) on targets surrounded by congruent (vs. neutral) flankers was not significant ( $p=.247$ ).

The effects of double cue (vs. no cue) on targets with incongruent (vs. neutral) flankers was significant,  $F(1,96)=11.58$ ,  $p < .001$ ,  $\eta_p^2=.108$ . Table 4.1 and Figure 4.5 (main text) show the error rate differences between targets with neutral and incongruent flankers are larger for double (4.57%) versus no cue (2.13%) conditions. This effect shows that alerting double cues modulate the incongruency effect. Specifically, when alerting double cues precede a target with incongruent (vs. neutral) flankers, ERs increase compared with no cue conditions. The effects of double cue (vs. no cue) on congruent (vs. neutral) flankers was significant,  $F(1,96)=4.04$ ,  $p=.047$ ,  $\eta_p^2=.04$ . Table 4.1 and Figure 4.5 (main text) show the error rate differences between targets with neutral and congruent flankers are larger for no cue (.58%) vs double (0%) conditions. This small effect is found because alerting double cues show no change in ER between targets with congruent and neutral flankers, whereas no cue conditions show higher errors in neutral (vs.

congruent) flanker conditions.

The effects of direction cue (vs. no cue) on targets with incongruent (vs. neutral) flankers was not significant ( $p=.457$ ). The effects of direction cue (vs. no cue) on congruent (vs. neutral) flankers was significant,  $F(1,96)=6.41$ ,  $p=.013$ ,  $\eta_p^2=.063$ . Table 4.1 and Figure 4.5 (main text) show the error rate differences between targets with neutral and congruent flankers are larger for no cue (.58%) versus direction (-.22%) conditions. This effect is found because ER for no cue and direction cue conditions are not different for congruent flankers, whereas no cue conditions show higher errors in neutral flanker conditions compared with direction cues.

For completeness, we also used contrasts to explore differences between alerting and spatial orienting conditions. The effects of direction versus centre cue,  $F(1,96)=15.82$ ,  $p < .001$ ,  $\eta_p^2=.142$ , and double cues,  $F(1,96)=17.99$ ,  $p < .001$ ,  $\eta_p^2=.158$ , on targets errors with incongruent (vs. neutral) flankers were significant. When alerting cues precede a target with incongruent (vs. neutral) flankers, ERs increase compared with direction cue conditions. The effects of direction cue (vs. centre or double cue) on congruent (vs. neutral) flankers were not significant ( $ps>.303$ ).

**Summary of ANOVA for reaction times and error rates.** Overall, we see main effects of both cue and flanker for both RT and error rate data. Targets preceded by cues with spatial information have the fastest RTs and lowest ER, whereas targets preceded by warning cues with no spatial information (and no cue conditions in RT data only) have the slowest RTs and highest ER. Also, targets with incongruent flankers have the slowest RTs and highest ER overall. These findings replicate the main effects of cue and flanker for RTs and the main effects of flanker for ER found in Fan et al. (2002). However, we additionally report main effects for cues, as well as a cue  $\times$  flanker interaction with ER data. Also, we additionally report that targets with congruent flankers are processed more quickly than targets with neutral flankers, although we do not



replicate the finding that congruent conditions have lower ER than neutral conditions. For errors, the main effect of flanker is common across ANT studies, including Fan et al. (2002), however only 60% of datasets may show main effects of cue (MacLeod et al., 2010).

The interaction effects between cue and flanker type show both centre and double alerting cues modulate the incongruency effect for RTs and ERs. Specifically, when alerting cues precede targets with incongruent (vs. neutral) flankers, RTs and ERs increase compared with no cue and direction cue conditions. The RT findings provide a replication, however the error rate interaction was not previously reported by Fan et al. (2002). Indeed, only 60% of ANT studies may show the cue  $\times$  flanker interaction with error data (MacLeod et al., 2010). Further, the incongruency effect is significantly weaker for double versus centre cues,  $t(96)=2.13$ ,  $p=.036$ , for RTs, however this effect is not significant for ERs ( $p=.691$ ), suggesting warning cue differences only affect speed and not accuracy of target decisions. However, centre and double cues differ in how they interact with congruent (vs. neutral) flankers in ER, although the effect is small. Double cues, but not centre cues, have lower ER in neutral conditions compared with no cue conditions, and this difference disappears in the congruent condition. The differences found between alerting cue types suggest that they should be analyzed separately, rather than collapsed into one alerting factor, as reported previously by Fan et al. (2002). We also found that direction cues modulate the RT incongruency effect. Specifically, when direction cues precede a target with incongruent (vs. neutral) flankers, RTs decrease compared with no cue conditions. This effect was not found with ER. However, direction cues give lower ER than no cue conditions for neutral (vs. congruent) flankers. This suggests that spatial versus no cue facilitates the efficiency but not the accuracy of conflict resolution.

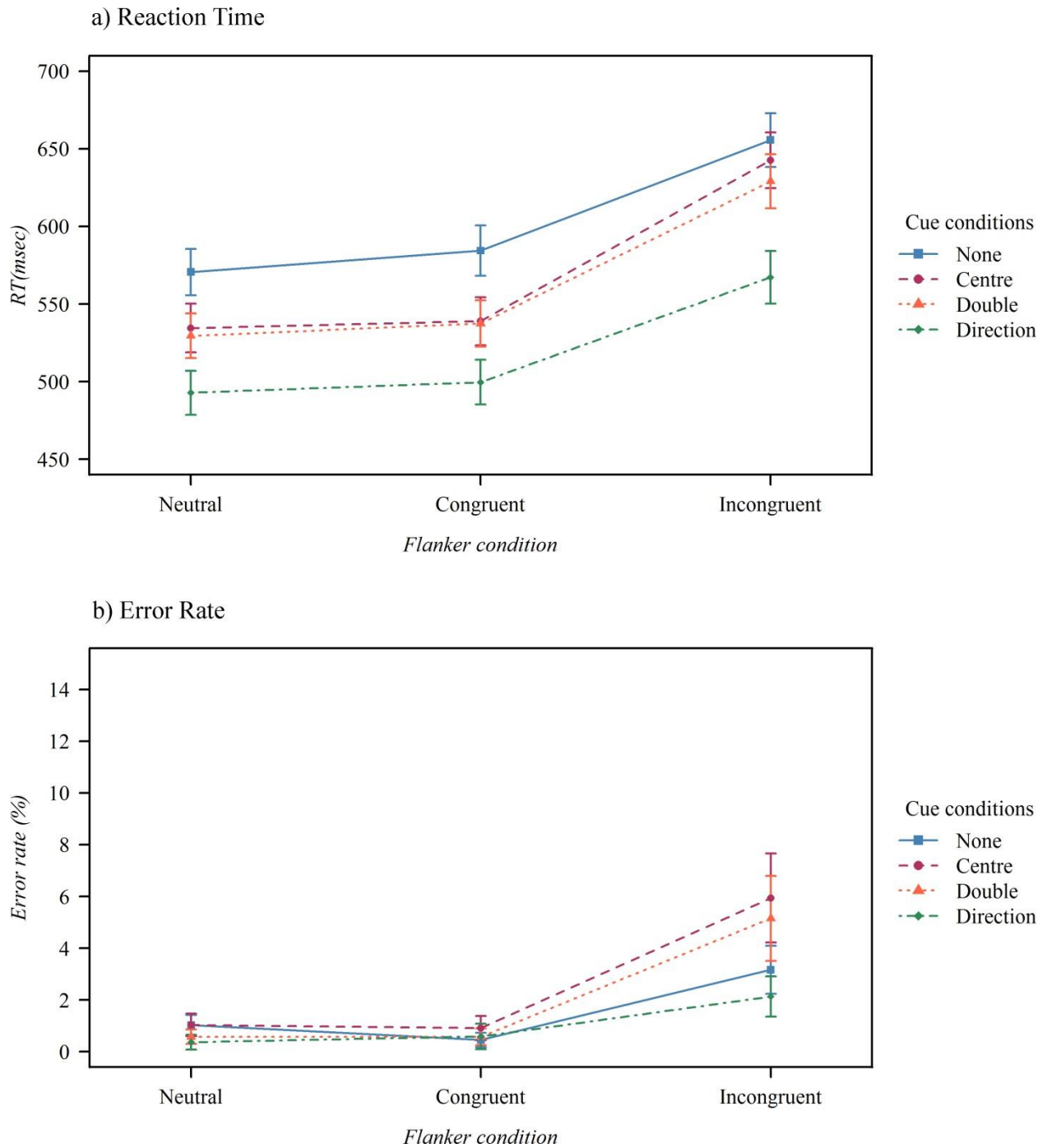


Figure D4.3. Visualization of the cue  $\times$  flanker interaction for mean a) reaction times and b) error rates. Error bars show with 95% confidence intervals.

### Alerting, Orienting and Conflict Overall Correlations

Table 4.3 shows the mean, standard deviation (SD) and correlation coefficients for the alerting, orienting and conflict variables.

Table D4.3

*Mean, standard deviation (SD) and Spearman's Rho correlation coefficients for alerting, orienting, conflict (executive function) variables for RT (msec) and error rates (%)*

	Mean	SD	Alerting	Orienting	Conflict
<i>Reaction times</i>					
Alerting	38	26	-		
Orienting	52	25	.072	-	
Conflict	84	30	.082	.113	-
Overall	565	75	.062	.219*	.291*
<i>Error rates</i>					
Alerting	-.55	2.31	-		
Orienting	1.6	2.62	-.01	-	
Conflict	3.46	4.81	-.238*	.411***	-
Overall	1.83	2.3	-.167	.553***	.819***

Note. \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ .

Fan et al. (2002) report that alerting RTs have a mean effect of 47msec and SD of 18msec, orienting RTs have a mean effect of 51msec and SD of 21msec, and conflict RTs have a mean effect of 84msec and SD of 25msec, and reported no correlations between alerting, orienting and conflict variables, although conflict correlated with overall mean RTs ( $r = .46$ ). The means and SD in Table 4.3 are very close to those reported by Fan et al. (2002) and no correlations between alerting, orienting or conflict variables were significant ( $ps > .05$ ), although orienting and conflict variables weakly positively correlate with overall mean RTs. This replicates Fan et al. (2002), and whilst the orienting correlation with overall RT is significant in this study, it is approximately the same strength correlation as that reported by Fan et al. (2002).

Alerting, orienting and conflict variables for ER are usually omitted from studies the ANT

literature, although both RTs and ER should be considered in speeded choice tasks, such as the ANT (MacLeod et al., 2010). Conflict errors are significantly weakly negatively correlated with alerting errors, and moderately positively correlated with orienting variables, similar correlations to those reported by MacLeod et al. (2010). The negative correlation between alerting and conflict errors results from the negative effects of alerting (no cue vs. double cue), which increase the number of negative signed differences, corresponding to greater differences between congruity conditions, i.e., an enhanced incongruity effect for alerting conditions, as demonstrated in the ANOVA results and Figure 4.5. The positive correlation between orienting and conflict errors does suggest an effect of spatial cue, but is that of the centre alerting cue, whereby the distance between centre and spatial cues increase due to poorer performance in the centre versus spatial condition, which correlates positively with greater incongruity effects.

Conflict and orienting also show strong and moderate positive correlations, respectively, with overall ER. Note, overall errors significantly weakly negatively correlated with overall RTs ( $r=.301, p<.01$ ) where higher errors are associated with faster reaction times, suggesting a speed-accuracy trade-off overall, but not specific to any one condition, although negative correlations between alerting and conflict RTs and ER have been reported elsewhere (e.g., MacLeod et al., 2010).

### **Individual Differences in ANT Performance by Condition**

**Mixed ANOVA for ANT performance using dichotomous HSPS.** The Mixed ANOVA with RT data revealed no significant between-groups effects ( $ps>.139$ ), 3-way ( $ps>.283$ ), or 2-way ( $ps>.250$ ) interactions for HSPS or HSPS (E, N) residual groups (see Table 4.4).

Table D4.4

*Mixed ANOVA output showing between-group effects for HSPS (and HSPS (E, N) residuals) and group interactions with cue and flanker conditions for reaction times (RT) and error rates*

	RT			Error rates		
	<i>F</i>	<i>df</i>	$\eta_p^2$	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>HSPS</i>						
Group	.07	1,95	.001	0	1,95	0
Group × Cue	1.38	3,256	.014	3.04*	3,341	.031
Group × Flanker	.52	2,149	.005	.179	1,103	.002
Group × Cue × Flanker	.84	5,447	.009	3.23*	3,323	.034
<i>HSPS (E, N) residuals</i>						
Group	2.22	1,95	.023	.04	1,95	0
Group × Cue	.05	3,255	.001	.81	3,239	.008
Group × Flanker	.02	2,150	0	.13	1,103	0
Group × Cue × Flanker	1.26	5,446	.013	.47	3,319	.005

*Note.* \*  $p < .05$ . *F*=ANOVA *F*-ratio; *df*=degrees of freedom;  $\eta_p^2$ =partial eta squared

The mixed ANOVA with error rate data revealed a significant cue × flanker × HSPS group interaction (see Table 4.4). Simple contrasts suggested that the 3-way interaction is the result of an effect of accuracy for incongruent (vs. neutral) flankers for centre cues (vs. no cue) where HSPs ( $M=4.86\%$ , 95% CI [2.0, 8.0]) have higher ER than non-HSP ( $M=1.88\%$ , 95% CI [2.2, 3.62]) groups, though the effect of group was not significant,  $F(1,95)=2.93$ ,  $p=.09$ ,  $\eta_p^2=.03$ . However, the interactions disappear with HSPS (E, N) residuals groups (see Table 4.4).

**Mixed ANOVA for ANT performance using dichotomous CAQ.** The mixed ANOVA using RT data did not reveal any significant between-groups effects ( $p=.214$ ) or significant 3-way ( $p>.943$ ) or 2-way interactions ( $ps>.105$ ). A separate mixed ANOVA using ER data did not reveal any significant between-groups effects ( $p=.421$ ) or significant 3-way ( $p>.87$ ) or 2-way interactions ( $ps>.85$ ).

**Mixed ANOVA for ANT performance using dichotomous RIBS.** The mixed ANOVA using RT data did not reveal any significant between-groups effects ( $p=.617$ ) or significant 3-way ( $p>.287$ ) or 2-way interactions ( $ps>.229$ ). A separate mixed ANOVA using ER data revealed a between-groups effect approaching significance,  $F(1,95)=3.53$ ,  $p=.063$ ,  $\eta_p^2=.036$ , where high RIBS groups ( $M=2.25\%$ , 95% CI[1.61, 2.9]) have higher ER than low RIBS groups ( $M=1.39\%$ , 95% CI[.74, 2.04]). No significant 3-way effects were found ( $p>.309$ ), and the group  $\times$  cue interaction was not significant ( $p=.409$ ). However a group  $\times$  flanker effect approached significance,  $F(1,95)=3.66$ ,  $p=.055$ ,  $\eta_p^2=.037$ . Simple contrasts show high RIBS groups have significantly greater ER for incongruent (vs. neutral) flankers compared with low RIBS groups,  $F(1,95)=4.54$ ,  $p=.036$ ,  $\eta_p^2=.046$ , but not in ERs for congruent (vs. neutral) flankers ( $p=.141$ ).

**Mixed ANOVA for ANT performance using dichotomous ATTA.** The mixed ANOVA using RT data did not reveal any significant between-groups effects ( $p=.315$ ) or significant 3-way ( $p>.36$ ) or 2-way interactions ( $ps>.23$ ). A separate mixed ANOVA using ER data did not reveal any significant between-groups effects ( $p=.635$ ) or significant 3-way ( $ps>.773$ ) or 2-way interactions ( $ps>.345$ ).

### **Individual Differences in ANT Alerting, Orienting and Conflict Efficiency**

**Creativity, temperament and personality correlations with ANT.** Correlations between creativity, temperament, personality and ANT performance across alerting, orienting, and conflict variables were analyzed, including HSPS (E, N) and ATQ-OS (E, N) residuals. See Table 4.5 for summary of correlation analysis.

Table D4.5

*Spearman's Rho correlation coefficients between creativity, temperament, and personality measures and the alerting, orienting, conflict (executive function) variables for RT (msec) and error rates (%)*

	Reaction Times				Error Rates			
	Alerting	Orienting	Conflict	Overall	Alerting	Orienting	Conflict	Overall
<i>Creativity</i>								
CAQ	-.142	.103	.139	.061	.018	-.033	.049	.05
RIBS	-.053	.009	-.041	-.082	.018	.087	.061	.112
ATTA	-.066	.028	.15	-.145	-.057	.022	.059	.123
<i>Temperament</i>								
HSPS	-.077	.054	-.108	.071	.121	-.017	-.113	-.210*
HSPS (E, N)	-.118	-.056	-.114	-.023	.125	-.037	-.039	-.113
HSPS_OS	-.157	.021	-.034	-.106	-.049	-.033	.002	-.035
HSPS_NA	-.001	.086	-.11	.131	.152	-.043	-.132	-.221*
HSPS_EOE	.032	.085	-.128	.13	.185	-.064	-.137	-.205*
HSPS_AES	-.219*	-.004	-.106	-.181	.004	.025	.039	-.021
HSPS_LST	-.072	.104	.029	.152	.084	-.088	-.211*	-.269**
ATQ_OS	-.174	.041	.045	-.135	-.222*	.075	.104	.133
ATQ-OS (E, N)	-.184	.035	.056	-.149	-.236*	.069	.109	.15
ATQ_EC	.002	-.08	.116	-.001	.016	-.009	-.003	.056
ATQ_NA	.049	.077	-.051	.141	.05	-.106	-.14	-.230*
ATQ_ES	-.079	-.003	.032	-.195	-.037	.072	.112	.261**
<i>Personality</i>								
B5_O	-.129	.001	.118	-.145	-.019	-.04	-.061	-.036
B5_C	.055	-.042	.086	-.008	.136	.001	.073	.1
B5_E	.023	-.042	.072	-.046	-.067	.03	.114	.182
B5_A	.043	.074	-.112	-.048	.017	-.071	-.128	-.095
B5_N	.068	.196	-.057	.094	.018	.015	-.119	-.198

*Note.* \*  $p < 0.05$  level, \*\*  $p < .01$  (2-tailed). *Note:* CAQ=Creative Achievement Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults; HSPS=Highly Sensitive Person Scale (full); HSPS (E, N)=full HSPS with BFI extraversion and neuroticism partialled out; HSP OS=orienting sensitivity factor of the HSPS; HSP NA=negative affect factor of the HSPS; HSP AES=aesthetic sensitivity factor of the HSPS; HSP EOE=ease of excitation factor of the HSPS; HSP LST=low sensory threshold factor of the HSPS; ATQ-OS=orienting sensitivity factor of the ATQ; ATQ OS (E, N)=ATQ OS with BFI extraversion and neuroticism partialled out; ATQ-EC=effortful control factor of the ATQ; ATQ-NA=negative affect factor of the ATQ; ATQ-ES=extraversion/surgency factor of the ATQ ; BFI O=openness to experience factor of the Big Five Inventory (BFI); BFI C=conscientiousness factor of the BFI; BFI E=extraversion factor of the BFI; BFI A=agreeableness factor of the BFI; BFI N=neuroticism factor of the Big Five Inventory.

The Spearman's correlation analysis revealed no significant correlations between personality or creativity measures for alerting, orienting, conflict or overall variables for either RT or ER. HSPS and negative affect related factors, including ATQ-NA and ATQ-ES (introversion inverted), show a significant weak negative correlation with overall ER. This correlation between HSPS and overall errors becomes non-significant with the HSPS (E, N) residual variable, suggesting this effect relates more strongly to negative affect. HSP LST significantly weakly negatively correlates with conflict errors, suggesting congruity effects are smaller with lower sensory thresholds. HSP AES is significantly weakly negatively correlated with alerting RTs, and ATQ-OS shows a similar non-significant trend ( $p=.088$ ). ATQ-OS is significantly weakly negatively correlated with alerting errors. Together with the RT effects, this suggests that higher ATQ-OS is associated with slower RTs and greater ER for double versus no cue alerting conditions. Interestingly, ATQ effortful control variable did not correlate with conflict reaction times or error rates.

#### **Individual differences in alerting and orienting by congruity.**

*Creativity.* No significant between-groups or interaction effects were found for RTs or ERs for any creativity measures, see Table 4.6.



Table D4.6

*Mixed ANOVA output showing between-group effects for creativity (CAQ, RIBS and ATTA) and group interactions with cue (centre – none, double – none, centre-direction) and flanker (congruent, incongruent) factors for reaction times (RTs) and error rates*

	RTs			Error rates		
	<i>F</i>	<i>df</i>	$\eta_p^2$	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>CAQ</i>						
Group	.51	1,95	.005	0	1,95	0
Group × Cue	.03	1,136	0	.17	1,133	.002
Group × Flanker	0	1,95	0	0	1,95	0
Group × Cue × Flanker	.04	2,147	0	.12	1,132	.001
<i>RIBS</i>						
Group	.09	1,95	.001	2.78	1,95	.028
Group × Cue	.04	1,136	0	1.54	1,134	.016
Group × Flanker	.64	1,95	.007	.82	1,95	.009
Group × Cue × Flanker	.81	2,146	.008	.15	1,132	.002
<i>ATTA</i>						
Group	.11	1,95	.001	.69	1,95	.007
Group × Cue	.07	1,136	.001	.28	1,133	.003
Group × Flanker	.53	1,95	.006	.08	1,95	.001
Group × Cue × Flanker	.24	1,148	.003	.14	1,131	.001

*Note.* \*  $p < .05$ , \*\*  $p < .01$ . *F*=ANOVA *F*-ratio; *df*=degrees of freedom;  $\eta_p^2$ =partial eta squared.

**HSPS.** No significant between-groups effects ( $ps > .56$ ) and no significant 3-way ( $ps > .29$ ) or 2-way ( $ps > .41$ ) interactions were found with RT data for any HSPS or HSPS (E, N) residuals groups, see Table 4.7.

Table D4.7

*Mixed ANOVA output showing between-group effects for HSPS, including HSPS (E, N) residuals, and group interactions with cue (centre – none, double – none, centre-direction) and flanker (congruent, incongruent) factors for reaction times (RTs) and error rates*

	RTs			Error rates		
	<i>F</i>	<i>df</i>	$\eta_p^2$	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>HSPS</i>						
Group	.22	1,95	.002	1.59	1,95	.017
Group × Cue	2.82	1,137	.029	6.97**	1,136	.068
Group × Flanker	.78	1,95	.008	1.25	1,95	.013
Group × Cue × Flanker	.32	2,147	.003	6.75**	1,128	.066
<i>HSPS (E, N) residuals</i>						
Group	.32	1,95	.003	.47	1,95	.005
Group × Cue	.03	1,136	0	.74	1,133	.008
Group × Flanker	1.12	1,95	.012	.21	1,95	.002
Group × Cue × Flanker	.97	2,148	.01	.58	1,132	.006

*Note.* \*  $p < .05$ . *F*=ANOVA *F*-ratio; *df*=degrees of freedom;  $\eta_p^2$ =partial eta squared.

The mixed ANOVA with ER data revealed a significant HSPS group × cue × flanker interaction and HSPS group × cue interaction, see Table 4.7. Figure 4.4 shows the 3-way interaction is the result of group differences in congruity effects across cues types. Non-HSP groups have higher ER for incongruent versus congruent targets following centre cues,  $t(67)=1.91, p=.061$ , double cues,  $t(67)=2.52, p=.014$ , and spatial cues,  $t(67)=2.8, p<.01$ . HSP groups have significantly higher ER for incongruent versus congruent targets following centre cues,  $t(28)=2.41, p=.023$ , and spatial cues,  $t(28)=3.07, p<.01$ , but not following double cues ( $p=.546$ ). However, the interaction is the result of greater spatial congruity effects for HSP groups versus non-HSP group,  $t(95)=2.47, p=.017$ , which shows that HSPs have more errors for incongruent versus congruent targets following centre versus orienting cues (see Figure 4.4), although Levene's test for equality of variance was violated ( $p<.001$ ), thus when equal variances between HSP groups are not assumed the effect approaches significance ( $p=.059$ ). The congruity

effect for double or centre cues does not differ between HSP groups ( $p_s > .159$ ). However, the 3-way and 2-way interactions disappear when controlling for negative affect using HSPS (E, N) residual groups as a between-groups factor in the ANOVA.

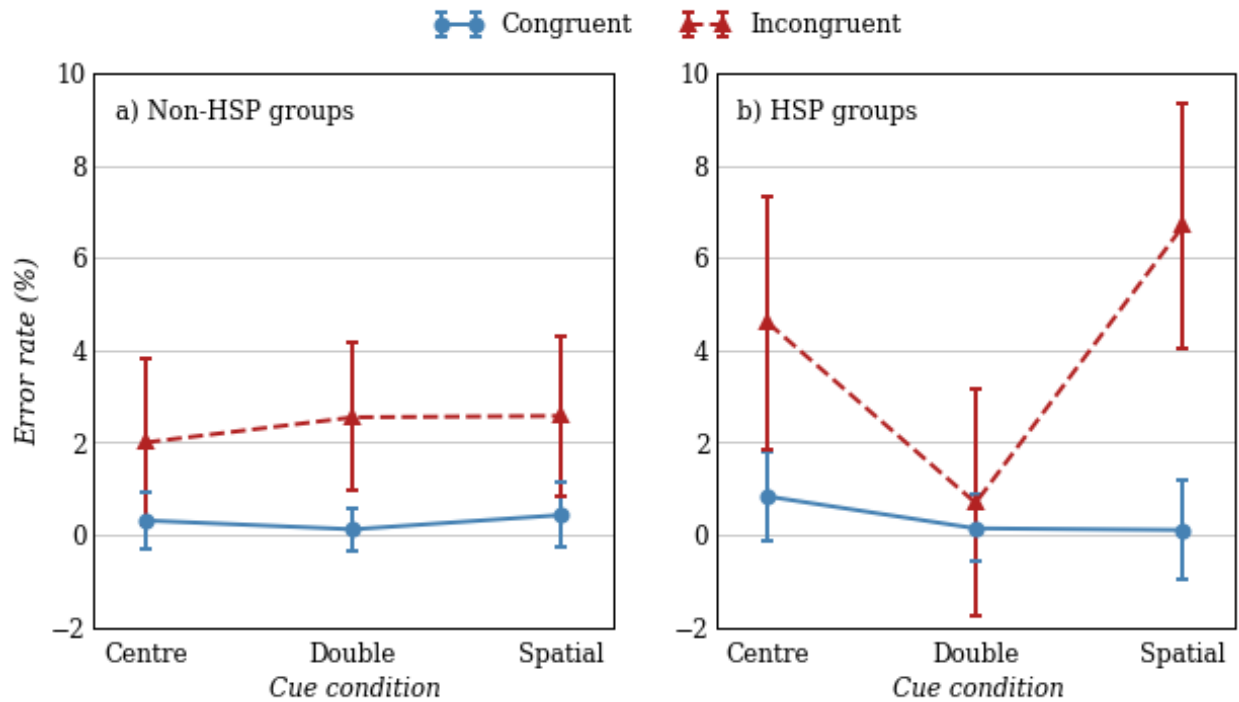


Figure D4.4. Visualisation of the HSP group  $\times$  cue  $\times$  flanker interaction. Error bars show 95% confidence intervals.

## Sensitivity and ANT as Predictors of Creativity

### Hierarchical multiple regression.

*HSPS*. For the HSPS, Model 1 accounting for 5.1% variance shows that congruity accounts for unique variance in RIBS scores. Model 2 accounts for 4.3% variance and does not provide a better fit for the data ( $p=.668$ ). In Model 2, HSPS does not account for unique variance in RIBS scores, and the addition of HSPS in Model 2 does not affect the significance of the congruity coefficient to account for unique RIBS variance. Model 3 accounts for 8.7% and the model fit is approaches significance ( $p=.058$ ). In Model 3, BFI-N is not significant, although BFI-E accounts for unique variance in RIBS but does not reduce the effects of congruity. Note, in the dichotomous sample, the BFI-E coefficient approaches significance ( $p =.051$ ). Model 4 accounts for 29.2% and gives a significantly better fit for the data. In Model 4, only congruity and BFI-O account for unique variance in RIBS scores, although BFI-E approaches significance in continuous ( $p=.067$ ) and dichotomous samples ( $p=.081$ ). The final regression equation for Model 4:  $\hat{Y}(\text{RIBS})=.362 + .195(\text{congruity}) + .068(\text{HSPS}) + .15(\text{BFI-N}) + .216(\text{BFI-E}) + .479(\text{BFI-O})$ . See Table 4.8.

Table D4.8

*Hierarchical multiple regression: Sensitivity (dichotomous), personality and congruity (incongruent – neutral flankers collapsed across alerting cue conditions) as predictors of creative ideation*

	RIBS					
	ATQ-OS			HSPS		
	Beta	SE	<i>t</i>	Beta	SE	<i>t</i>
<b>Model 1</b>						
Congruity	.247	.007	2.49*	.247	.007	2.49*
<b>Model 2</b>						
Congruity	.135	.007	1.39	.245	.007	2.45*
Sensitivity	.384	.111	3.97***	.043	.115	.43
<b>Model 3</b>						
Congruity	.142	.007	1.48	.252	.007	2.54*
Sensitivity	.39	.111	4.05***	.103	.132	.9
BFI-N	.112	.08	.94	.118	.089	.88
BFI-E	.238	.081	2*	.261	.089	1.98
<b>Model 4</b>						
Congruity	.138	.007	1.57	.191	.006	2.19*
Sensitivity	.222	.11	2.31*	.017	.116	.17
BFI-N	.16	.073	1.45	.017	.116	.17
BFI-E	.207	.074	1.89	.203	.078	1.77
BFI-O	.406	.087	4.37***	.49	.083	5.52***
<b>Model fit</b>						
	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>	<i>F</i>	<i>df</i>	<i>R</i> <sup>2</sup>
Model 1	6.18*	1,95	.051	6.18*	1,95	.051
Model 2	15.76***	1,94	.179	.19	1,94	.043
Model 3	2.1	2,92	.198	1.99	2,92	.063
Model 4	19.1***	1,91	.329	30.49***	1,91	.29

*Note.* \*  $p < .05$ , \*\*\*  $p < .001$ . RIBS=Runco Ideational Behaviour Scale; ATQ-OS=orienting sensitivity factor of the ATQ; HSPS=Highly Sensitive Person Scale (full); BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory; *F* =*F*-change in model fit; *df*=degrees of freedom; *R*<sup>2</sup>=adjusted *R*<sup>2</sup>.



**Appendix E**





## Results

First, we evaluated whether this fully within-subjects design replicated results of Funes et al. (2007), which manipulated cue type (task) using a between-subjects design. The interactions of main interest are those which may demonstrate dissociations of effects between endogenous and exogenous cue types. See Table 5.1 for descriptive statistics for each condition, across task type.

### Response Time (RT) Performance

RT results replicated Funes et al. (2007), except with the endogenous task. ANOVA revealed a main effect of SOA,  $F(1,64)=199.42$ ,  $p<.001$ ,  $\eta_p^2=.757$ , where participants responded faster to targets following 850ms ( $M=429$ ms, 95% CI[421, 438]) versus 100ms SOA ( $M=448$ ms, 95% CI[438, 457]). A main effect of cue validity,  $F(1,64)=9.78$ ,  $p<.01$ ,  $\eta_p^2=.133$ , shows that participants responded faster to valid ( $M=437$ ms, 95% CI[428, 446]) versus invalid targets ( $M=440$ ms, 95% CI[431, 449]). A main effect of congruity,  $F(1,64)=386.36$ ,  $p<.001$ ,  $\eta_p^2=.858$ , shows that participants responded faster to congruent ( $M=415$ ms, 95% CI[406, 424]) versus incongruent targets ( $M=462$ ms, 95% CI[453, 471]). No main effect of cue type / task was found ( $p = .143$ ).

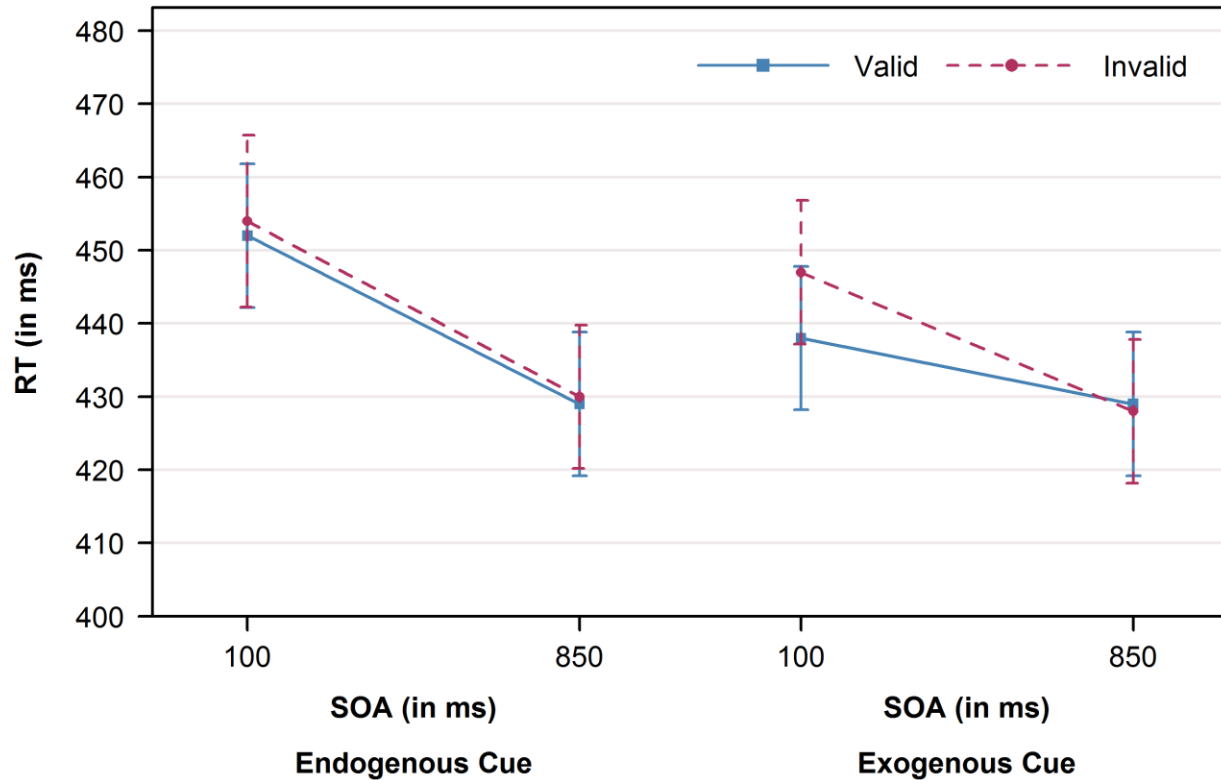


Figure E5.1. Mean reaction times (RTs) for valid and invalid conditions as a function of stimulus onset asynchrony (SOA), for the endogenous cue task (left) and the exogenous cue task (right).

3-way interactions reported by Funes et al. (2007) were also found. The  $SOA \times Validity \times Cue$  type/Task interaction was significant,  $F(1,64)=5.9$ ,  $p=.018$ ,  $\eta_p^2=.084$ , indicating SOA and cue validity modulated differently by exogenous versus endogenous cues (see Figure 5.1), and the  $Validity \times Congruity \times Cue$  type/Task interaction was significant,  $F(1,64)=32.51$ ,  $p<.001$ ,  $\eta_p^2=.337$ , indicating cue validity and spatial congruity effects modulated differently by exogenous versus endogenous cues.

However, unlike Funes et al. (2007), the  $SOA \times Validity \times Congruity$  interaction was also significant,  $F(1,64)=5.05$ ,  $p=.028$ ,  $\eta_p^2=.073$ , and a 4-way  $SOA \times Validity \times Congruity \times Cue$  type/Task interaction approached significance,  $F(1,64)=3.85$ ,  $p = .054$ ,  $\eta_p^2=.057$ . Results show

the spatial Stroop effects change depending on the Cue type/Task, SOA and Validity, visualized in Figure 5.2. In this 4-way interaction, for short 100ms SOA, the spatial congruency effect for valid versus invalid conditions was larger for exogenous ( $M=25\text{ms}$ , 95% CI[19, 30]) versus endogenous ( $M=0\text{ms}$ , 95% CI[-6, 6]) conditions,  $t(64)=5.3$ ,  $p<.001$ . For long 850ms SOA, the spatial congruency effect for valid versus invalid conditions was larger for exogenous ( $M=12\text{ms}$ , 95% CI[6, 18]) versus endogenous ( $M=-1\text{ms}$ , 95% CI[-6, 5]) conditions,  $t(64)=3.18$ ,  $p<.01$ . The difference in spatial congruency effects across tasks for valid versus invalid conditions and 100ms versus 850ms SOA approaches significance,  $t(64)=1.96$ ,  $p=.054$ .

Two separate planned 2-way ANOVAs with factors of SOA and Cueing Validity collapsed across Congruity conditions were conducted to examine interactions with cueing task further, as in Funes et al. (2007).

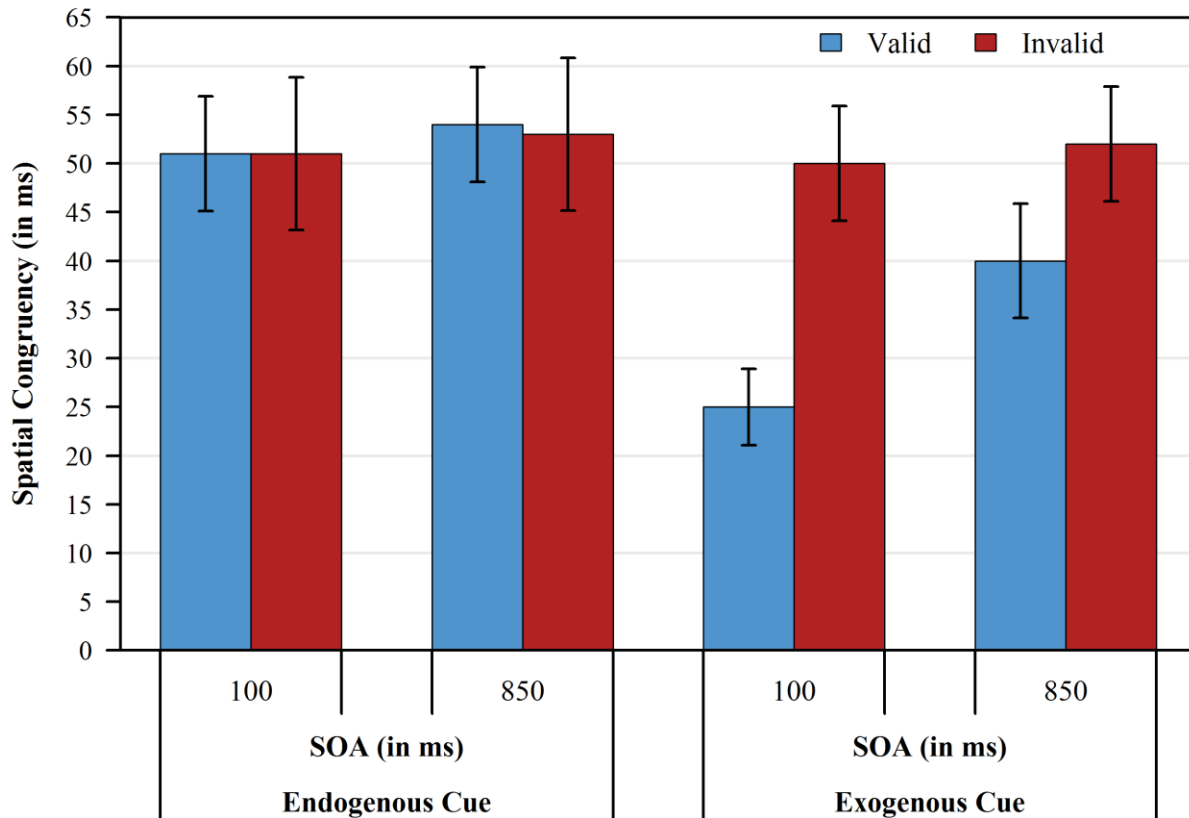


Figure E5.2. Spatial Stroop effect (incongruent target RT–congruent target RT, in ms) across task type (endogenous cues vs. exogenous cues), SOA (100 vs. 850ms) and cue validity (valid vs. invalid cues).

**Exogenous RT for SOA×Validity.** The 2-way ANOVAs with factors of SOA and Cue Validity for exogenous RTs revealed a significant main effect of SOA,  $F(1, 64)=71.29$ ,  $p<.001$ ,  $\eta_p^2=.527$ , where RTs were significantly faster for long ( $M=429$ , 95% CI[419, 438]) versus short ( $M=442$ ms, 95% CI[433, 452]) SOAs. A significant main effect of Validity was found,  $F(1, 64)=10.05$ ,  $p<.01$ ,  $\eta_p^2=.136$ , where RTs were significantly faster for valid ( $M=433$ , 95% CI[424, 443]) versus invalid ( $M=438$ , 95% CI[428, 447]) cues. However, a significant SOA×Validity interaction was observed,  $F(1, 64)=15.53$ ,  $p<.001$ ,  $\eta_p^2=.195$ , see Figure 5.1. Simple effects analysis revealed that RTs were significantly faster for valid ( $M=438$ ms, 95% CI[429, 447]) versus

invalid ( $M=447\text{ms}$ , 95% CI[437, 457]) conditions at short SOAs,  $t(64)=5.54$ ,  $p<.001$ , but no significant validity effect was observed for long SOAs ( $p=.6$ ).

**Endogenous RT for SOA×Validity.** The 2-way ANOVAs with factors of SOA and Cueing Validity for endogenous RTs revealed a significant main effect of SOA,  $F(1, 64)=136.63$ ,  $p<.001$ ,  $\eta_p^2=.681$ , where RTs were significantly faster for long ( $M=430\text{ms}$ , 95% CI[420, 436]) versus short ( $M=453\text{ms}$ , 95% CI[442, 464]) SOAs, see Figure 5.1. No main effect of Validity ( $p=.22$ ) or SOA×Validity interaction ( $p=.69$ ) was found.

Two separate 3-way planned ANOVAs for each cueing task were conducted to examine interactions with Cue type/Task further, as in Funes et al. (2007), and given that the 4-way interaction approached significance.

**Exogenous RT for SOA×Validity×Congruity.** A repeated-measures ANOVA using within-subjects factors of SOA (100ms, 850ms), validity (valid, invalid), and spatial congruity (congruent, incongruent) was conducted for the exogenous task, see Table 5.2 for ANOVA summary.

Unlike Funes et al. (2007), results showed main effects. ANOVA revealed a main effect of SOA where participants responded faster to targets following 850ms ( $M=429\text{ms}$ , 95% CI[419, 438]) versus 100ms SOA ( $M=442\text{ms}$ , 95% CI[433, 452]); a main effect of validity where participants responded faster to valid ( $M=433\text{ms}$ , 95% CI[424, 443]) versus invalid ( $M=438\text{ms}$ , 95% CI[428, 447]) target locations; a main effect of congruity where participants responded faster to congruent ( $M=415\text{ms}$ , 95% CI[405, 425]) versus incongruent ( $M=456\text{ms}$ , 95% CI[447, 466]) targets.

Unlike Funes et al. (2007), the Validity and Congruity interaction was not significant, but, like Funes et al. (2007), the ANOVA revealed a significant Validity×Congruity×SOA interaction,

which replicates their finding that cue validity reduces spatial congruity effects for the exogenous task, and the effect of cue validity on spatial congruity is larger at the 100 ms than 850 ms SOA. The spatial congruency effects change depending on cue validity and SOA. At 100ms SOA, the spatial congruency effect is smaller for valid ( $M=25\text{ms}$ , 95% CI[20, 30]) versus invalid ( $M=50\text{ms}$ , 95% CI[44, 55]) conditions,  $t(64)=9.24$ ,  $p<.001$ . At 850ms SOA, the spatial congruency effect is smaller for valid ( $M=40\text{ms}$ , 95% CI[34, 45]) versus invalid ( $M=52\text{ms}$ , 95% CI[46, 58]) conditions,  $t(64)=3.76$ ,  $p<.001$ . The significant interaction was found because the difference in spatial congruency effects between valid and invalid cues is significantly greater for 100ms ( $M=25\text{ms}$ , 95% CI[19, 30]) versus 850ms ( $M=12\text{ms}$ , 95% CI[5, 18]) SOA,  $t(1,64)=3.18$ ,  $p <.01$ .

**Endogenous RT for SOA×Validity×Congruity.** Unlike Funes et al. (2007), ANOVA revealed a main effect of SOA where participants responded faster to targets following 850ms ( $M=430\text{ms}$ , 95% CI[420, 439]) versus 100ms SOA ( $M=453\text{ms}$ , 95% CI[442, 464]), and a main effect of congruity where participants responded faster to congruent ( $M=415\text{ms}$ , 95% CI[405, 425]) versus incongruent ( $M=467\text{ms}$ , 95% CI[457, 478]) targets. No 3-way or 2-way interactions were found in the endogenous condition ( $ps>.05$ ), see Table 5.2. Thus unlike Funes et al. (2007), cueing validity and congruity interaction was not significant.

**Order effects for endogenous and exogenous task RT performance.** The Task×SOA×Validity×Congruity ANOVA was repeated using between-subjects counterbalance factors of cue color (whether participants learn to associate green or red with left or right locations) and task order (whether the endogenous or exogenous task was completed first or second) to examine whether those factors explain why validity effects were observed in the exogenous, but not endogenous task. Note, cue color is only relevant for the endogenous task. The task×validity×task order interaction was significant,  $F(1,61)=11.63$ ,  $p=.001$ ,  $\eta_p^2=.16$ . Two

separate 3-way ANOVAs were conducted for both endogenous and exogenous tasks to examine the task order interaction further.

**Exogenous order effects.** The ANOVA revealed a significant between-groups effect of task order,  $F(1,61)=6.31$ ,  $p=.015$ ,  $\eta_p^2=.094$ , where overall response times were faster for groups taking the exogenous task first ( $M=424\text{ms}$ , 95% CI[411,437]) versus those taking the exogenous task second ( $M=447\text{ms}$ , 95% CI[434,460]). The main effect of validity was significant in the presence of the counterbalance factors ( $p=.002$ ), and the task order $\times$ cue validity interaction was also significant,  $F(1,61)=6.99$ ,  $p=.01$ ,  $\eta_p^2=.103$ . For the group taking the exogenous task second, the validity effect was significant,  $t(32)=3.79$ ,  $p<.001$ , where invalid locations ( $M=450\text{ms}$ , 95% CI[437,463]) have slower response times than valid locations ( $M=443\text{ms}$ , 95% CI[430, 456]). No significant validity effect was observed for the group taking the exogenous task first ( $p>.63$ ).

**Endogenous order effects.** The ANOVA revealed a significant between-groups effect of task order,  $F(1,61)=4.91$ ,  $p=.031$ ,  $\eta_p^2=.074$ , where overall response times were faster for groups taking the endogenous task second ( $M=431\text{ms}$ , 95% CI[417, 444]) versus those taking the endogenous task first ( $M=452\text{ms}$ , 95% CI[438,466]). The main effect of validity was not significant in the presence of the counterbalance factors ( $p=.21$ ), however the task order $\times$ cue validity interaction approached significance,  $F(1,61)=3.76$ ,  $p=.057$ ,  $\eta_p^2=.058$ . For the group taking the endogenous task first, the validity effect approaches significance,  $t(31)=1.94$ ,  $p=.055$ , where invalid locations ( $M=454\text{ms}$ , 95% CI[440, 468]) are have slower response times than valid locations ( $M=450\text{ms}$ , 95% CI[437, 464]). No validity effect was observed for the group taking the endogenous task second ( $p>.57$ ). No significant between-groups effects ( $ps>.072$ ) or interactions were found with cue color ( $ps>.22$ ).

The analysis revealed that the effect of order on validity effects differs by task, where the

typical validity patterns (i.e., slower RTs for invalid vs. valid locations) observed by Funes et al. (2007) are observed in endogenous tasks, but only when presented first. Exogenous validity effects are present regardless of task order, but when order effects are considered, the validity effects are only present when exogenous tasks are presented second, contrary to endogenous validity order effects. The analysis suggests that order effects may influence whether validity effects are observed in endogenous tasks, possibly relating to effects of fatigue on learning cue-target probabilities. However, the task order effect is small, does not reach conventional levels of significance for endogenous tasks (i.e.,  $p < .05$ ), and has no significant effect with other interactions between SOA, validity and congruity for either task ( $ps > .12$ ).

Thus, exogenous task replicates the finding that cue validity affects spatial congruity, and this interaction varies further with SOA, but no evidence that cue validity affects spatial congruity was found for endogenous task. Order effects may influence whether validity effect are observed in the endogenous task, but this does not interact with SOA, congruity, or both. Nonetheless, the endogenous task showed numerically the opposite cue validity effect at the 850 ms SOA (Figure 5.2), and the results do clearly dissociate spatial congruity effects between exogenous and endogenous cueing type tasks. As only the exogenous task replicated, group analyses of RTs and corresponding conclusions focus on the exogenous task, though endogenous results will be reported.

### **Error Rate Performance**

ANOVA revealed a significant main effect of SOA,  $F(1,64)=8.4$ ,  $p < .01$ ,  $\eta_p^2=.116$ , where participants responded with fewer errors to targets following 100ms ( $M=3.43\%$ , 95% CI[2.82, 4.05]) versus 850ms SOA ( $M=4.15\%$ , 95% CI[3.31, 4.98]); a main effect of validity,  $F(1,64)=12.16$ ,  $p < .001$ ,  $\eta_p^2=.16$ , where participants responded with fewer errors to valid



( $M=3.47\%$ , 95% CI[2.81, 4.13]) versus invalid targets ( $M=4.11\%$ , CI[3.34, 4.87]); a main effect of congruity,  $F(1,64)=90.61$ ,  $p<.001$ ,  $\eta_p^2=.586$ , where participants responded with fewer errors to congruent ( $M=1.27\%$ , 95% CI[1.0, 1.54]) versus incongruent targets ( $M=6.31\%$ , 95% CI[5.11, 7.51]). No main effect of cue type was found ( $p = .462$ ).

A four-way Task×SOA×Validity×Congruity interaction did not reach significance ( $p = .267$ ) for error rates. However, a Task×Validity×Congruity interaction was observed,  $F(1,64)=18.06$ ,  $p<.001$ ,  $\eta_p^2=.22$ , and is visualized in Figure 5.3, which shows the effect of validity differs by congruity across tasks. Two separate ANOVAs were conducted to examine this interaction further, see Table 5.2 for ANOVA summary. Note, results are reported collapsed across the SOA factor, thus SOA effects and interactions are not reported.

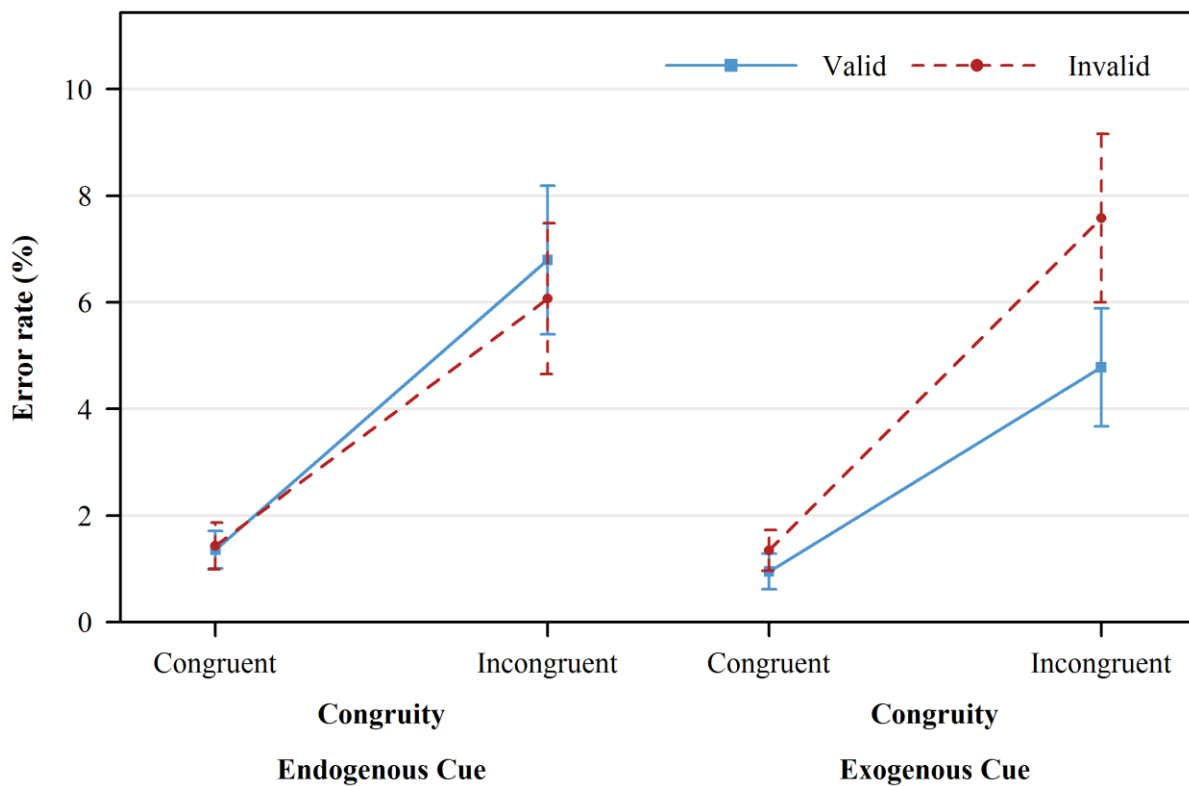
**Exogenous error rates.** For the exogenous condition, ANOVA revealed a significant main effect of validity where participants responded with fewer errors to valid ( $M=2.86\%$ , 95% CI[2.2, 3.53]) versus invalid targets ( $M=4.46\%$ , 95% CI[3.58, 5.35]) and a significant main effect of congruity where participants responded with fewer errors to congruent ( $M=1.15\%$ , 95% CI[.84, 1.47]) versus incongruent targets ( $M=6.18\%$ , 95% CI[4.88, 7.48]).

For the exogenous task, ANOVA revealed a significant Validity×Congruity interaction. A paired samples t-test revealed that the difference in exogenous error rates between valid ( $M=4.78\%$ , 95% CI[3.65, 5.91]) versus invalid conditions ( $M=7.58\%$ , 95% CI[5.97, 9.19]) for incongruent conditions is larger than the difference in error rates between valid ( $M=.95\%$ , 95% CI[.61, 1.29]) versus invalid conditions ( $M=1.35\%$ , 95% CI[.96, 1.74]) for congruent conditions,  $t(1,64)=4.41$ ,  $p<.001$ .

**Endogenous error rates.** For the endogenous condition, ANOVA revealed a significant main effect of congruity where participants responded with fewer errors to congruent ( $M=1.39\%$ ,

95% CI[1.04, 1.74]) versus incongruent targets ( $M=6.43\%$ , 95% CI[5.07, 7.8]).

The Validity×Congruity interaction was not found in the endogenous condition ( $p=.1$ ) as the difference in spatial congruency effects between valid and invalid conditions was not significant ( $M=-.8\%$ , 95% CI[-1.75, .16]),  $p = .1$ . The Task×Validity×Congruity interaction was found because the spatial congruency effects across validity conditions were significantly larger for the exogenous versus endogenous condition,  $t(64)=4.25$ ,  $p<.001$ .



*Figure E5.3.* Error rates across task (endogenous vs. exogenous), cue validity (valid vs. invalid) and target congruity (congruent vs. incongruent).

### Interim Summary

To replicate Funes et al. (2007), we hypothesized that if spatial Stroop effects should differ across cue type, this should constitute a dissociation between exogenous and endogenous

orienting and serve as evidence against a unitary view of attention (e.g., Jonides, 1981). Specifically, in the spatial Stroop paradigm, exogenous cues should reduce spatial Stroop interference, such that spatial congruency effects are smaller on valid versus invalid trials, whereas endogenous cues should either a) fail to reduce, or b) increase spatial congruency effects for valid versus invalid trials. Different SOAs are used in the spatial Stroop paradigm to observe maximal effects typically found for exogenous and endogenous cues at short (100ms) and long (850ms) SOA, respectively (Funes et al., 2007; Jonides, 1981; Posner & Cohen, 1984). In this study, using the same spatial Stroop paradigm, we report similar, and additional findings, which support Funes et al. (2007) hypotheses. Note, all replications reported in this study are partial replications, considering only 2 SOA (100ms, 850ms) were used in this study versus 4 SOA (100ms, 350ms, 600ms, 850ms) used by Funes et al. (2007).

We replicate main effects of SOA, Validity and Congruity for reaction times and error rates reported by Funes et al. (2007), wherein participants responded faster, but with more errors, to targets following 850ms versus 100ms SOAs, and faster, but with fewer errors, to targets following valid versus invalid cues, and to congruent versus incongruent targets. We additionally report a Task×SOA×Validity×Congruity interaction which approached significance, resulting from differences in spatial congruency effects across tasks for valid versus invalid conditions which differ across 100ms versus 850ms SOA. This was not reported by Funes et al. (2007), albeit within the 4-way interaction we replicate the Task×Validity×Congruity interaction with reaction time data that was reported by Funes et al. (2007). However, the nature of the interactions reported in this study are different to those reported previously. Funes et al. (2007) report that, in the Task×Validity×Congruity interaction, exogenous and endogenous cue-types have opposing spatial congruency effects on reaction times, such that for exogenous cue types,

the spatial congruency effects are smaller for valid versus invalid conditions, but vice versa with endogenous cues. In our study, spatial congruency effects between valid and invalid conditions are only present in the exogenous condition (see Figure 5.1 and Table 5.2). We additionally report Task×Validity×Congruity interaction for error rates not reported by Funes et al. (2007). In this study, the interaction was observed where the difference in spatial congruency effects between valid versus invalid conditions are larger for exogenous versus endogenous tasks (see Figure 5.2), and follow-up ANOVAs revealed that the Validity×Congruity interaction for error rates was only significant in the exogenous, not endogenous conditions. However, the effect trends towards those reported for reaction times by Funes et al. (2007), wherein opposite effects are observed across tasks for valid versus invalid conditions.

Funes et al. (2007) also report a Task×SOA×Validity and, separately, an SOA×Validity×Congruity interaction with reaction times for exogenous, but not endogenous tasks, both of which are found in this study and explained under the SOA×Validity×Congruity interaction for reaction times in the exogenous task (Table 5.2). We found that spatial congruency effects on reaction times are faster for valid versus invalid cues across SOA, but this difference greater for 100ms versus 850ms SOA. Further, this interaction was only significant for exogenous, but not endogenous tasks (Table 5.2) and thus demonstrates inhibition-of-return, wherein reaction times in exogenous tasks for valid conditions show a negative facilitation effect at long versus short SOA (Jonides, 1981; Posner & Cohen, 1984). This effect is consistent with results reported by Funes et al. (2007), who report a significant positive facilitation effect for valid versus invalid cues at 100ms SOA, but not later SOAs in the exogenous task.

Overall, with reaction times and error rates, spatial congruency effects were faster for valid versus invalid conditions for exogenous conditions only, however for reaction times the

difference in spatial congruency effects between valid versus invalid cues was significantly greater for 100ms versus 850ms SOA, demonstrating both positive facilitation at short SOAs, and inhibition-of-return at long SOAs. Thus, our study provides further support for the hypothesis (see Funes et al., 2007) that, in the spatial Stroop paradigm, exogenous cues should reduce spatial Stroop interference, such that spatial congruency effects are smaller on valid versus invalid trials, whereas endogenous cues should either a) fail to reduce, or b) increase spatial congruency effects. This evidence constitutes a dissociation between exogenous and endogenous orienting and evidence against a unitary view of attention (e.g., Jonides, 1981). The reaction time and error rate data show exactly this pattern of results, but specifically where endogenous cues fail to reduce spatial congruency effect for valid versus invalid conditions.

Individual differences. The HSPS may be a taxon consisting of HSP's (i.e., those high on HSPS) and non-HSP's, therefore Aron and Aron (2013) suggest dichotomizing the sample. As the sample majority consists of Psychology majors who may include a larger percentage of HSPs than the typical 20%, the break point was chosen to be 30% (high) HSP's and 70% (low) non-HSP's (Aron & Aron, 2013). For the HSPS, the HSP group ( $n=20$ ,  $M = 5.02$ , 95% CI[4.84, 5.2]) have significantly higher ratings on the HSPS,  $t(63)=10.87$ ,  $p<.001$ , than non-HSP groups ( $n=45$ ,  $M = 3.63$ , 95% CI[3.48, 3.77]).

As many HSPS items have negative affect involved (Aron & Aron, 2013), and introversion and neuroticism correlate with the HSPS (Aron & Aron, 1997), additional sensitivity scores for both HSPS and ATQ-OS were calculated with BFI-E (introversion inverted) and BFI-N (neuroticism/negative affect) partialled-out to create new variables capturing SPS more precisely henceforth referred to as HSPS (E, N) residuals and ATQ-OS (E, N) residuals.

**Dichotomous samples in HSPS measures.** A 4-way mixed ANOVA was used to explore within-subjects factors SOA (100ms, 850ms), Validity (valid, invalid cue), and congruity (congruent, incongruent target) and between subjects factors of HSP group (HSP, non-HSP) for exogenous and endogenous task reaction times and error rates. Two separate ANOVAs were performed in order to look at HSPS and HSPS (E,N) residuals group differences. The ANOVAs were performed separately for exogenous and endogenous tasks, because the hypotheses regarding sensitivity relate specifically to automatic exogenous attention. See Table 5.4 and Table 5.5 for a summary of mixed ANOVA results for HSPS groups, respectively, and see Table 5.3 for descriptive statistics of sensitivity measures.

### **HSPS Mixed ANOVA for Reaction Times and Error Rates across Task**

**Mixed ANOVA with endogenous task reaction times for HSPS.** No between-groups effects were observed for HSPS, or HSPS (E,N) residuals groups ( $ps > .05$ ). An SOA×Validity×Congruity×HSPS group interaction was observed for endogenous task RTs (Table 5.4). Figure 5.4 shows that the interaction is the result of HSPS group differences in spatial congruency across SOA for invalid versus valid conditions. An independent samples t-test revealed that for 100ms versus 850ms SOA and invalid versus valid conditions, HSP groups ( $M=14\text{ms}$ , 95% CI[-3, 32]) show larger spatial congruency effects than non-HSP groups ( $M=-8\text{ms}$ , 95% CI[-17, 1]),  $t(63)=2.42$ ,  $p=.019$ . However, this interaction is not significant when controlling for negative affect using HSPS (E,N) residuals ( $p = .11$ ). Interestingly, both HSPs and non-HSPs show similar endogenous spatial Stroop patterns reported by Funes et al. (2007),

i.e., greater spatial congruency effects for valid versus invalid conditions, but the effects are observed at different SOAs for each group. HSPs show the pattern at 100ms and non-HSPs show the pattern at 850ms SOA, although simple contrasts reveal that validity effects on spatial congruency at those SOA are not significant for either group ( $p > .257$ ). This suggests that endogenous orienting is easier for HSPs at short SOAs but for non-HSPs at long SOAs. Alternatively, non-HSPs have better endogenous attention because the non-HSP pattern resembles the expected endogenous pattern more because increasing the SOA should increase the validity effect on spatial congruency, which it does in the non-HSPs. Nonetheless, this result suggests that endogenous attention differs between HSP and non-HSP groups (full HSPS). Further, the group pattern indicates that one reason endogenous spatial Stroop patterns (i.e., greater spatial congruency effects for valid versus invalid conditions, observed with greater magnitude for 850ms versus 100ms) was not found in this study could be related to individual differences related to sensitivity with negative affect, such that opposing HSPS group differences in SOA and validity effects on spatial congruency tend to cancel each other out across the entire sample.

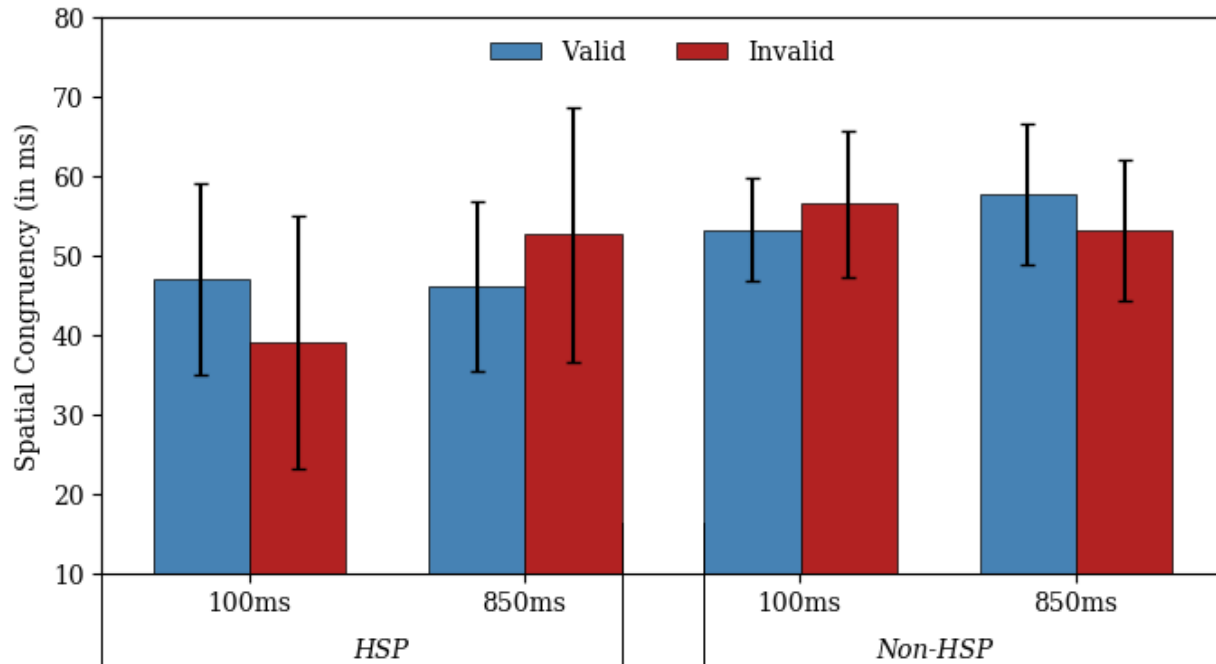


Figure E5.4. The SOA (100ms, 850ms)  $\times$  Validity (Valid, Invalid)  $\times$  Congruity  $\times$  HSPS (HSP, Non-HSP) Group interaction for endogenous task reaction times. Error bars show 95% confidence intervals for each HSPS group by condition.

**Mixed ANOVA with exogenous task reaction times for HSPS.** No between-group effects or interactions were found for exogenous task RTs, see Table 5.4, or when controlling for negative affect using HSPS (E,N) residuals groups ( $ps > .159$ ).

**Mixed ANOVA with endogenous task error rates for HSPS.** No between-groups effects of interactions were observed with error rates for the HSPS groups (Table 5.4). However, an SOA  $\times$  HSPS (E,N) residual group was observed,  $F(1,63) = 4.89$ ,  $p = .031$ ,  $\eta_p^2 = .072$ . For non-HSP groups, error rates were significantly lower for 100ms ( $M=3.61\%$ , 95% CI[2.67, 4.64]) versus 850ms SOA ( $M=5.04\%$ , 95% CI[3.97, 6.17]),  $t(44)=3.12$ ,  $p = .003$ , whereas for HSP groups, error rates are higher for 100ms ( $M=3.11\%$ , CI [2.14, 4.20]) versus 850ms SOA ( $M=2.86\%$ , CI [2.01, 3.86]), but this difference is not significant ( $p = .61$ ). Independent samples



t-test revealed that the SOA effect is larger for the non-HSP versus HSP group,  $t(63)=2.21$ ,  $p=.031$ . These error results provide evidence for interpreting the RT result on this task, with both suggesting that endogenous orienting was more effective / easier at the 100 ms SOA for HSPs but at the 850 ms SOA for non-HSPs (with the caveat that RTs were full HSPs but errors were HSPS residuals).

**Mixed ANOVA with exogenous task error rates for HSPS.** No between-groups effects or interactions were observed with error rates for the HSPS groups (Table 5.4). However, an SOA×Congruity×HSPS (E,N) residuals group interaction was found,  $F(1,63) = 4.14$ ,  $p = .046$ ,  $\eta_p^2 = .062$ . Figure 5.5 shows the interaction is the result of HSPS group differences in error rates between SOA conditions for incongruent versus congruent targets. Both groups show no effect of SOA on error rates for congruent targets ( $ps >.27$ ). However, for incongruent targets, non-HSP groups have significantly higher error rates following 850ms ( $M=7.6\%$ , 95% CI[5.62, 9.84]) versus 100ms SOA ( $M=5.73\%$ , 95% CI[4.44, 7.14]),  $t(44)=3.02$ ,  $p=.016$ , whereas HSP groups show numerically lower error rates following 850ms ( $M=4.96\%$ , 95% CI[3.21, 6.96]) versus 100ms SOA ( $M=5.22\%$ , 95% CI[3.53, 7.14]), but this difference is not significant ( $p=.69$ ). Accordingly, for non-HSPs, the effect of SOA was larger for incongruent versus congruent conditions,  $t(44)=3.02$ ,  $p<.01$ , but not for HSP groups ( $p=.715$ ), and an independent samples t-test revealed the SOA effects (100ms – 850ms) across congruity conditions is significantly larger for non-HSP versus HSP groups,  $t(63)=2.04$ ,  $p=.046$ . In summary, only non-HSPs make more errors for incongruent targets at long 850 ms SOA. Overall, these results show that only non-HSPs show an overall increase in errors for incongruent targets at long 850 relative to short 100 ms SOA; HSPs show comparable errors across SOA and congruity conditions, suggesting HSP have a greater ability to maintain accuracy regardless of SOA and cue-target

congruity, and the null RT group effects indicate that this does not reflect speed-accuracy trade-off.

**Sensitivity with negative affect affects endogenous orienting.** For the HSPS, a significant SOA×Validity×Congruity×HSPS group interaction was observed for endogenous task reaction times, wherein larger spatial congruency effects for 100ms versus 850ms SOA, and invalid versus valid conditions, were observed for HSP groups versus non-HSP groups. Figure 5.4 shows that the spatial congruency effects are in opposite directions for HSP versus non-HSP groups, which explains the nature of the differences found. This result suggests that HSPs display greater costs when disengaging attention from endogenously cued locations at long versus short SOA. This was not predicted in the hypothesis that (iiia) for the HSPS, HSPs versus non-HSPs would be associated with greater costs when disengaging from invalid peripheral cues at short SOA for exogenous tasks, as found with strong BIS (Poy et al., 2004). However, the 4-way interaction for the endogenous task reaction times are not significant when negative affect is controlled using HSPS (E,N) residuals groups, suggesting the interaction effects relate to negative affect, rather than sensitivity. Further, this interaction was not observed with the ATQ-OS, a positive-affect-related measure (Sobocko & Zelenski, 2015), further supporting the conclusion that negative affect can explain the 4-way interaction found with the HSPS for endogenous task reaction times. However, controlling for negative affect revealed an SOA×HSPS (E,N) residuals interaction for endogenous task error rates, wherein the effect of SOA on errors is larger for non-HSP versus HSP groups, as non-HSPs show greater accuracy for 100ms versus 850ms. This difference in errors across SOA is in the opposite direction for HSP groups, but is not significant Overall, these results suggest that endogenous orienting was more effective / easier at the 100 ms SOA for HSPs but at the 850 ms SOA for non-HSPs.

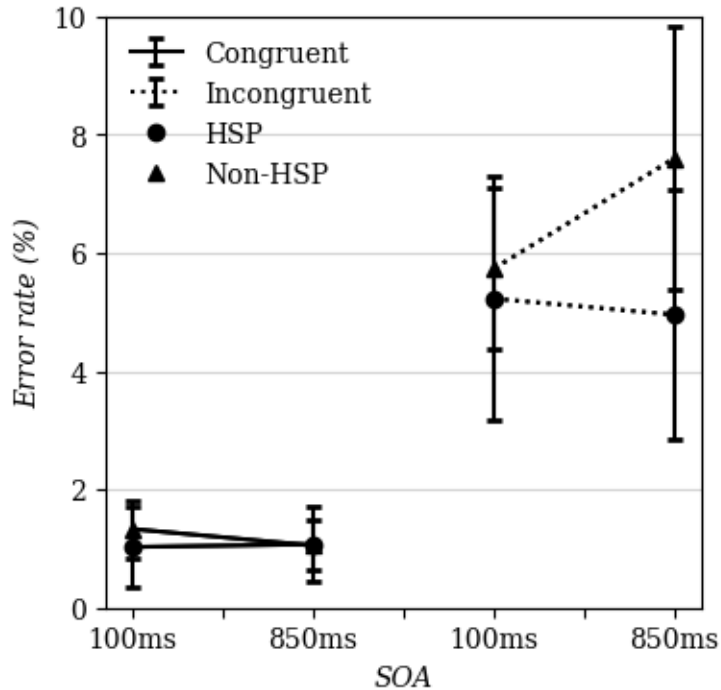


Figure E5.5. The SOA  $\times$  Congruity  $\times$  HSPS (E,N) residuals group interaction for error rates in the exogenous task. Error bars show 95% confidence intervals.

### Sensitivity and inhibition-of-return.

For the HSPS (E,N) residuals group, the inhibition-of-return effects were not observed. However, a significant SOA $\times$ Congruity $\times$ HSPS (E,N) residuals group interaction was observed for exogenous task error rates. In this interaction, non-HSP groups show higher error rates for incongruent targets following 850ms versus 100ms SOA, whereas HSP groups show non-significant effects in the opposite direction. Neither groups show effects of SOA on error rates for congruent targets, therefore the interaction is the result of greater differences in SOA effects for incongruent targets for non-HSP versus HSP groups. This finding suggests that HSPs versus non-HSPs are less affected by the attention and perception associated with SOA typically observed in inhibition-of-return with validity conditions.

## Creativity and Spatial Stroop Performance

**Dichotomous samples in CAQ, RIBS and ATTA creativity measures.** A 4-way mixed ANOVA was used to explore within-subjects factors SOA (100ms, 850ms), validity (valid, invalid cue), and congruity (congruent, incongruent target) and between-subjects factors of creativity group (high, low) for exogenous and endogenous task reaction times and error rates. Two separate ANOVAs were performed for each creativity measure, (CAQ, RIBS, ATTA) for exogenous and endogenous tasks, because the hypotheses regarding sensitivity and creativity relate more specifically to automatic exogenous attention. See Table 5.5, Table 5.6, and Table 5.7 for a summary of mixed ANOVA results for CAQ, RIBS, and ATTA groups, respectively, and see Table 5.3 for descriptive statistics of creativity measures. Note, no exogenous or endogenous task effects were found for RIBS and thus are not reported further, but see Table 5.6.

**CAQ spatial Stroop performance.** No between-groups effects or interactions were found for endogenous reaction times, or exogenous reaction times and error rates (see Table 5.5). However, an SOA×Congruity×CAQ group interaction approached significance ( $p=.055$ ) for endogenous task error rates. Figure 5.8 shows the interaction is the result of group differences in error rates across SOA conditions for incongruent versus congruent targets. A paired samples t-test revealed that neither high nor low CAQ groups show SOA effects for congruent conditions ( $p>.603$ ). However, high CAQ groups show significantly larger errors for 850ms ( $M=8.82\%$ , 95% CI[6.51, 11.2]) versus 100ms SOA ( $M=5.82\%$ , 95% CI[4.17, 7.79]) for incongruent trials,  $t(31)=2.91$ ,  $p<.01$ . Low CAQ groups show larger errors for 850ms ( $M=6\%$ , 95% CI[4.33, 7.97]) versus 100ms SOA ( $M=5.14\%$ , 95% CI[3.34, 7.29]) for incongruent trials, but this difference is not significant ( $p=.23$ ). For high CAQ groups, the effect of SOA on error rates is larger for incongruent versus congruent conditions,  $t(31)=3.16$ ,  $p<.01$ , but not for low CAQ groups,  $p=.23$ .

An independent samples t-test revealed that the SOA effects on incongruent versus congruent targets are larger for high versus low CAQ groups,  $t(63)=1.96, p=.055$ .

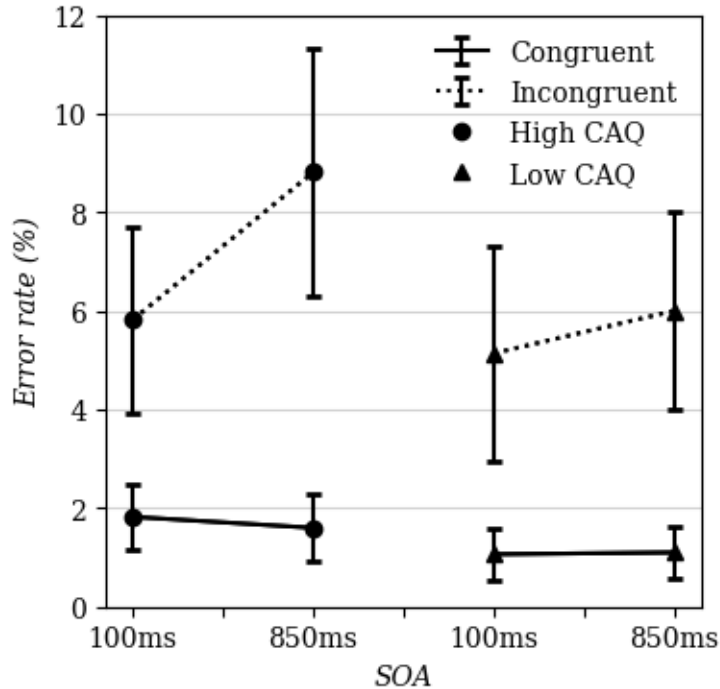


Figure E5.8. The SOA  $\times$  Congruency  $\times$  CAQ group interaction for error rates in the endogenous task. Error bars show 95% confidence intervals.

**ATTA spatial Stroop performance.** No between-groups effects or interactions were found for endogenous reaction times (see Table 5.7). No between-groups effects were found for exogenous reaction times, however a SOA $\times$ Validity $\times$ ATTA group interaction approached significance ( $p=.053$ ). Figure 5.9 shows the interaction is the result of group differences in exogenous reaction times across SOA and validity conditions. For valid conditions, the high ATTA group reaction times are significantly slower for 100ms ( $M=434\text{ms}$ , 95% CI[422, 447]) versus 850ms ( $M=422\text{ms}$ , 95% CI[412, 433]) SOA,  $t(29)=4.43, p<.001$ , and the low ATTA group reaction times are significantly slower for 100ms ( $M=441\text{ms}$ , 95% CI[429, 454]) versus

850ms ( $M=435\text{ms}$ , 95% CI[423,449]) SOA,  $t(34)=2.35$ ,  $p=.024$ . For invalid conditions, the high ATTA group reaction times are significantly slower for 100ms ( $M=441\text{ms}$ , 95% CI[429, 454]) versus 850ms ( $M=424\text{ms}$ , 95% CI[414, 435]) SOA,  $t(29)=4.75$ ,  $p<.001$ , and the low ATTA group reaction times are significantly slower for 100ms ( $M=452\text{ms}$ , 95% CI[440, 467]) versus 850ms ( $M=431\text{ms}$ , 95% CI[418, 445]) SOA,  $t(34)=6.8$ ,  $p<.001$ . For high ATTA groups, the effect of SOA does not change across validity conditions ( $p=.17$ ), however for low ATTA groups, the effect of SOA is larger for invalid versus valid conditions,  $t(34)=4$ ,  $p<.001$ , and an independent samples t-test revealed the SOA effect on validity is marginally larger for low versus high ATTA groups,  $t(63)=1.97$ ,  $p=.053$ .

For ATTA groups, between-groups effects were found for in both endogenous and exogenous task error rates. For the endogenous task, higher error rates are found in low ( $M=4.61\%$ , 95% CI[3.54, 5.67]) versus high ( $M=3.11\%$ , 95% CI[1.95, 4.26]) ATTA groups ( $p=.061$ ). For the exogenous task, higher error rates are found in low ( $M=4.38\%$ , 95% CI[3.4, 5.35]) versus high ( $M=2.84\%$ , 95% CI[1.78, 3.89]) ATTA groups ( $p=.036$ ).

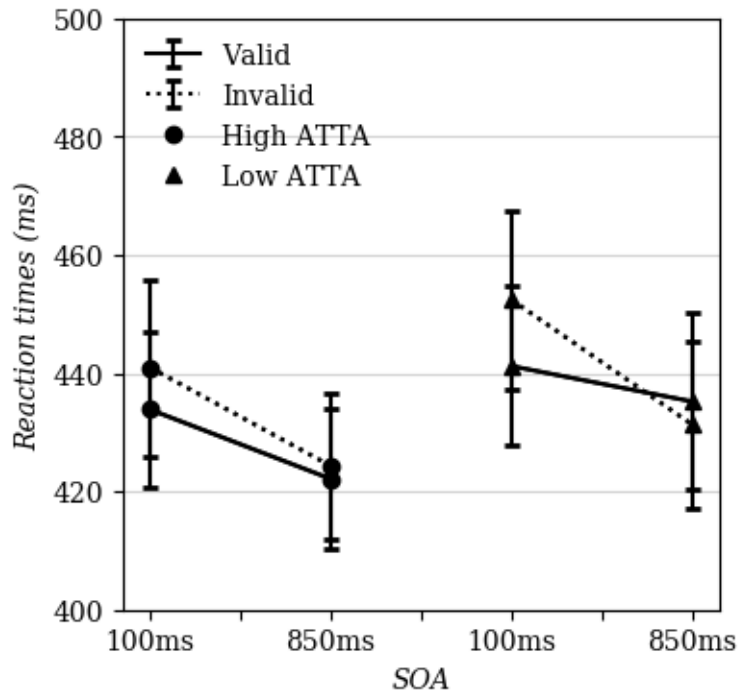


Figure E5.9. The SOA  $\times$  Validity  $\times$  ATTA group interaction for error rates in the exogenous task. Error bars show 95% confidence intervals.

### Interim Summary: Creativity and Spatial Stroop Performance

Evidence supports the hypothesis that (iv) spatial Stroop performance will differ across creativity measures, providing further evidence that different processes are implicated in different measures of creative achievement (CAQ), ideation (RIBS) and divergent thinking (ATTA; see Chapter 2 for analysis of relationship between CAQ, RIBS & ATTA). CAQ groups were associated with differences in spatial conflict resolution at different SOAs for endogenous tasks only, wherein high creative achievers show less ability to resolve spatial conflict at long versus short SOAs in endogenous tasks. ATTA groups were associated with differences in exogenous task reaction times, wherein SOA modulated response times across validity conditions uniquely for each group. Specifically, high ATTA groups show no effects of SOA

across validity conditions, but SOA effects were larger between invalid versus valid conditions for low ATTA groups (Figure 5.9). Thus, low versus high ATTA are slower to disengage from invalid cued locations at short SOAs, suggesting high ATTA display greater cognitive flexibility for disengaging attention from exogenously cued locations. This is consistent with evidence linking higher ATTA scores with higher levels of flexible cognitive control (Zabelina & Robinson, 2010). Further, high ATTA groups were overall more accurate for endogenous and exogenous tasks. No significant effects were found for RIBS.

Whether there are shared underlying mechanisms between spatial Stroop effects for sensitive (HSP) and creative (high) groups is not clear, as the spatial Stroop effects found do not strongly overlap within or between sensitivity and creativity measures. For exogenous tasks errors, ATQ-OS is associated with greater facilitation and/or inhibition-of-return with spatial congruency effects, but the HSPS measure, with negative affect controlled, is associated with group differences how SOA modulates resolution of spatial conflict for exogenous tasks, and accuracy more generally for endogenous tasks, although the interactions are the result of null findings for the HSP groups. Creativity measures also perform differently across task. SOA modulates spatial conflict resolution differently across CAQ groups for endogenous tasks, but modulates response time between validity conditions across ATTA groups in the exogenous task, and, additionally, accuracy more generally over endogenous and exogenous tasks.

We found no evidence to support the hypothesis that (iiib) ATQ-OS HSPs versus non-HSPs would have greater ability to disengage voluntary cued attention from invalid target locations at long SOA, thus we found no justification for the hypothesis (vi) that this performance would predict creative achievement and divergent thinking. However, the hypothesis that (ii) ATQ-OS HSPs versus non-HSPs would be associated with greater IOR was supported. Thus, one



question emerges whether inhibition-of-return accounts for unique variance in creativity measures, and whether that variance is shared, or independent from ATQ-OS variance, thus demonstrating whether exogenous attention mechanisms partially explain the relationship between sensitivity and creativity.

Table E5.1

Mean reaction times (RT) and error rates (ER; %) with standard deviations (SD) for validity, stimulus onset asynchrony (SOA), and congruity for exogenous and endogenous cue types

		Exogenous				Endogenous				
		Valid		Invalid		Valid		Invalid		
	SOA	Congruity	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<b>RT</b>	100	Congruent	425	38	422	45	426	42	428	48
		Incongruent	450	39	472	43	477	45	479	50
	850	Congruent	409	42	402	42	402	39	404	41
		Incongruent	449	39	454	37	456	43	457	46
<b>ER</b>	100	Congruent	1.13	1.86	1.35	1.92	1.5	1.9	1.37	2.06
		Incongruent	4.42	4.29	6.73	5.85	5.73	6.15	5.22	6.62
	850	Congruent	0.77	1.55	1.35	1.87	1.21	1.68	1.48	2.59
		Incongruent	5.14	6.09	8.43	8.12	7.86	6.31	6.92	7.57

Table E5.2

Summary of separate repeated-measures ANOVA by task for endogenous and exogenous tasks using factors of SOA, Validity and Congruity for reaction time, and without SOA factor for error rate performance

	Reaction times				Error rates			
	Endogenous		Exogenous		Endogenous		Exogenous	
	F	$\eta_p^2$	F	$\eta_p^2$	F	$\eta_p^2$	F	$\eta_p^2$
<i>Main effects</i>								
SOA	136.63***	.681	71.29***	.527	---	---	---	---
Validity	1.52	.023	10.05**	.136	1.95	.03	37.97***	.372
Congruity	304.05***	.826	390.74***	.859	71.13***	.526	72.22***	.53
<i>Interactions</i>								
SOA×Validity	.16	.002	15.53***	.195	---	---	---	---
SOA×Congruity	1.09	.017	15.81***	.198	---	---	---	---
Validity×Congruity	.08	.001	68.16***	.516	2.75	.041	19.43***	.233
SOA×Validity×Congruity	.05	.001	10.12**	.137	---	---	---	---

Note, \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ ; degrees of freedom = 1,64.

Table E5.3

*Mean, standard deviation (SD), and lower (LCI) and upper (UCI) 95% confidence intervals for creativity, temperament and personality variables (n=65)*

	Mean	SD	LCI	UCI
<i>Creativity</i>				
CAQ	7.78	8.87	5.85	9.97
RIBS	2.93	.56	2.81	3.06
ATTA	65.63	10.00	62.95	67.95
<i>Temperament</i>				
HSPS	4.06	.81	3.86	4.25
ATQ_OS	4.67	.81	4.5	4.85
ATQ_EC	3.94	.81	3.74	4.13
ATQ_NA	4.21	.73	4.04	4.39
ATQ_ES	4.64	.64	4.48	4.8
<i>Personality</i>				
B5_O	3.15	.56	3	3.29
B5_C	3.39	.64	3.23	3.55
B5_E	3.14	.81	2.95	3.32
B5_A	3.87	.56	3.73	4
B5_N	3.09	.89	2.89	3.29

*Note:* CAQ = Creative Achievement Questionnaire; RIBS = Runco Ideational Behaviour Scale; ATTA = Abbreviated Torrance Test for Adults; HSPS = Highly Sensitive Person Scale (full); ATQ-OS = orienting sensitivity factor of the ATQ; ATQ-EC = effortful control factor of the ATQ; ATQ-NA = negative affect factor of the ATQ; ATQ-ES = extraversion/surgency factor of the ATQ; BFI-O = openness to experience factor of the Big Five Inventory (BFI); BFI-C = conscientiousness factor of the BFI; BFI-E = extraversion factor of the BFI; BFI-A = agreeableness factor of the BFI; BFI-N = neuroticism factor of the BFI.

Table E5.4

*Summary of separate mixed ANOVA for endogenous and exogenous tasks using within-groups factors of SOA, Validity and Congruity, and between-groups factors of HSPS group, for reaction time and error rate performance*

	<i>Reaction times</i>				<i>Error rates</i>			
	Endogenous		Exogenous		Endogenous		Exogenous	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
HSPS	.35	.006	.25	.004	.28	.004	1.39	.022
<i>Interactions</i>								
HSPS×SOA	2.83	.043	.2	.003	.88	.014	.02	0
HSPS×Validity	.67	.011	0	0	.64	.01	.22	.004
HSPS×Congruity	1.93	.03	1.61	.025	.31	.005	.89	.014
HSPS×SOA×Validity	1.12	.017	.37	.006	.01	0	.05	.001
HSPS×SOA×Congruity	1.47	.023	2.44	.037	.19	.003	.45	.007
HSPS×Validity×Congruity	.98	.001	.71	.011	1.98	.03	.44	.007
HSPS×SOA×Validity×Congruity	5.84*	.085	.1	.001	.03	0	.14	.002

*Note, \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ ; degrees of freedom = 1,64.*

Table E5.5

*Summary of separate mixed ANOVA for endogenous and exogenous tasks using within-groups factors of SOA, Validity and Congruity, and between-groups factors of CAQ group, for reaction time and error rate performance*

	<i>Reaction times</i>				<i>Error rates</i>			
	Endogenous		Exogenous		Endogenous		Exogenous	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
CAQ	.06	.001	1.14	.018	2.26	.035	1.24	.019
<i>Interactions</i>								
CAQ×SOA	1.89	.029	1.1	.017	1.69	.026	.63	.01
CAQ×Validity	.45	.007	.21	.003	.06	.001	.38	.006
CAQ×Congruity	2.61	.04	.17	.003	.87	.014	.87	.014
CAQ×SOA×Validity	.16	.003	1.09	.017	.58	.009	1.6	.025
CAQ×SOA×Congruity	2.5	.038	.36	.006	3.83	.057	.02	0
CAQ×Validity×Congruity	2.26	.035	3.34	.05	1	.016	.72	.011
CAQ×SOA×Validity×Congruity	.32	.005	.02	0	.13	.002	1.59	.025

Table E5.6

*Summary of separate mixed ANOVA for endogenous and exogenous tasks using within-groups factors of SOA, Validity and Congruity, and between-groups factors of RIBS group, for reaction time and error rate performance*

	<i>Reaction times</i>				<i>Error rates</i>			
	Endogenous		Exogenous		Endogenous		Exogenous	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
RIBS	1.4	.022	.37	.006	.79	.012	1.04	.016
<i>Interactions</i>								
RIBS×SOA	.2	.003	.07	.001	.92	.014	.01	0
RIBS×Validity	.9	.014	.25	.004	.04	.001	2.69	.041
RIBS×Congruity	.79	.012	.9	.014	.03	.001	.19	.003
RIBS×SOA×Validity	.43	.007	.18	.003	.78	.012	2.48	.038
RIBS×SOA×Congruity	1.29	.02	1.94	.03	.25	.004	0	0
RIBS×Validity×Congruity	.23	.004	1.29	.02	.2	.003	.8	.013
RIBS×SOA×Validity×Congruity	1.09	.017	.1	.002	1.6	.025	3.21	.048

*Note, \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ ; degrees of freedom = 1,63.*

Table E5.7

*Summary of separate mixed ANOVA for endogenous and exogenous tasks using within-groups factors of SOA, Validity and Congruity, and between-groups factors of ATTA group, for reaction time and error rate performance*

	<i>Reaction times</i>				<i>Error rates</i>			
	Endogenous		Exogenous		Endogenous		Exogenous	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
ATTA	1.21	.019	1.07	.017	3.65	.055	4.58*	.068
<i>Interactions</i>								
ATTA×SOA	.03	.001	.04	.001	.07	.001	0	0
ATTA×Validity	.02	0	.14	.002	2.14	.03	.77	.012
ATTA×Congruity	.09	.001	0	0	2.52	.038	2.21	.034
ATTA×SOA×Validity	2.96	.045	3.89	.058	0	0	.81	.013
ATTA×SOA×Congruity	1.11	.017	0	0	.94	.015	.79	.012
ATTA×Validity×Congruity	.42	.007	3.16	.048	.85	.013	.15	.002
ATTA×SOA×Validity×Congruity	.06	.001	2.08	.032	.13	.002	.63	.01

*Note, \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ ; degrees of freedom = 1,63.*

Table E5.8

*Spearman's Rho correlations between inhibition-of-return variables for exogenous and exogenous reaction times and error rates (rows) and creativity, temperament, and personality variables (columns)*

Task	<i>Creativity</i>			<i>Temperament</i>			<i>Personality</i>				
	CA	RIB	ATT	HSP	ATQ-	BF-	BF-	BF-	BF-	BF-	
<b>R</b> Exogenous	-.03	.085	.246*	.09	.108	.131	.027	.053	-.026	-.086	
<b>T</b> Endogenous	-.08	-.068	-.012	.192	-.032	-.242	.042	-.091	.134	.045	
<b>E</b> Exogenous	-.15	-.176	-.104	-.13	-.336**	-.18	.078	.063	.008	.038	
<b>R</b> Endogenous	-.00	-.199	-.013	-.101	-.12	-.132	-.086	.059	.177	.053	

*Note, \* $p < .05$ , \*\* $p < .01$ ,  $n = 65$ . Note: CAQ = Creative Achievement Questionnaire; RIBS = Runco Ideational Behaviour Scale; ATTA = Abbreviated Torrance Test for Adults; HSPS = Highly Sensitive Person Scale (full); ATQ-OS = orienting sensitivity factor of the ATQ; BF-O = openness to experience factor of the Big Five Inventory (BFI); BF-C = conscientiousness factor of the BFI; BF-E = extraversion factor of the BFI; BF-A = agreeableness factor of the BFI; BF-N = neuroticism factor of the BFI.*

**Appendix F**





## Methods

As (a) many HSPS items have negative affect involved (Aron & Aron, 2013), (b) introversion and neuroticism correlate with the HSPS (Aron & Aron, 1997), and (c) higher introversion and neuroticism are associated with greater learning without awareness (Deo & Singh, 1973), additional sensitivity scores for both HSPS and ATQ-OS were calculated with BFI-E (introversion inverted) and BFI-N (neuroticism/negative affect) partialled-out to create new variables capturing SPS more precisely, henceforth referred to as HSPS (E,N) residuals and ATQ-OS (E,N) residuals.

Group differences were explored using mixed ANOVA and *t*-test comparisons where appropriate using between-groups factors of full HSPS and ATQ-OS measures and HSPS (E,N) and ATQ-OS (E,N) residuals variables, separately. Thus, for every analysis undertaken, the full HSPS/OS measures, and HSPS/ATQ-OS (E,N) residuals were used in order to examine effects of sensitivity with, and without negative affect controlled. For the HSPS, the HSP groups ( $M=.75$ , 95% CI [.72,.78]) had significantly higher scores,  $t(78)=10.12$ ,  $p<.001$ , than non-HSPs ( $M=.45$ , 95% CI [.41,.49]). For the ATQ-OS, the HSP groups ( $M=.76$ , 95% CI [.74,.79]) had significantly higher scores,  $t(78)=9.46$ ,  $p<.001$ , than non-HSPs ( $M=.52$ , 95% CI [.48,.55]). The same analysis was also performed for between-groups factors of creativity for CAQ, RIBS and ATTA, separately. For each creativity measure, two groups were formed from the 79 available participants using a median split with the following group sizes: High groups  $\geq$  CAQ  $Mdn=.08$ , and low groups  $<$  CAQ  $Mdn$  giving high (n=39) and low CAQ (n=40) groups; High groups  $\geq$  RIBS  $Mdn=.5$ , and low groups  $<$  RIBS  $Mdn$  giving high (n=42) and low RIBS (n=37) groups. High groups  $\geq$  ATTA  $Mdn=.86$ , and low groups  $<$  ATTA  $Mdn$  giving high (n=41) and low ATTA (n=38) groups. ). Note, all personality, temperament, and creativity measures are scaled

between 0 and 1, see Chapter 2 for scaling. Max scores used for scaling CAQ are 94, and 83 for the ATTA.

## Results

### Overall Implicit SRTT Performance

A repeated measures ANOVA was run to look at implicit SRTT RT performance across within-groups factors of Run (Run 1, Run 2, Run 3, and Run 4), Condition (Random, Sequence) and Block (Block 1, Block 2, and Block 3). Mauchleys Test of Sphericity was violated for factors of Run and Block, and for interaction terms of Run×Block ( $ps<.001$ ), thus Greenhouse-Geisser correction was applied for those main effects and interactions analysed henceforth. See Table 6.1 for ANOVA summary.

A Run×Condition×Block interaction was observed for implicit SRTT RTs. Figure 6.1 shows that RTs for Sequence conditions were faster than RTs for Random conditions, demonstrating sequence-specific learning, and this learning varied by Run and Condition.

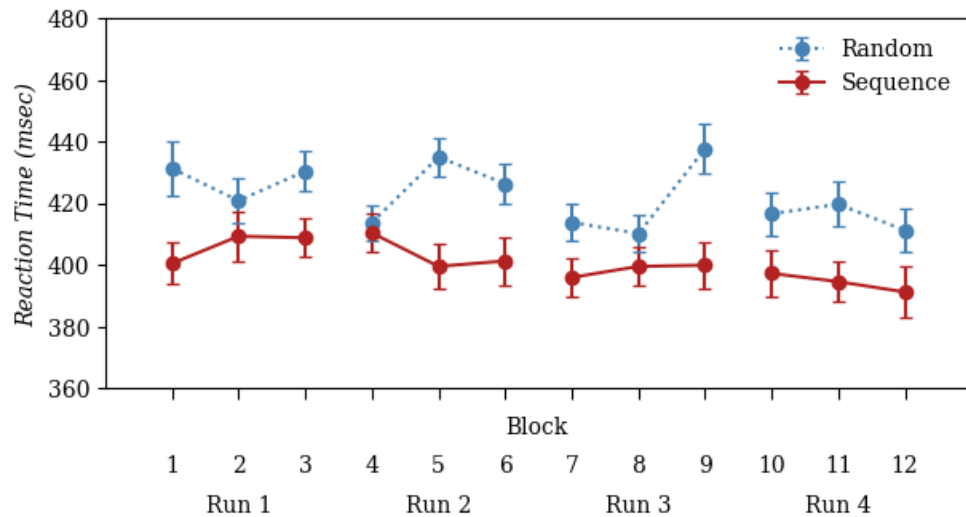


Figure F6.1. Median RTs plot for Run (4×3 blocks), Condition (Sequence, Random) and Block (block 1 to block 12). Error bars show 95% confidence intervals.

**Implicit SRTT performance and sensitivity.** A mixed ANOVA was run using within-groups factors of Run, Condition, and Block and between-groups factors of Sensitivity (HSP, non HSP). See Table 6.2 for the summary of results from the mixed ANOVA for full sensitivity and sensitivity residual group outputs.

For the HSPS (E,N) residuals, the Sensitivity×Condition interaction approached significance ( $p=.075$ ), visualized in Figure 6.2. An independent measures t-test revealed that both groups responded faster for Sequence versus Random conditions ( $p<.001$ ). However, the difference between conditions was almost significantly larger for HSP ( $M=27\text{ms}$ , 95% CI [20,33]) versus non-HSP ( $M=19\text{ms}$ , 95% CI [15,23]) groups,  $t(77)=1.8$ ,  $p=.075$ . No other between-groups or interaction effects were found for the HSPS or ATQ-OS or for the HSPS (E,N) or ATQ-OS (E,N) residuals groups ( $ps>.05$ ).

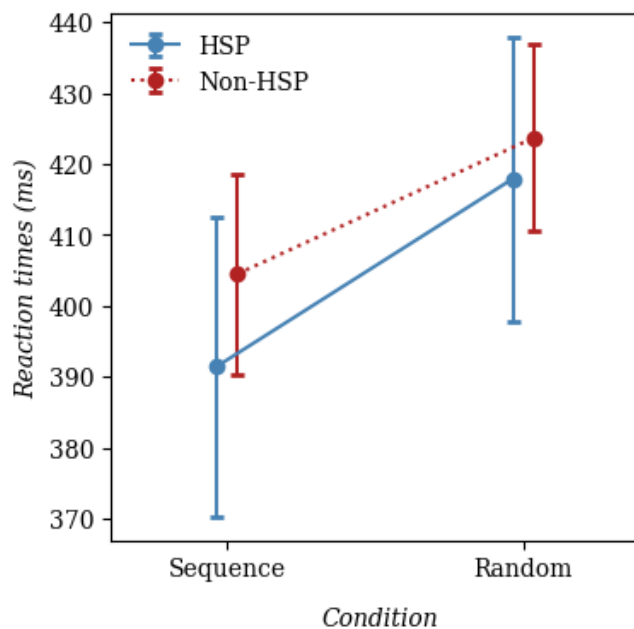


Figure F6.2. Sensitivity (HSP, non-HSP)×Condition (Sequence, Random) interaction. Error bars represent 95% confidence intervals.

**Implicit SRTT performance and creativity.** A mixed ANOVA was run using within-groups factors of Run, Condition, and Block and between-groups factors of Creativity (High, Low), separately for CAQ, RIBS and ATTA. No significant 4-way ( $p > .574$ ), 3-way ( $ps > .173$ ) or 2-way ( $ps > .225$ ) interactions or between groups effects ( $ps > .312$ ) were found for CAQ, RIBS, or ATTA measures.

### **Overall Explicit SRTT Performance**

RTs were analyzed with a repeated-measures ANOVA using within-groups factors of Condition (Random, Sequence) and Block (1 to 6). Due to missing values from participants who did not complete the task correctly, 19 participants were excluded from the analysis. See Table 6.3 for summary of repeated measures ANOVA.

Table 6.3 shows main effects of Block and Condition and the 2-way Block $\times$ Condition interaction are significant. Figure 6.3 below shows that the interaction is the result of learning effects between conditions differing over runs. Sequence RTs demonstrate sequence learning, becoming faster between runs 1 – 3 but stabilizing thereafter, whereas Random RTs remain stable and show little change over each run.

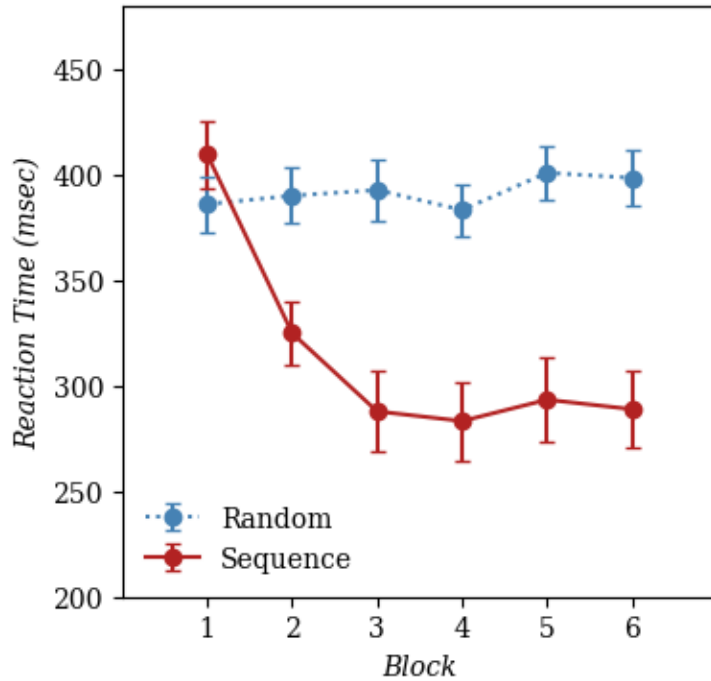


Figure F6.3. Reaction Times (RT) for Condition (Random, Sequence)×Block (1 to 6) interaction. Error bars show 95% confidence intervals.

**Explicit SRTT performance and sensitivity.** A mixed ANOVA was run using within-groups factors of Block and Condition and between-groups factors of Sensitivity (HSP, non HSP) group. Table 6.4 shows the output of the mixed ANOVA. For the ATQ-OS (E,N) residuals groups, a significant Sensitivity×Block interaction was found ( $p=.027$ ), indicating the group effect varies by Block. To interpret this interaction, planned simple effects analysis were done. The group effect was evaluated for each block separately, although no groups differences between blocks emerged ( $ps>.15$ ). To assess the Block effect in each group, Block 1 was compared to each of the other blocks. Simple contrasts using Block 1 as the baseline comparison revealed that ATQ-OS (E,N) residuals groups significantly differed in performance between Block 1 and Block 2,  $F(1,58)=7.5$ ,  $p<.01$ ,  $\eta_p^2=.115$ , as shown in Figure 6.4. Non-HSP showed a larger decrease in RTs from Blocks 1 to 2 than HSPs, indicating slower early learning in HSPs.

No other significant effects were found between ATQ-OS (E,N) groups when comparing blocks to baseline Block 1 performance ( $p > .05$ ). However, Figure 6.4 shows that by the last 2 blocks, HSPs are numerically faster than non-HSPs. Indeed, difference contrasts (comparing two consecutive blocks) indicate that group differences approach significance between Block 4 and 5,  $F(1,58)=3.55$ ,  $p=.065$ ,  $\eta_p^2=.058$ , and between block 5 and 6,  $F(1,58)=3.25$ ,  $p=.077$ ,  $\eta_p^2=.053$ . These patterns demonstrate that HSPs and non-HSPs have a different style of explicit SRTT learning.

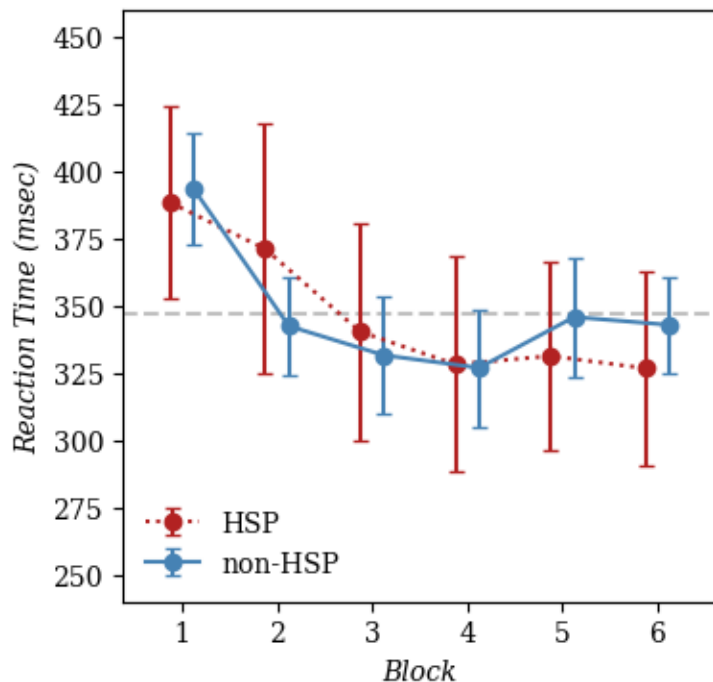


Figure F6.4. Reaction times for Block (1 to 6)×ATQ-OS (E,N) residuals group. Grey dashed line represents overall mean performance. Error bars show 95% confidence intervals.

**Explicit SRTT performance and creativity.** A mixed ANOVA was run using within-groups factors of Block and Condition and between-groups factors of Creativity (high, low), for CAQ, RIBS and ATTA, separately. Table 6.5 shows the output of the mixed ANOVA. A significant ATTA × Block interaction was found and visualized in Figure 6.5. To interpret this

interaction, planned simple effects analysis were done. The group effect was evaluated for each block separately, and results showed group differences emerged in Block 1,  $F(1,58)=5.85$ ,  $p=.019$ , where high ATTA groups ( $M=372\text{ms}$ , 95% CI[355,390]) were significantly faster than low ATTA groups ( $M=413\text{ms}$ , 95% CI[382,443]). No other groups differences between blocks emerged ( $ps>.45$ ). To assess the Block effect in each group, Block 1 was compared to each of the other blocks (with no correction). The Hochberg method of adjustment for family-wise error revealed that, in descending order of significance, performance in Blocks 6, 3 and 5 differed significantly from Block 1 across ATTA groups ( $ps<.05$ ). The largest effect was found between Block 1 and 6, and the pattern remains the same for Blocks 3 and 5 versus Block 1. For example, with low ATTA groups, the RTs in Block 6 ( $M=333\text{ms}$ , 95% CI[310,357]) versus Block 1 ( $M=413\text{ms}$ , 95% CI[389,437]) is a greater decrease than the RTs in Block 6 ( $M=342\text{ms}$ , 95% CI[319,364]) versus Block 1 ( $M=372\text{ms}$ , 95% CI[349,396]) for high ATTA groups, a difference of 50ms,  $F(1,58)=10.37$ ,  $p<.01$ ,  $\eta_p^2=.152$ . Difference contrasts (comparing two consecutive blocks) revealed no further significant group differences with the Hochberg method of adjustment for family-wise error other than those reported in comparison with Block 1. These patterns demonstrate that high and low ATTA groups have a different style of explicit SRTT learning.

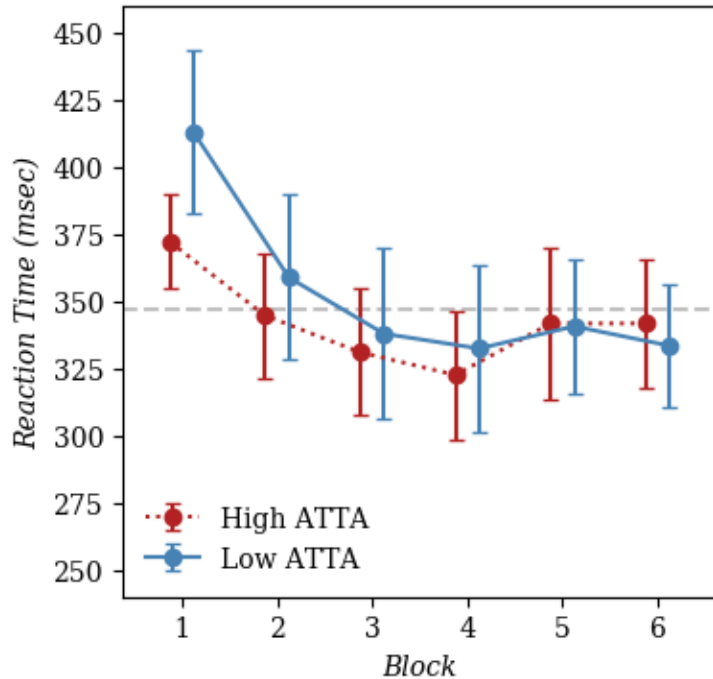


Figure F6.5. Reaction times for Run (Run 1 to 6)×ATTA group. Grey dashed line represents overall mean performance. Error bars show 95% confidence intervals.

### Implicit SRTT: Higher-Order Associative Learning

Higher-order association learning was analyzed for RTs with a repeated measures ANOVA using within-groups factors of Run (Run 1 to Run 4) and Transition Pair (12 pairs). Mauchleys Test of Sphericity was violated for Transition Pair, and for interaction terms of Run×Transition Pair ( $p_s < .001$ ), thus Greenhouse-Geisser correction was applied for those main effects and interactions henceforth. See Table 6.6 for the summary of ANOVA results.

Results showed that higher-order associative learning did not differ across runs. However, learning differed between transitions, where some transitions showed higher learning scores than others. For example, transition pair “4-3” ( $M=-1.16$ , 95% CI [-5.63, 3.3]) was not significantly different from zero,  $t(78)=.52$ ,  $p=.606$ , and transition pair “2-1” ( $M=-17.77$ , 95% CI [-13.46, -22.08]) median RTs were significantly slower for Sequence versus Random conditions,



$t(78)=8.21, p < .001$ . However all other transition pairs differed significantly from zero ( $ps < .001$ ), except “4-2” ( $p=.002$ ). The significant Run $\times$ Transition Pair showed that the increase in RT differences from higher-order associative learning across runs differed between transition pair. See Figure 6.6 for a visualization of the Run $\times$ Transition Pair interaction.

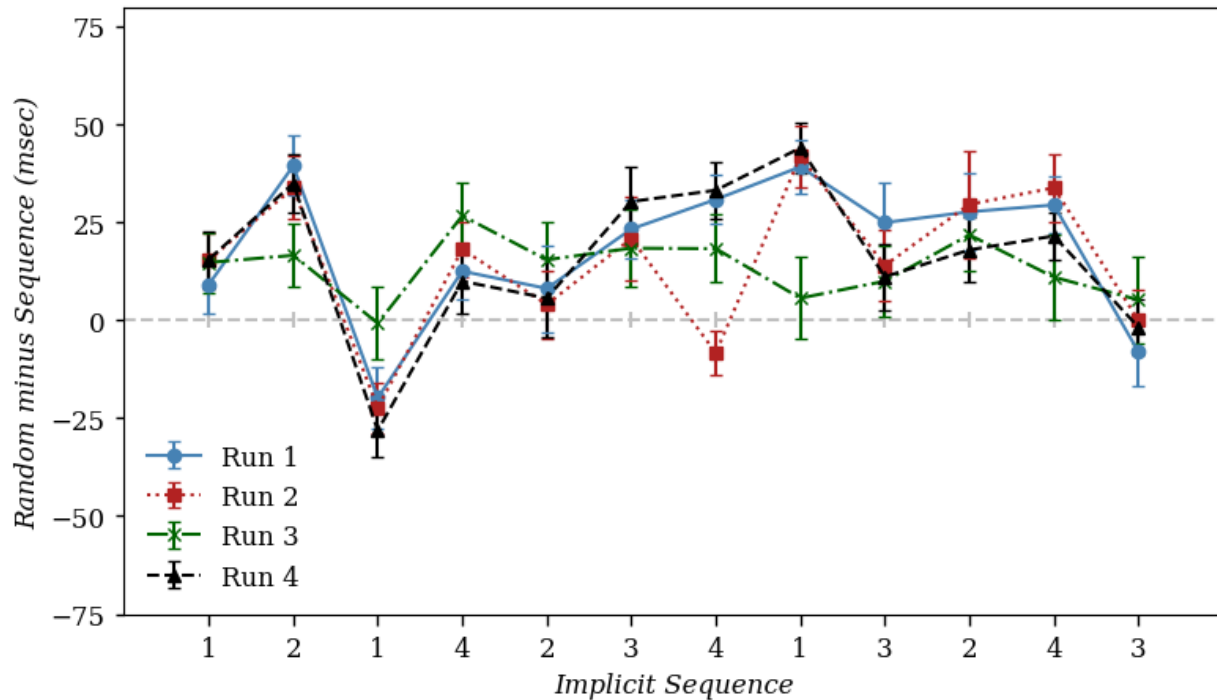


Figure F6.6. Median reaction time (ms) difference for Conditions (Random – Sequence) by Run (run 1 to run 4) and Transition Pair (12 pairs). Error bars show 95% confidence intervals. Grey horizontal dashed line at  $y=0$  shows no difference between Sequence and Random conditions.

**Implicit SRTT: higher-order associative learning and sensitivity.** Sensitivity group differences in higher-order association learning for RTs was analyzed with a mixed measures ANOVA using within-groups factors of Run (Run 1 to Run 4) and Transition Pair (12 pairs) and between-groups factors of Sensitivity (HSP, non HSP). See Table 6.7 for ANOVA output.

A between-groups effect of HSPS (E,N) residuals approached significance ( $p=.083$ ),

where HSPs ( $M=20\text{ms}$ , 95% CI [14,25]) had more positive transition RTs than non-HSPs ( $M=14\text{ms}$ , 95% CI [11,17]) overall suggesting comparatively greater acquisition of higher-order associations overall. No other effects were observed ( $p>.05$ ).

**Implicit SRTT: higher-order associative learning and creativity.** Creativity groups differences in higher-order association learning for RTs were analyzed with a mixed measures ANOVA using within-groups factors of Run and Transition Pair and between-groups factors of Creativity (high, low), separately for CAQ, RIBS and ATTA. See Table 6.8 for ANOVA output. A 3-way Run $\times$ Transition Pair $\times$ ATTA Group interaction was found ( $p=.022$ ) where RT differences in higher-order associative learning across runs differed between transition pair, and this effect differed between high and low ATTA groups (see Figure 6.7 for visualization). A between-groups effects for ATTA groups approached significance ( $p=.094$ ) where high ATTA groups ( $M=13\text{ms}$ , 95% CI [9, 17]) show overall smaller effects of higher-order associative learning than low ATTA groups ( $M=18\text{ms}$ , 95% CI [14, 22]).

The 3-way interactions suggest that run effects varied between groups for some transition pairs. To interpret the 3-way interaction, for each transition pair, the run $\times$ group interaction was assessed (run with no correction). The Hochberg method of adjustment for family-wise error revealed that only transition points “2-4” ( $p=.006$ ) and “4-3” ( $p=.012$ ) were significant in the Run $\times$ ATTA group interaction. Figure 6.7 suggests that the Run $\times$ Group interaction for transition pair “2-4” is a result of High ATTA groups showing reduced higher-order associative learning for run 3, not evident in the low ATTA group. However, the high ATTA group shows greater higher-order associative learning than the low ATTA group in run 3 for transition pair “4-3”. Thus the pattern of how higher-order associative learning develops across runs for each transition pair differs between high and low ATTA, suggesting learning processes differ with ATTA creativity.

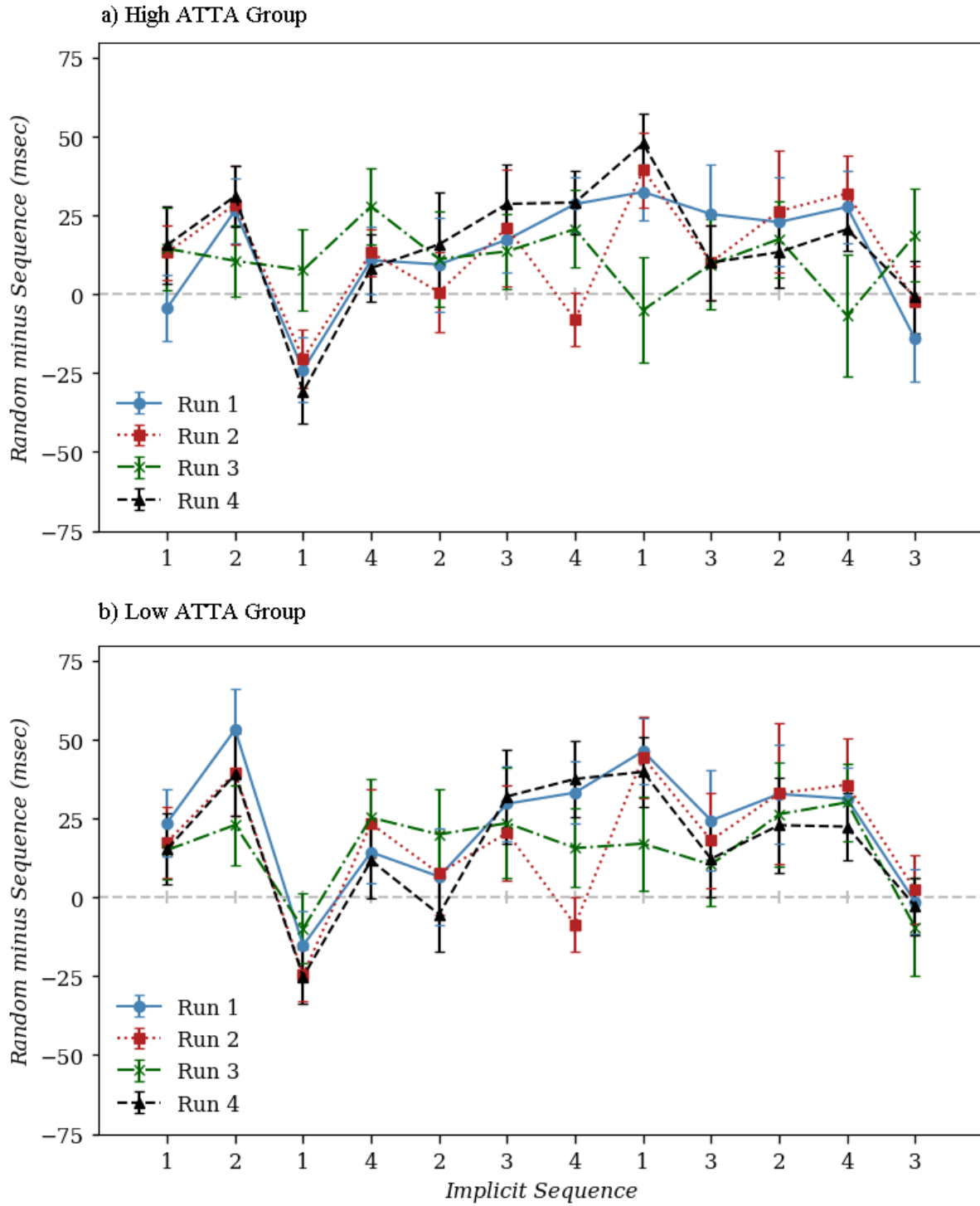


Figure F6.7. Median RT for Run (run 1 to run 4) and Transition Pair (12 pairs) for a) High ATTA groups and b) Low ATTA groups. Error bars show 95% confidence intervals. Grey

horizontal dashed line at  $y=0$  represents no differences between Sequence and Random conditions.

### Explicit SRTT Higher-Order Associative Learning

Higher-order associative learning in the explicit condition was analyzed by collapsing RTs across runs to look at overall higher-order learning for transition pairs. Analysis of Block (1 to 6)×Transition pair (12 pairs) was not performed as only 26 participants had complete data for each transition across each Block, and thus **individual difference analyses were not performed due to inadequate group sizes**. The Hochberg method of adjustment for family-wise error revealed that transition pairs differed according to higher-order learning. For example, transition pair “1-2”,  $t(69)=.891$ ,  $p=.376$ , and transition pair “4-3”,  $t(69)=1.88$ ,  $p=.064$ , were not significantly different from zero. The remaining transition pairs were significantly different from zero ( $ps<.001$ ). See Figure 6.8 for visualization of higher-order associative learning.

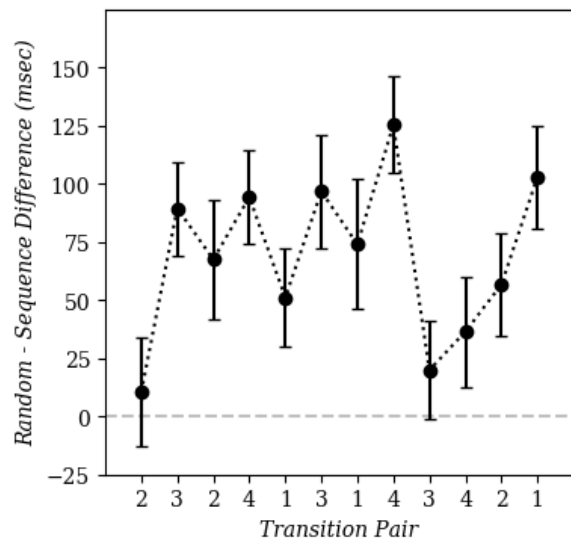


Figure F6.8. Median RT for Transition Pair (12 pairs) in explicit SRTT. Error bars show 95% confidence intervals. Grey horizontal dashed line at  $y=0$  represents no difference between Sequence and Random conditions.

### Explicit Memory Tests: Awareness

**Implicit SRTT: awareness.** Table 6.9 shows ratings participants reports to (Q1) the boxes lit up at random locations the entire time; (Q2) some boxes lit up more often than other boxes; (Q3) the task was easier at times and harder at other times; (Q4) there was a repeating pattern of locations some of the time. The frequency values suggest that at least 9 participants report the locations were not always random (Q1), and at least 35 participants report that there was a repeating pattern of locations some of the time (Q4), suggesting awareness.

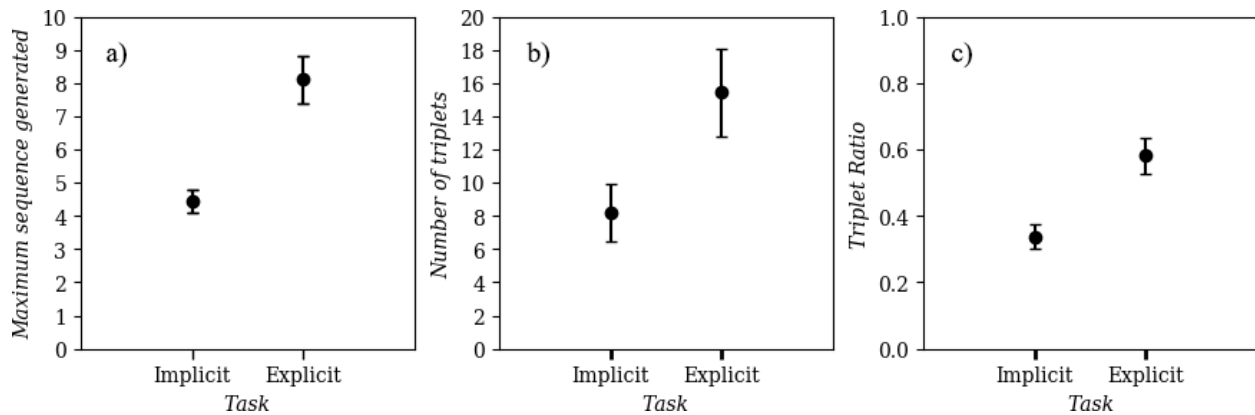
**Implicit SRTT: awareness and sensitivity.** An independent samples t-test was run to compare question ratings between sensitivity (HSP, non-HSP) groups. No between-groups differences in awareness ratings were observed between HSPs or ATQ-OS groups ( $p>.128$ ) or ATQ-OS (E,N) residuals groups ( $p>.351$ ). However, a significant group difference,  $t(77)=2.3$ ,  $p=.024$ , was observed between HSPs (E,N) groups for Q4, where HSPs ( $M=1.71$ , 95% CI [1.36,2.1]) showed lower mean ratings than non-HSPs ( $M=2.35$ , 95% CI [2,2.7]), suggesting that HSPs versus non-HSPs were more likely to think there was a repeating pattern some of the time (Q4) and thus suggesting greater awareness in HSPs versus non-HSPs groups.

**Implicit SRTT: awareness and creativity.** An independent samples t-test was run to compare question ratings between Creativity groups (high, low) for CAQ, RIBS and ATTA, separately. No between groups differences were observed between CAQ ( $p>.340$ ) or ATTA groups ( $p>.144$ ). However, RIBS groups showed significantly different responses,  $t(77)=2.19$ ,  $p=.032$ , to Q1 where the high RIBS group ( $M=2.26$ , 95% CI [1.98,2.56]) have higher mean ratings for Q1 than the low RIBS group ( $M=1.78$ , 95% CI [1.49,2.11]), demonstrating that the high RIBS group rate sequences as less random than the low RIBS group, suggesting more awareness of sequence structure in the high versus low RIBS groups. No other differences in

ratings were found for RIBS groups ( $ps > .467$ ).

### Explicit Memory Tests: Free Generation

**Free generation omnibus task comparison for implicit and explicit SRTT.** A within-groups ANOVA was performed to analyze performance on free generation across implicit and explicit SRTT tasks for a) maximum sequences generated, b) number of triplets generated, and c) ratio of triplets to keypresses. Table 6.10 shows the summary ANOVA output and Figure 6.9 shows the overall performance for each measure of free generation for both implicit and explicit SRTT tasks. For each measure of free generation, recall in the explicit task was significantly greater than in the implicit task ( $ps < .001$ ).



*Figure F6.9.* The significant within-groups main effects for implicit and explicit SRTT free generation tasks for a) maximum sequence generated, b) number of triplets generated and c) triplet ratios with error bars showing 95% confidence intervals.

**Free generation omnibus task comparison and sensitivity.** Separate omnibus mixed ANOVA were performed to analyze group differences in performance on free generation across implicit and explicit SRTT task for a) maximum sequences generated, b) number of triplets generated, and c) ratio of triplets to keypresses between sensitivity (HSP, non-HSP) groups. Results relating to group main effects and interactions are reported, but see Table 6.10 for overall

within-groups effects. The mixed ANOVA used within-groups factor of task (implicit, explicit) and between-groups variable of Sensitivity group. Table 6.11 shows the ANOVA revealed no 2-way, or between-groups main effects for full HSPS and ATQ-OS or HSPS (E,N) and ATQ-OS (E,N) residuals.

**Free generation omnibus task comparison and creativity.** Separate omnibus mixed ANOVA were performed to analyze group differences in performance on free generation across implicit and explicit SRTT task for a) maximum sequences generated, b) number of triplets generated, and c) ratio of triplets to keypresses between creativity groups (high, low) for CAQ, RIBS and ATTA, separately. Each mixed ANOVA used within-groups factor of task (implicit, explicit) and between-groups variable of Creativity group. See Table 6.12 for the mixed ANOVA output.

Table 6.12 shows a significant task×group interaction was observed for both maximum sequence generated and triplet ratios for the ATTA measure, visualized in Figure 6.10. Both high and low ATTA groups generate longer sequences for explicit versus implicit tasks ( $p < .001$ ), however the differences in maximum sequences generated for explicit versus implicit tasks is significantly larger for low ( $M = 4.51$ , 95% CI [3.53, 5.5]) versus high ( $M = 2.84$ , 95% CI [1.84, 3.85]) ATTA groups,  $t(77) = 2.28$ ,  $p = .025$ . Figure 6.10b below shows the interaction between triplet ratios by task and ATTA group. Both high and low ATTA groups generate higher triplet ratios for explicit versus implicit tasks ( $p < .001$ ), but the differences in triplet ratios for explicit versus implicit tasks is significantly larger for low ( $M = .316$ , 95% CI [.24, .395]) versus high ( $M = .175$ , 95% CI [.094, .253]) ATTA groups,  $t(77) = 2.28$ ,  $p = .025$ . Together, the findings show that high versus low ATTA groups generate shorter sequences and lower triplet ratios during explicit versus implicit tasks. No 2-way or between-groups effects for CAQ or RIBS were

observed ( $p > .05$ ).

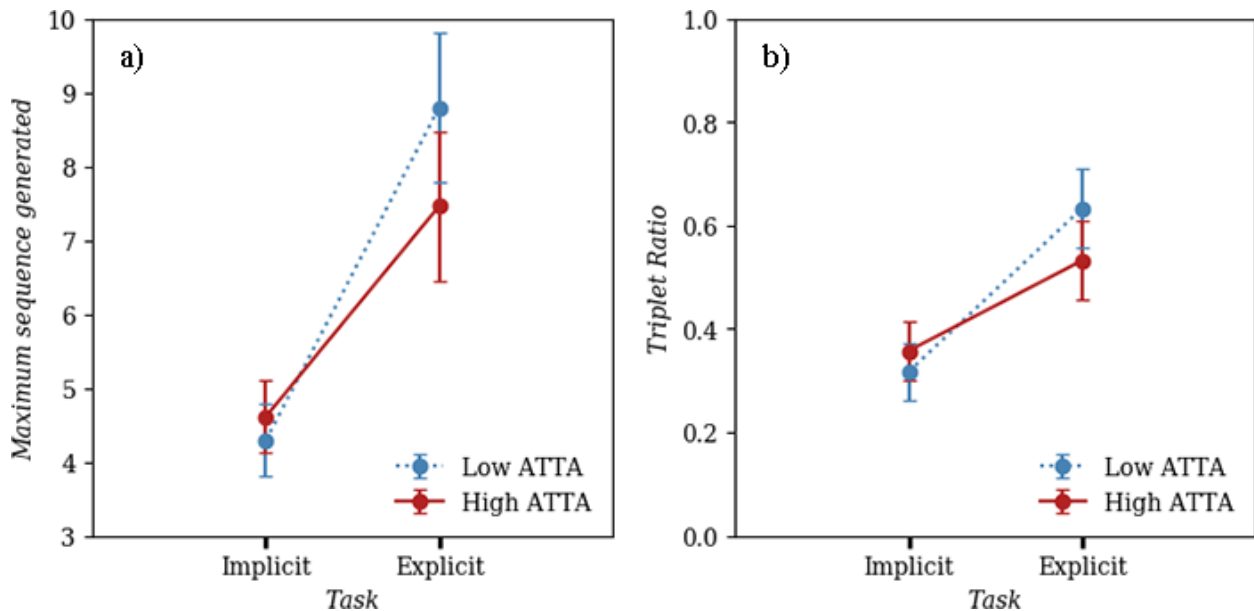


Figure F6.10. The significant two-way interaction of learning (implicit, explicit) and ATTA group (low, high) for free generation following the SRTT tasks for a) maximum sequence generated and b) triplet ratios. Error bars show 95% confidence intervals.

**Implicit SRTT: free generation and sensitivity.** An independent samples t-test was run to compare maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses between sensitivity (HSP, non-HSP) groups. No between-groups differences were found for the full HSPS ( $p > .589$ ) or ATQ-OS ( $p > .413$ ), or ATQ-OS (E,N) residuals groups ( $p > .487$ ). For HSPS (E,N) residuals, a group difference in maximum sequences generated was significant,  $t(77) = 2.29$ ,  $p = .025$ , where HSP groups ( $M = 5.04$ , 95% CI [4.53, 5.58]) show longer mean maximum sequences generated in free recall compared with non-HSP groups ( $M = 4.2$ , 95% CI [3.8, 4.6]). Also, a significant group difference was found for triplet ratio,  $t(77) = 2.54$ ,  $p = .013$ , where HSP groups ( $M = .41$ , 95% CI [.344, .475]) show higher triplet ratios in free generation compared with non-HSP groups ( $M = .307$ , 95% CI [.266, .348]). No between-groups effects were



found for number of triplet reported ( $p > .632$ ) for HSPS (E,N) residuals. See Figure 6.11 for visualization.

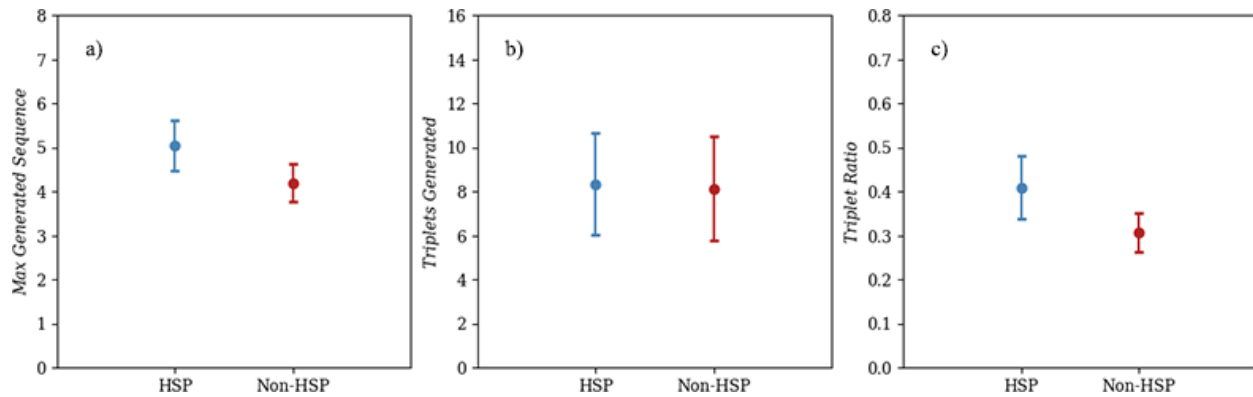


Figure F6.11. Free generation mean a) maximum length of sequences generated, b) number of sequence consistent triplets generated, and c) triplet ratios following the implicit task for HSP and non-HSP groups as defined by HSPS (E,N) residuals. Error bars represent 95% confidence interval.

Overall, when negative affect is partialled out, HSP versus non-HSP groups of the HSPS, but not the ATQ-OS, freely generate longer sequences, and show greater accuracy in regards to triplets recalled versus sequence inconsistent keypresses, following exposure to implicit sequences.

**Implicit SRTT: free generation and creativity.** An independent samples t-test was run to compare maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses between Creativity (high, low) groups, for CAQ, RIBS and ATTA, separately. No effects were found ( $ps > .235$ ).

**Explicit SRTT: free generation.** Figure 6.12 below shows the outcome of the free generation runs (blocks) within the explicit SRTT task, showing a) maximum number of sequences generated, b) number of consistent triplets generated, and c) triplet ratios, for each run,

and with overall mean represented by dashed line. Overall, Figure 6.12 shows a sharp increase in recall in free generation within the first 3 runs, with learning and recall leveling out in the remaining runs.

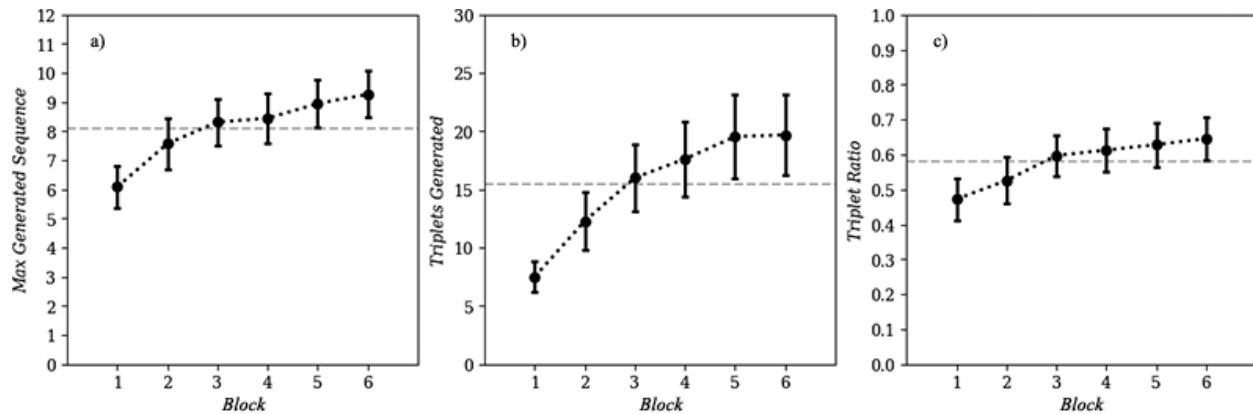


Figure F6.12. Free generation mean a) maximum length of sequences generated, b) number of sequence consistent triplets generated, and c) triplet ratios for each Block in the explicit task. Dashed silver line represents overall mean across Block. Error bars represent 95% confidence interval.

**Explicit SRTT: free generation and sensitivity.** Group differences in maximum sequences generated, number of sequence consistent triplets generated, and triplet ratios in free generation were analyzed separately with a mixed ANOVA using within-groups factor of Block (1 to 6) and between-groups factor of sensitivity (HSP, non-HSP) groups. See Table 6.13 for mixed ANOVA results. For maximum generated sequences, a 2-way Block $\times$ Group interaction was found for HSPS (E,N) residuals groups ( $p=.01$ ). Simple effects analysis comparing HSPS (E,N) residuals group performance across each block did not reveal any significant group differences ( $ps>.24$ ). Figure 6.13 and simple contrasts using Block 1 as a baseline comparison reveal that HSPS (E,N) residual group differences are significant in Block 5 ( $p=.024$ ) and marginal in Block 6 ( $p=.058$ ), showing that explicit memory improves significantly more with

learning after 5 blocks of trials for HSPs than non-HSPs. No other significant main effects or interactions were found ( $p>.05$ ).

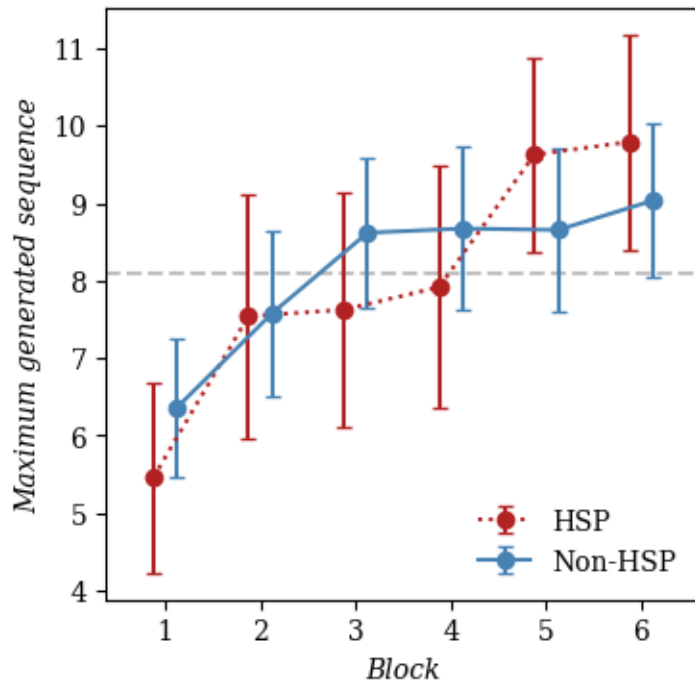


Figure F6.13. The Block $\times$ HSPS (E,N) residuals group interaction for maximally generated sequences in the free generation task following each explicit SRTT block. Error bars represent 95% confidence interval.

**Explicit SRTT: free generation and creativity.** Creativity group differences in maximum sequences generated, number of consistent triplets generated, and triplet ratios in free generation were analyzed separately with a mixed ANOVA using within-groups factor of Block (1 to 6) and between-groups factor of Creativity (high, low) for CAQ, RIBS and ATTA, separately. See Table 6.14 for ANOVA output.

For maximum generated sequences, a group difference approached significance,  $F(1,77)=3.57$   $p=.063$ ,  $\eta_p^2=.044$ , for ATTA groups where high ATTA groups ( $M=7.46$ , 95% CI [6.49, 8.44]) have shorter maximum length of sequences generated than low ATTA groups

( $M=8.8$ , 95% CI [7.78, 9.81]). For triplets ratios, a group difference approached significance,  $F(1,77)=3.68$   $p=.059$ ,  $\eta_p^2=.046$ , for ATTA groups where high ATTA groups ( $M=.53$ , 95% CI [.46, .61]) have lower triplet ratios than low ATTA groups ( $M=.63$ , 95% CI [.56, .71]). Overall, the findings show that high versus low ATTA groups freely generate shorter sequences, and display less accuracy in regards to triplets recalled versus sequence inconsistent keypresses, following exposure to explicit sequences. No other effects were found ( $ps>.05$ ).

### **Explicit Memory Tests: Cued Generation**

**Implicit SRTT: cued generation.** Table 6.15 shows summary statistics for a) maximum number of sequences generated, b) number of consistent triplets generated, and c) triplet ratios taken from the cued generation task following the implicit SRTT.

**Implicit SRTT: cued generation and sensitivity.** An independent samples t-test was run to compare maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses between sensitivity (HSP, non-HSP) groups. No effects were found for the full HSPS ( $ps>.361$ ), or HSPS (E,N) residuals groups ( $ps>.113$ ). For full ATQ-OS, a significant group difference was found for maximum sequence generated,  $t(77)=2.31$ ,  $p=.024$ , where HSP groups ( $M=6.92$ , 95% CI [6.22,7.65]) showed longer mean maximum sequences generated in cued recall compared with non-HSP groups ( $M=6.02$ , 95% CI [5.64,6.42]). However, this group difference disappears when negative affect is partialled out ( $p>.179$ ). No between-groups effects were found for triplets generated, or ratio of triplets to keypresses for the full ATQ-OS ( $ps>.55$ ), or ATQ-OS (E,N) residuals ( $ps>.95$ ).

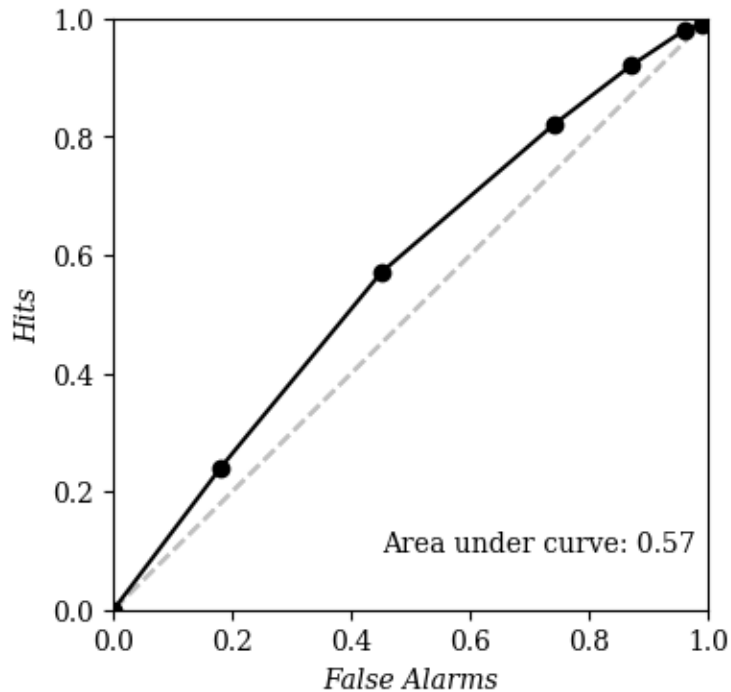
Overall, HSPS scores do not differ according to maximum sequences generated number of triplets generated, or triplet ratios. Group differences in maximum sequences generated emerge between ATQ-OS groups, but these group differences disappear when negative affect is partialled

out, suggesting these effects relate to negative affect.

**Implicit SRTT: cued generation and creativity.** An independent samples t-test was run to compare maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses between Creativity (high, low) groups, for CAQ, RIBS and ATTA, separately. No effects were found ( $ps > .133$ ).

### **Explicit Memory Tests: Triplet Recognition**

**Implicit SRTT: triplet recognition.** In triplet recognition, ratings closer to 1 indicate higher certainty the sequence was seen before, and ratings closer to 6 indicate higher certainty that the sequence was not seen before. Ratings for Sequence (Old) triplets ( $M=2.47$ , 95% CI [2.35, 2.61]) were significantly lower,  $t(78)=5.72$ ,  $p < .001$ , than ratings for Random (New) triplets ( $M=2.81$ , 95% CI [2.67, 2.95]), showing that participants rated old triplets as more similar than new triplets to the repeating sequences. Figure 6.14 below shows the area under curve as .57 (95% CI [.55, .59]) and a linear discriminant analysis showed that cases from the two conditions (i.e., new and old) could be classified with 59.5% accuracy (one-out cross-validation). Whilst the t-test analysis suggests that old triplets are more familiar than new triplets thus suggesting explicit knowledge of the repeating sequence, the ROC analysis suggests that participants fail to explicitly discriminate old and new triplets because classification accuracy of old versus new triplets is just above chance level (Tape, 2006).



*Figure F6.14.* Receiver Operating Characteristics (ROC) and area under curve for triplet recognition ratings.

In triplet recognition, certainty ratings of triplets may be influenced by implicit memory or motor fluency (Schendan et al., 2003b; Shanks & Johnstone, 1999). According to Shanks and Johnstone (1999), motor fluency cannot be considered the same as implicit learning because motor fluency is consciously experienced and may be associated with explicit sequence knowledge. Motor fluency would be suggested with faster RTs for old versus new sequences at Location 3, and as motor fluency suggests either explicit sequence knowledge (Shanks & Johnstone, 1999), or feelings of sequence familiarity (Schendan et al., 2003b), then faster RTs for old versus new sequences at Location 3 should be related to higher recognition ratings for old versus new sequences (i.e., positively correlated). Triplet RTs were thus analysed with the goal to examine whether ratings were contaminated with motor fluency.

Performance for triplets was analyzed between conditions by comparing median RTs for the three locations in a repeated measures ANOVA using within-groups factors of Condition (New, Old) and Location (Location 1, Location 2, Location 3). 9 participants were excluded in the triplet generation RT analysis due to not responding with key presses during sequence presentation. See Table 6.16 for the ANOVA summary output. The ANOVA revealed effects of condition where median RTs for new conditions ( $M=411\text{ms}$ , 95% CI [400,423]) were slower than median RTs for old conditions ( $M=403\text{ms}$ , 95% CI [392,414]). The main effect of location is due to location 1 conditions ( $M=439\text{ms}$ , 95% CI [426,451]) having slower median RTs than both location 2 ( $M=392\text{ms}$ , 95% CI [382, 403]) and location 3 ( $M=391\text{ms}$ , CI [379,402]) ( $p<.001$ ), but no difference was found between location 2 and location 3 ( $p=1$ ). Simple contrasts show the Condition $\times$ Location interaction was the result of a greater condition effect for Location 3 versus Location 1,  $F(1,69)=7.02$ ,  $p=.01$ ,  $\eta_p^2=.092$ , and Location 2,  $F(1,69)=6.29$ ,  $p=.014$ ,  $\eta_p^2=.084$ . As SOC sequences are equated for bi-item frequency, higher-order learning effects with SOC are only observed between 3 or more locations (Curran, 1997; Reed & Johnson, 1994; Schendan et al., 2003b). Put another way, SOCs refer to the fact that at least two prior locations are needed to predict the next location in the sequence (Shanks & Johnstone, 1999). Thus higher-order associative learning is only observed in Location 3. Indeed, simple effects analysis of median RTs were significantly faster for old than new triplets for Location 3,  $t(69)=3.75$ ,  $p<.001$ , but not other locations ( $ps>.276$ ), as shown in Figure 6.15. This raises the possibility that implicit memory or motor fluency could influence explicit ratings of sequence triplet recognition. To check for motor fluency influence on ratings, a Spearman's correlation was performed to examine the relationship between new – old difference RTs for Location 3 and new – old difference ratings. The analysis revealed no significant relationship between the two variables,  $r_s(69)=.056$ ,

$p=.64$ , thus showing that motor fluency does not influence ratings.

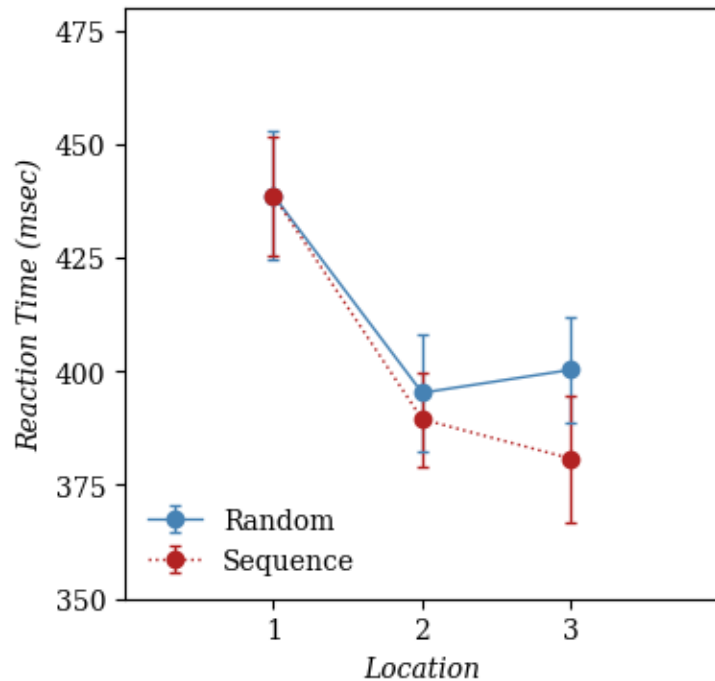


Figure F6.15. Triplet recognition median RT for Condition (Random, Sequence) by Location (Location 1 to Location 3). Error bars show 95% confidence intervals.

**Implicit SRTT: triplet recognition and sensitivity.** Ratings for Sequence and Random triplets were analysed with a mixed ANOVA using within-subjects factors of sequence (Random [New], Sequence [Old]) and between-groups factors of sensitivity (HSP, non-HSP). For the HSPs, a between-groups effect approached significance,  $F(1,69)=3.83$ ,  $p=.054$ ,  $\eta_p^2=.053$ , where HSPs ( $M=2.45$ , 95% CI[2.21, 2.68]) gave lower ratings overall than non-HSPs ( $M=2.72$ , 95% CI[2.57,2.87]), although this effect is not significant when negative affect is controlled ( $p>.3$ ), and no other between-groups effects were significant ( $p>.102$ ). Further, no sequence $\times$ sensitivity interactions emerged for any sensitivity measures ( $p>.349$ ).

A comparison of new versus old triplet recognition on median RTs was performed using a mixed ANOVA using within-groups factors of Condition (Random, Sequence) and Location



(1,2,3), and between-groups factor of Sensitivity (HSP, non-HSP) groups. See Table 6.17 for results of the mixed ANOVA.

A 3-way interaction was observed for the full ATQ-OS ( $p=.04$ ). Simple effects were used to determine whether RTs for each condition differed at Location 3. Paired samples t-tests showed that non-HSPs were faster to respond in old ( $M=372\text{ms}$ , 95% CI[356,388]) versus new ( $M=400\text{ms}$ , 95% CI[386,414]) conditions,  $t(49)=4.51$ ,  $p<.001$ , whereas HSPs show little difference in Location 3 for old ( $M=403\text{ms}$ , 95% CI[378,432]) versus new ( $M=402\text{ms}$ , 95% CI[379,426]) conditions ( $p=.9$ ). Further, the difference between conditions was significantly larger for non-HSPs versus HSPs,  $t(68)=2.6$ ,  $p=.011$ .

No between-groups ( $p>.489$ ) or interaction effects ( $p>.350$ ) were observed for the full HSPS, but, with negative affect partialled out, a 3-way interaction (see Figure 6.16) emerged with HSPS (E,N) residuals ( $p=.01$ ) similar in nature to the ATQ-OS 3-way interaction. Simple effects were used to determine whether RTs for each condition differed at Location 3. Paired samples t-tests revealed that non-HSPs were faster to respond in old ( $M=373\text{ms}$ , 95% CI[358,389]) versus new ( $M=399\text{ms}$ , 95% CI[385,413]) conditions,  $t(49)=4.29$ ,  $p<.001$ , whereas HSPs show almost no difference in Location 3 for old ( $M=400\text{ms}$ , 95% CI[371,430]) versus new ( $M=403\text{ms}$ , 95% CI[383,423]) conditions ( $p=.73$ ). Further, the difference between conditions was significantly larger for non-HSPs versus HSPs,  $t(68)=2.02$ ,  $p=.047$ . This raises the possibility that implicit memory or motor fluency could influence explicit ratings of sequence triplet recognition in non-HSPs, but not HSPs. To check for the influence of motor fluency on ratings, data were split by HSPS (E,N) residuals group and a Spearman's correlation was performed for each group to examine the relationship between new – old difference RTs for Location 3 and new – old difference ratings. The analysis revealed no significant linear relationship between the two

variables for HSPs,  $r_s(19)=.001$ ,  $p=1$ , or for non-HSPs,  $r_s(48)=.095$ ,  $p=.51$ , showing that motor fluency does not influence ratings for either HSPS (E,N) residuals group.

Overall, the effects show that HSPs on the HSPS rate all triplets as more familiar than non-HSPs, or, put another way, non-HSPs rate all triplets as more novel than HSPs, although effects disappear when negative affect is partialled out. Further, HSPs show less evidence than non-HSPs of implicit learning or motor fluency in higher-order associations measured with the triplets, but neither group shows evidence of motor fluency contamination of ratings.

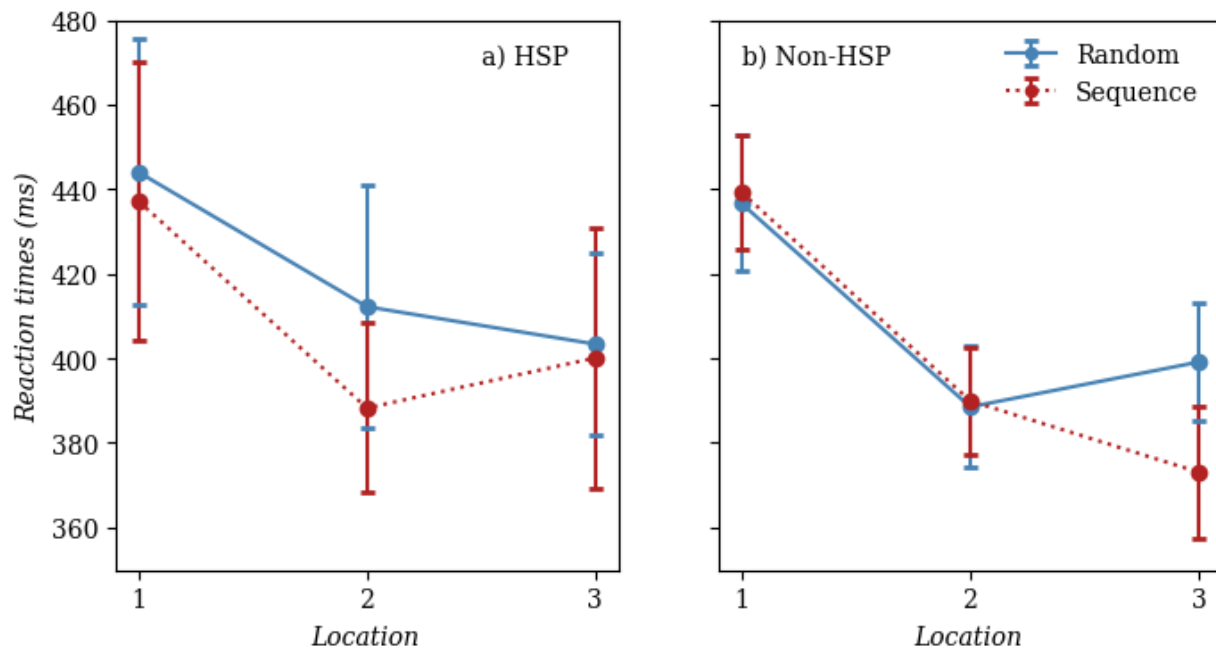


Figure F6.16. Triplet recognition median RT for Condition (Random, Sequence) by Location (Location 1 to Location 3) for a) HSPs and b) non-HSPs for HSPS (E,N) residuals. Error bars show 95% confidence intervals.

**Implicit SRTT: triplet recognition and creativity.** Ratings for Sequence and Random triplets were analysed with a mixed ANOVA using within-subjects factors of sequence (Random [new], Sequence [old]) and between-groups factors of creativity (high, low). No between-groups

effects ( $p > .29$ ) or sequence  $\times$  creativity interactions ( $p > .38$ ) were found for the CAQ, RIBS or ATTA.

A comparison of Random versus Sequence triplet recognition was performed using a mixed ANOVA using within-groups factors of Condition (Random, Sequence) and Location (1,2,3), and between-groups factor of Creativity (high, low) for CAQ, RIBS and ATTA, separately. For each creativity measure, no 3-way ( $p = .110$ ) or 2-way interactions ( $p > .189$ ) or between-groups effects ( $p = .103$ ) were found.

### **Explicit Memory Tests: Full Recognition**

**Full recognition omnibus task comparison for implicit and explicit SRTT.** An omnibus repeated-measures ANOVA was used to analyze recognition ratings of the full sequence between implicit and explicit tasks using factors of task (implicit, explicit) and sequence (target, random). Note, higher ratings indicate awareness of the repeating sequence. Table 6.18 shows the summary results of the ANOVA.

Table 6.18 shows that main effects of task were not significant ( $p > .05$ ), but the main effect of Sequence was significant, where overall Target sequences ( $M = 7.01$ , 95% CI[6.57,7.44]) had higher ratings overall (where higher ratings indicate greater recognition of sequences) than Random sequences ( $M = 5.04$ , 95% CI[4.75,5.32]). The significant Task  $\times$  Sequence interaction, visualized in Figure 6.17 shows that the difference between Target and Random ratings changes depending on the task. Targets sequences were given higher recognition ratings in explicit versus implicit tasks,  $t(78) = 3.65$ ,  $p < .001$ , and Random sequences were given lower recognition ratings in explicit versus implicit tasks,  $t(78) = 4.15$ ,  $p < .001$ , giving a larger mean difference in recognition ratings ( $M = 2.46$ , 95% CI [1.44,3.47]) for the explicit versus implicit tasks,  $t(78) = 4.8$ ,  $p < .001$ . These effects show that explicit knowledge of the repeated sequence was more

consciously available following the explicit versus implicit task. However, target sequences produced significantly higher recognition ratings than random sequences for explicit and implicit tasks ( $p < .01$ ), meaning the repeated versus random sequence was more consciously available following both explicit and implicit task, where the effect of sequence was larger for explicit tasks ( $p < .001$ ).

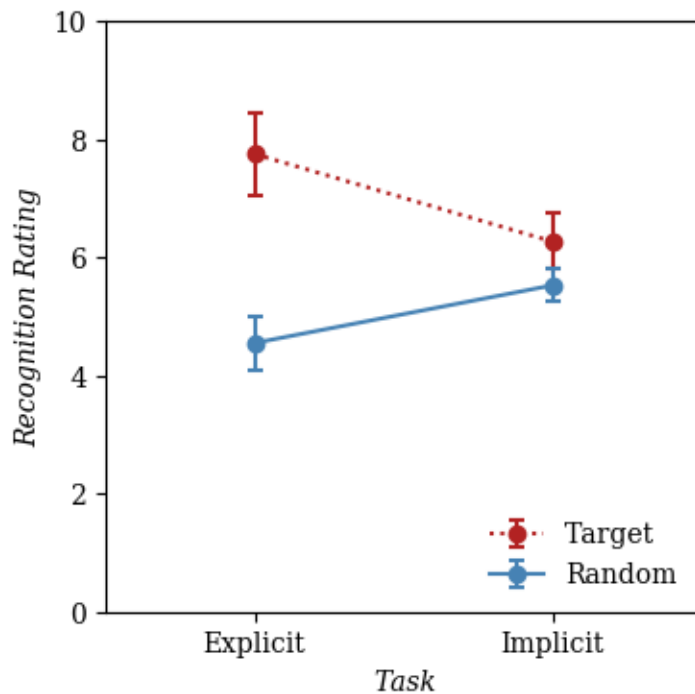


Figure F6.17. The Task (implicit, explicit)×Sequence (Target, Random) interaction for full sequence recognition ratings. Error bars show 95% confidence intervals.

**Full recognition omnibus task comparison and sensitivity.** An omnibus mixed measures ANOVA was used to analyze group differences in recognition ratings of the full sequence between implicit and explicit tasks using within-group factors of task (implicit, explicit) and sequence (target, random), for between groups factors of sensitivity (HSP, non-HSP),

separately. Table 6.19 shows the ANOVA results, revealing a significant between-groups effect for the HSPS groups, where HSP ( $M=6.43$ , 95% CI [5.97,6.9]) groups gave higher recognition ratings overall than non-HSPs ( $M=5.84$ , CI [5.54,6.15]). This effect remains significant when negative affect is controlled in HSPS (E,N) residuals groups. However, this between-groups effect suggests no distinction in recognition for sequence versus random patterns, or across tasks. HSPs rate all 12-location sequences as more familiar than non-HSPs, or, put another way, non-HSPs rate all sequences as more novel than HSPs.

**Full recognition omnibus task comparison and creativity.** An omnibus mixed measures ANOVA was used to analyze creativity group differences in recognition ratings of the full sequence between implicit and explicit tasks using within-group factors of task (implicit, explicit) and sequence (target, random), and between-groups factors of creativity (high, low) for CAQ, RIBS and ATTA, separately. No between-groups effects ( $ps>.198$ ), three-way ( $ps>.176$ ) or two-way ( $ps>.198$ ) interactions were observed for CAQ, RIBS, or ATTA.

**Implicit SRTT: full recognition and sensitivity.** Ratings for target sequences and mean ratings of the four Random sequences were compared across sensitivity groups with a mixed ANOVA using within-subjects factors of sequence (Target, Random) and between-groups factors of sensitivity (HSP, non-HSP). No between-groups effects ( $ps>.19$ ) of sequence $\times$ sensitivity interactions ( $ps>.21$ ) were found for any sensitivity measure.

**Implicit SRTT: full recognition and creativity.** Ratings for target sequences and mean ratings of the four Random sequences were compared across sensitivity groups with a mixed ANOVA using within-subjects factors of sequence (Target, Random) and between-groups factors of creativity (high, low). No between-groups effects ( $ps>.58$ ) of sequence $\times$ creativity interactions ( $ps>.66$ ) were found the CAQ, RIBS or ATTA.

**Explicit SRTT: full recognition and sensitivity.** Ratings for target sequences and mean ratings of the four Random sequences were compared across sensitivity groups with a mixed ANOVA using within-subjects factors of sequence (Target, Random) and between-groups factors of sensitivity (HSP, non-HSP). A between-groups effect approached significance for HSPS groups,  $F(1,77)=3.8$ ,  $p=.055$ ,  $\eta_p^2=.047$ , where HSPs ( $M=6.47$ , 95% CI[6.03,7.37]) gave higher ratings overall than non-HSPs ( $M=5.91$ , 95% CI[5.47,6.35]). This effect is similar when negative affect is controlled in HSPS (E,N) residuals groups ( $p=.077$ ). No between-groups effects were found for any ATQ-OS groups ( $ps>.5$ ). No significant sequence $\times$ sensitivity interactions were found for any sensitivity measures ( $ps>.14$ ). Overall, HSPs rate all 12-location sequences from the explicit task as more familiar than non-HSPs, or, put another way, non-HSPs rate all sequences from the explicit task as more novel than HSPs.

**Explicit SRTT: full recognition and creativity.** Ratings for target sequences and mean ratings of the four Random sequences were compared across sensitivity groups with a mixed ANOVA using within-subjects factors of sequence (Target, Random) and between-groups factors of creativity (high, low). No between-groups effects ( $ps>.19$ ) of sequence $\times$ creativity interactions ( $ps>.11$ ) were found the CAQ, RIBS or ATTA.

### Discussion

Overall, this diverse group of young to middle-aged people showed similar patterns of sequence-specific, higher-order associative, implicit and explicit learning and evidence of explicit awareness found in prior work using these tasks (Curran, 1997; Reber & Squire, 1998; Schendan et al., 2003a; Schendan et al., 2013). New findings reported in this study have revealed how implicit and explicit learning and memory relate to concepts of sensitivity and creativity.

Using the implicit SRTT, learning during the task shows different patterns of individual differences for sensitive versus creative people. Regarding sensitivity, findings demonstrate that highly sensitive people have a greater ability than less sensitive people to become more consciously aware of subtle higher-order, structured information during implicit learning. Relative to non-HSPs, while HSPs show marginally better implicit learning on the task, they develop more explicit awareness of a repeating pattern and more explicit knowledge about the exact sequence in this pattern. For implicit SRTT performance, trends show that HSPs relative to non-HSPs defined using the HSPS tend to show greater implicit learning (i.e., faster RTs for sequence versus random) when negative affect is controlled. This supports the first hypothesis, that HSPs versus non-HSPs should have greater ability to incidentally extract and exploit information during the implicit learning task due to the links between sensitivity and automatic information-gathering attention systems (Evans & Rothbart, 2007). Further support for the first hypothesis is the difference in transition RTs between HSPs versus non-HSPs, as defined with the HSPS when negative affect is controlled, suggesting that HSPs were more able to incidentally acquire and exploit higher-order associations in repeating sequences.

Regarding creativity, implicit learning processes differ between high and low creativity groups, as defined using the ATTA. Higher-order associative learning across runs differs between ATTA groups, as high versus low ATTA groups show lower and higher associative learning for the respective final two transition pairs between runs. No other evidence was found that implicit sequence learning varies with sensitivity and creativity

Following implicit and explicit SRTT learning, explicit memory tasks were performed to measure awareness and explicit memory for implicit and explicit task sequences. Importantly, regarding sensitivity, following both implicit and explicit SRTT tasks, HSPs demonstrated more

knowledge about the repeating sequence than non-HSPs. Specifically, the maximum sequence generated on the free generation task of explicit knowledge was higher for HSPs than non-HSPs by the end of both implicit and explicit SRTT learning. This finding for the implicit SRTT is particularly important because it provides key confirmation that sensitivity is associated with the ability to become more consciously aware of information automatically under implicit conditions, supporting the first and second hypotheses. Finding a similar pattern following explicit learning indicates that this same ability also supports greater memory under explicit learning conditions for high versus low sensitive people.

Following the implicit SRTT, as predicted by the first and second hypotheses, HSPs compared to non-HSPs develop more conscious knowledge about the sequence (i.e., awareness of structure, greater accuracy when reporting triplets, and longer sequences) during implicit learning. HSPs, compared to non-HSPs defined by HSPS with negative affect controlled, were more likely to think there was a repeating pattern some of the time (Q4), suggesting awareness of a structured, repeating pattern of locations. On free generation, HSPs also freely generate longer sequences and show better free recall of triplets from the repeating sequence than non-HSPs. Further, on the triplet recognition task, recognition ratings revealed that HSPs tend to rate all triplet sequences (repeated and random) as more familiar overall than non-HSPs, but not when negative affect is controlled. Full sequence recognition shows that HSPs tend to rate all 12-location sequences (repeated and random) as more familiar overall than non-HSPs when negative affect is controlled. Put another way, non-HSPs rate all triplet and full sequences as more novel than HSPs. The ratings on the triplet and full recognition tasks suggest a bias toward feeling information is familiar in HSPs, compared to non-HSPs. However, this bias did not enable HSPs to recognize the sequence better than non-HSPs.



Overall, as the result of implicit SRTT learning, HSPs developed larger amounts of consciously available knowledge about the repeating sequence than non-HSPs, providing support for the second hypothesis, that higher sensitivity is associated with greater awareness of implicit knowledge. Altogether, this consistent with conceptualizations of the sensitive individual as being more consciously aware of subtleties that others may not notice (Aron et al., 2012; Evans & Rothbart, 2007, 2008).

Intriguingly, group differences in implicit and explicit SRTT RTs, higher-order associative learning, sequence awareness, triplet recognition, and explicit recall of implicit and explicit sequences only emerge when negative affect is controlled. These findings suggest that the better HSP performance disappears when negative affect is present, presumably because negative affect affects MTL function, which impairs learning and memory and thus cancels out the advantage of sensitivity. This provides support for the hypothesis that negative-affect-related sensitivity may impact negatively on hippocampal memory functions and associated learning and memory performance.

Altogether, these findings provide strong evidence that high sensitive temperament is related to a greater ability to acquire and exploit implicit information and bring this information to conscious awareness, but mainly when negative affect is controlled. Notably, implicit learning and memory tends to remain unaffected by neurological issues, whereas explicit learning and memory differs with many neurological changes. For example, aging (Schendan, et al., 2013), or mediotemporal lobe damage (Scoville & Milner, 1957) affect explicit learning but leave implicit learning unaffected or relatively spared. In contrast, implicit learning tends to be affected mainly by neurological issues affecting dopamine systems in the basal ganglia, such as Parkinson's disease (Schendan, et al., 2013). Given the association between implicit learning, dopamine, and

the basal ganglia, sensitivity effects on implicit learning and conscious sequence knowledge suggests the dopamine system implicated in sensitivity could underlie these effects. This is consistent with the evidence that dopamine changes underlie changes in implicit and explicit learning and memory with aging and Parkinson's disease (Schendan et al., 2013), as suggested above. However, learning effects are not specific to implicit memory. On the explicit SRTT, HSPs versus non-HSPs show improved performance on the second versus first block (for ATQ-OS), with longer freely recalled sequences in the final two blocks of the explicit SRTT (for HSPs), but only when negative affect is controlled. This shows that HSPs versus non-HSPs are better able to consciously improve performance and recall consciously acquired information during explicit SRTT tasks.

Regarding creativity, like HSPs groups, high creative ideation (RIBS) groups found the locations less random than low RIBS groups in the implicit SRTT, suggesting awareness of a repeating pattern of locations. This is consistent with the positive relationship between sensitivity and creative ideation (see Chapter 2), suggesting both are associated with higher ability to become aware of structured patterns during implicit learning, consistent with evidence that both constructs are grounded in attention mechanisms (see Chapter 4 & 5). Like sensitivity, creativity also benefits explicit SRTT performance, as people high in ATTA creativity respond faster overall on the explicit SRTT in the first block. Most of the learning takes place by the end of the first block resulting in a sharp drop in RT for the sequence relative to random locations by the second block. Learning the sequence is most effortful in the first block, as indicated by RTs being instead slower to sequence than random locations in the first block only. Altogether, this pattern indicates that people with high ATTA creativity need to exert less effort to learn the sequence than those with low ATTA. This could reflect higher working memory functions in the

frontal lobe, which enable chunking and other working memory functions that contribute to explicit SRTT learning (Bo, Borza, & Seidler, 2009; Graybiel, 1998). However, higher ATTA and divergent thinking scores are more commonly associated with less efficient working memory and executive functions (Fugate, Zentall, & Gentry, 2013; Takeuchi et al., 2011), and lower working memory is associated with difficulty blocking out, or inhibiting, distracting information (Conway, Cowan, & Bunting, 2001) and difficulty focusing in selective attention tasks (Engle, Kane, & Tuholski, 1999). This is consistent with our findings that explicit memory for high versus low ATTA groups is less efficient following explicit versus implicit tasks, and during explicit SRTT tasks, suggesting high ATTA groups are less able to block out competing items during sequence recall. One intriguing possibility is that explicit learning is better for people with high versus low ATTA creativity because more creative people have higher ability to make loose associations, which could reflect better relational memory in the MTL system thereby enabling higher-order associations to be made more readily.

### **Conclusions**

Overall, this study shows that sensitivity is associated with a greater ability to incidentally acquire and exploit information during the implicit learning task, and both sensitivity and creative ideation are associated with higher ability to develop more awareness and conscious knowledge about that information, consistent with conceptualizations of the sensitive individual as being more consciously aware resulting from more sensitive exogenous attention systems (Aron et al., 2012; Evans & Rothbart, 2007, 2008). However, highly sensitive people are more able to consciously improve performance and recall consciously acquired information during explicit SRTT tasks. As learning and memory effects were found across tasks, this suggests that HSP groups differ in how automatic and obligatory associative learning systems are

recruited in the MTL during explicit and implicit learning, consistent with relational accounts of memory (Cohen & Eichenbaum, 1993; Schendan et al., 2003b), although conclusions regarding group differences in associative learning across implicit and explicit tasks are limited due to lack of data in the explicit condition probably resulting from boredom and fatigue. Further, evidence suggests that negative-affect-related sensitivity may be detrimental for learning and memory. Findings also suggest that differences associated with higher divergent thinking, such as working memory, affect recall of explicitly acquired information.

Table F6.1

*Summary output of repeated measures ANOVA showing main effects and interactions for within-groups factors of Run, Condition and Block for implicit SRTT performance*

	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>Main effects</i>			
Run	5.81**	3,234	.069
Condition	129.82***	1,78	.624
Block	2	2,156	.025
<i>2-way interactions</i>			
Run×Condition	0.04	3,234	0
Run×Block	4.2**	6,468	.051
Condition×Block	4.95**	2,156	.06
<i>3-way interactions</i>			
Run×Condition×Block	9.31***	6,468	.107

*Note.* \*\* $p < .01$ , \*\*\* $p < .001$ .  $\eta_p^2$ =partial eta squared effect size; *df*=degrees of freedom.

Table F6.2

*Mixed ANOVA using within-groups factors of Run, Condition and Block with between-groups factors of Sensitivity for implicit SRTT performance*

	HSPS		ATQ-OS		HSPS (E,N)		ATQ-O(E,N)	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
Sensitivity	.74	.009	0	0	.61	.008	0	0
<i>2-way interactions</i>								
Sensitivity×Run	.17	.002	.61	.008	1.03	.013	.34	.004
Sensitivity×Condition	.01	0	.69	.009	3.25	.04	.01	0
Sensitivity×Block	1.34	.017	.88	.011	1.48	.019	.5	.006
<i>3-way interactions</i>								
Sensitivity×Run×Condition	.57	.007	.56	.007	.35	.005	.39	.005
Sensitivity×Run×Block	.46	.006	1.33	.017	1.43	.018	2.02	.026
Sensitivity×Condition×Block	1.72	.022	0	0	.01	0	.29	.004
<i>4-way interactions</i>								
Sensitivity×Run×Condition×Block	.64	.008	1.32	.017	.84	.011	.57	.007

*Note.* HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

Table F6.3

Summary output of repeated measures ANOVA showing main effects and interactions for within-groups factors of Run and Condition for explicit SRTT performance

	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>Main effects</i>			
Run	25.58***	1,59	.302
Condition	55.39***	5,295	.484
<i>2-way interactions</i>			
Run×Condition	32.49***	5,295	.355

Note. \*\*\* $p < .001$ .  $\eta_p^2$ =partial eta squared effect size; *df*=degrees of freedom.

Table F6.4

Summary output of mixed ANOVA showing main effects and interactions for within-groups factors of run and condition with between-groups factors of sensitivity for explicit SRTT performance

	HSPS		ATQ-OS		HSPS(E,N)		ATQ-OS(E,N)	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
Sensitivity	.32	.005	1.77	.03	.01	0	0	0
<i>2-way interactions</i>								
Sensitivity×Condition	.97	.016	1.96	.033	.07	.001	.04	.001
Sensitivity×Block	.37	.006	1.07	.018	.99	.017	2.97*	.049
<i>3-way interactions</i>								
Sensitivity×Condition×Block	.93	.016	.47	.008	1.12	.019	.77	.013

Note. \* $p < .05$ . HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

Table F6.5

*Summary output of mixed ANOVA showing main effects and interactions for within-groups factors of Run and Condition with between-groups factors of creativity for explicit SRTT performance*

	CAQ		RIBS		ATTA	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>						
Creativity	1.85	.031	.14	.002	.41	.007
<i>2-way interactions</i>						
Creativity×Condition	.55	.009	.59	.01	1.37	.023
Creativity×Run	.46	.008	.77	.013	3.53*	.057
<i>3-way interactions</i>						
Creativity×Condition×Run	.28	.005	.65	.011	1.19	.02

*Note.* \* $p$ =.01. CAQ=Creative Achievements Questionnaire; RIBS=Runco Ideational Behavioural Scale; ATTA=Abbreviated Torrance Test of Adults;  $\eta_p^2$ =partial eta squared effect size.

Table F6.6

*Summary output of repeated measures ANOVA showing main effects and interactions for within-groups factors of Run and Transition Pair for implicit SRTT*

	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>Main effects</i>			
Run	1.21	3,234	.015
Transition Pair	39.28***	11,858	.335
<i>2-way interactions</i>			
Run×Transition Pair	6.62***	33,2574	.078

*Note.* \*\*\* $p$ <.001.  $\eta_p^2$ =partial eta squared effect size; *df*=degrees of freedom.

Table F6.7

*Summary output of mixed ANOVA showing main effects and interactions for within-groups*

*factors of Run and Transition Pair with between-groups factors of sensitivity for implicit SRTT*

	HSPS		ATQ-OS		HSPS (E,N)		ATQ-O(E,N)	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
Sensitivity	.03	0	.71	.009	3.08	.038	.01	0
<i>2-way interactions</i>								
Sensitivity×Run	.3	.004	.59	.008	.62	.008	.21	.003
Sensitivity×Pair	1.45	.018	.83	.011	1.12	.014	1.16	.015
<i>3-way interactions</i>								
Sensitivity×Run×Pair	.89	.011	1.18	.015	.81	.01	1.22	.016

*Note.* HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

Table F6.8

*Summary output of mixed ANOVA showing main effects and interactions for within-groups*

*factors of Run and Transition Pair with between-groups factors of creativity for implicit SRTT*

	CAQ		RIBS		ATTA	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>						
Creativity	.24	.003	.04	.001	2.88	.036
<i>2-way interactions</i>						
Creativity×Run	1	.013	.79	.01	1.22	.016
Creativity×Pair	.73	.009	.59	.008	1.58	.02
<i>3-way interactions</i>						
Creativity×Run×Pair	.54	.007	1.14	.015	1.78*	.023

*Note.* \* $p < .05$ . CAQ=Creative Achievements Questionnaire; RIBS=Runco Ideational Behavioural Scale; ATTA=Abbreviated Torrance Test of Adults;  $\eta_p^2$ =partial eta squared effect size.



Table F6.9

*Frequency of rating by question with mean (M), standard deviation (SD), and lower (LCI) and upper (UCI) 95% confidence intervals for questions 1-4 measuring awareness of sequences for both implicit and explicit tasks*

Task	Question	Response				M	SD	LCI	UCI
		Yes	Probably	Unlikely	No				
Implicit	Q1	28	29	13	9	2.04	.99	1.82	2.26
	Q2	19	22	5	33	2.66	1.25	2.38	2.94
	Q3	42	12	8	17	2	1.23	1.72	2.28
	Q4	35	18	5	21	2.15	1.25	1.87	2.43
Explicit	Q1	15	26	14	24	2.59	1.12	2.35	2.84
	Q2	27	27	11	14	2.15	1.09	1.91	2.39
	Q3	39	12	7	21	2.13	1.29	1.86	2.41
	Q4	46	18	4	11	1.75	1.07	1.52	1.99

Table F6.10

*Summary ANOVA output for repeated measures ANOVA comparing free generation performance across implicit and explicit SRTT tasks*

	F	$\eta_p^2$
Maximum sequence	96.14***	.552
Number of triplets	26.79***	.256
Triplet ratio	68.89***	.469

*Note.* \*\*\*  $p < .001$ .  $\eta_p^2$  = partial eta squared effect size; degrees of freedom (df1, df2) = (1, 78).

Table F6.11

*Summary of separate omnibus mixed ANOVA for free generation, including maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses for between-groups factor of sensitivity*

		HSPS		ATQ-OS		HSPS(E,N)		ATQ-OS(E,N)	
		<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
Maximum sequence	Main effects	.01	0	.02	0	.54	.007	.9	.012
	Interaction	.06	.001	0	0	1.54	.02	1.54	.02
Number of triplets	Main effects	.07	.001	.06	.001	.39	.005	.66	.008
	Interaction	.12	.002	1.87	.024	.85	.011	.02	0
Triplet ratio	Main effects	.01	0	.35	.004	1.7	.022	.13	.002
	Interaction	.1	.001	.02	0	2.67	.034	1.89	.024

Note. HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

Table F6.12

*Summary of separate omnibus mixed ANOVA for free generation, including maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses for creativity (high, low) groups for CAQ, RIBS and ATTA*

		CAQ		RIBS		ATTA	
		<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
Maximum sequence	Main effects	.08	.001	1.53	.019	1.44	.018
	Interaction	.18	.002	.32	.004	5.2*	.063
Number of triplets	Main effects	.37	.005	.79	.01	1.04	.013
	Interaction	.46	.006	.02	0	2.2	.028
Triplet ratio	Main effects	.66	.009	1.69	.021	.73	.009
	Interaction	.3	.004	0	0	6.21*	.075

Note. \* $p < .05$ . CAQ=Creative Achievements Questionnaire; RIBS=Runco Ideational Behavioural Scale; ATTA=Abbreviated Torrance Test of Adults;  $\eta_p^2$ =partial eta squared effect size.

Table F6.13

*Summary of separate mixed ANOVA for explicit SRTT free generation, including maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses for between-groups factor of sensitivity*

		HSPS		ATQ-OS		HSPS(E,N)		ATQ-OS(E,N)	
		<i>F</i>	$\eta_p^{22}$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
Maximum sequence	Main effect	.04	0	.01	0	.04	.001	1.46	.019
	Interaction	1.59	.02	1.59	.02	3.63*	.045	1.36	.017
Number of triplets	Main effect	0	0	.79	.01	.82	.011	.38	.005
	Interaction	1.16	.015	1.72	.022	.94	.012	.47	.006
Triplet ratio	Main effect	.06	.001	.1	.001	0	0	.98	.013
	Interaction	1.67	.021	1.18	.015	2.3	.029	.52	.007

*Note.* \* $p < .05$ . HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

Table F6.14

*Summary of separate mixed ANOVA for explicit SRTT free generation, including maximum sequences generated, number of triplets generated, and ratio of triplets to keypresses for between-groups factor of creativity*

		CAQ		RIBS		ATTA	
		<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
Maximum sequence	Main effects	.15	.002	1.04	.013	3.57	.044
	Interaction	.23	.003	1.57	.02	.92	.012
Number of triplets	Main effects	.59	.008	.44	.006	2.17	.027
	Interaction	.23	.003	.29	.004	.98	.013
Triplet ratio	Main effects	.06	.001	.82	.01	3.68	.046
	Interaction	.69	.009	.95	.012	.6	.008

*Note.* CAQ=Creative Achievements Questionnaire; RIBS=Runco Ideational Behavioural Scale; ATTA=Abbreviated Torrance Test of Adults;  $\eta_p^2$ =partial eta squared effect size.

Table F6.15

*Mean, standard deviation, lower (LCI) and upper (UCI) 95% confidence intervals and min/max values for maximum length of correct sequences reported, number of triplets reported and ratio of triplets to keypresses in the cued generation task for the implicit SRTT*

	<i>M</i>	<i>SD</i>	<i>LCI</i>	<i>UCI</i>	<i>Min</i>	<i>Max</i>
Maximum sequence	6.29	1.63	5.95	6.66	3	10
Triplets generated	35.42	7.71	33.75	37.09	21	54
Triplet ratio	.38	.08	.36	.4	.22	.57

Table F6.16

*Summary output of repeated measures ANOVA showing main effects and interactions for within-groups factors of Condition and Location for implicit SRTT triplet recognition response times*

	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>Main effects</i>			
Condition	9.48**	1,69	.121
Location	75.95***	2,138	.524
<i>2-way interactions</i>			
Condition×Location	3.58*	2,138	.049

*Note.* \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ .  $\eta_p^2$ =partial eta squared effect size; df=degrees of freedom.

Table F6.17

*Summary output of mixed ANOVA showing group effects and interactions for within-groups factors of Condition and Location and between-groups variables of sensitivity for implicit SRTT triplet recognition response times*

	HSPS		ATQ-OS		HSPS(E,N)		ATQ-OS(E,N)	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
Sensitivity	.49	.007	.83	.012	.7	.01	.42	.006
<i>Two way interactions</i>								
Sensitivity×Condition	.05	.001	1.93	.028	.43	.006	.41	.006
Sensitivity×Location (Loc)	.08	.001	.74	.011	.89	.013	1.29	.019
<i>Three way interactions</i>								
Sensitivity×Condition×Loc	1.06	.015	3.29*	.046	4.64*	.064	2.72	.038

*Note.* \* $p < .05$ . HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

Table F6.18

*Summary output of repeated measures omnibus ANOVA for comparison of full recognition ratings for factors of Task and Sequence*

	<i>F</i>	$\eta_p^2$
Task	1.43	.018
Sequence	57.7***	.425
Task×Sequence	23.08***	.228

*Note.* \*\*\*  $p < .001$ ;  $\eta_p^2$ =partial eta squared effect size; degrees of freedom (df1, df2)=(1,78).

Table F6.19

*Summary output of mixed ANOVA of full recognition ratings for factors of Task and Sequence and between-groups factor of sensitivity*

	HSPS		ATQ-OS		HSPS(E,N)		ATQ-OS(E,N)	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>								
Sensitivity	4.44*	.055	.08	.001	4.21*	.052	.78	.01
<i>Two-way interactions</i>								
Sensitivity×Task	.75	.01	.47	.006	.45	.006	.01	0
Sensitivity×Sequence	.01	0	.65	.008	.07	.001	.08	.001
<i>Three-way interactions</i>								
Sensitivity×Task×Sequence	1.92	.024	.01	0	.01	0	.23	.003

*Note.* \* $p < .05$ . HSPS=Highly Sensitive Person Scale; ATQ-OS=Orienting sensitivity of the adult temperament questionnaire (ATQ); HSPS(E,N)=HSPS with Big-Five Extraversion and Big-Five Neuroticism partialled out; ATQ-OS(E,N)=ATQ-OS with Big-Five Extraversion and Big-Five Neuroticism partialled out;  $\eta_p^2$ =partial eta squared effect size.

**Appendix G**





## Methods

Sensitivity and creativity group differences were explored using mixed ANOVA and t-test comparisons using between-groups factors of full HSPS and ATQ-OS measures and HSPS (E,N) and ATQ-OS (E,N) residuals variables, separately. Thus, for every analysis undertaken, the full HSPS/ATQ-OS measures, and HSPS/ATQ-OS (E,N) residuals were used in order to examine effects of sensitivity with, and without negative affect controlled. For the HSPS, the HSP groups ( $M=.74$ , 95% CI [.71,.78]) had higher scores than non-HSPs ( $M=.44$ , 95% CI [.40,.48]). For the ATQ-OS, the HSP groups ( $M=.76$ , 95% CI [.73,.78]) had higher scores than non-HSPs ( $M=.51$ , 95% CI [.48,.54]). The same analysis was also performed for between-groups factors of creativity for CAQ, RIBS and ATTA, separately. For each creativity measure, two groups were formed from the 73 available participants using a median split with the following group sizes: High groups  $\geq$  CAQ  $Mdn=.07$ , and low groups  $<$ CAQ  $Mdn$  giving high ( $n=39$ ) and low CAQ ( $n=34$ ) groups; High groups  $\geq$  RIBS  $Mdn=.49$ , and low groups  $<$ RIBS  $Mdn$  giving high ( $n=41$ ) and low RIBS ( $n=32$ ) groups. High groups  $\geq$  ATTA  $Mdn=.86$ , and low groups  $<$ ATTA  $Mdn$  giving high ( $n=38$ ) and low ATTA ( $n=35$ ) groups. For the Ravens short-form measure scaled between 0 and 1 using maximum possible score of 12 (participant score/12), two groups were formed from the 73 available participants using a median split with the following group sizes: High groups  $>$  Ravens  $Mdn=.58$ , and low groups  $\leq$  Ravens  $Mdn$  giving high ( $n=35$ ) and low Ravens groups ( $n=38$ ). Note, all personality, temperament, and creativity measures are scaled between 0 and 1, see Chapter 2 for scaling. Max scores used for scaling in this study are CAQ are 94, and 83 for the ATTA in this study only.

## Results

### Task Accuracy and Participant Exclusion

Overall, 39 participants made errors of omission (miss) at least once across 60 target presentations, ranging between 0 and 14 omissions ( $M=1.1$ ,  $SD=2.05$ ). 77 participants made errors of commission (false alarm) across all trials ranging between 0 and 37 commissions ( $M=7.93$ ,  $SD=7.46$ ). Using the median absolute deviation method of outlier detection, 5 participants were detected as outliers with errors of commission  $\geq 24$ . For errors of omission, more than 50% of error values were zero and thus median absolute deviation was not applicable. Using the mean absolute deviation method of outlier detection, 2 participants were detected as outliers with errors of omission  $\geq 9$ . Therefore, 7 participants were rejected ( $n=5$  via errors of commission &  $n=2$  via errors of omission), leaving  $n=73$  participants for further analysis.

### Latent Inhibition

**Response times.** Figure 7.1 below shows response times for targets following pre-exposed, non pre-exposed and filler stimuli.

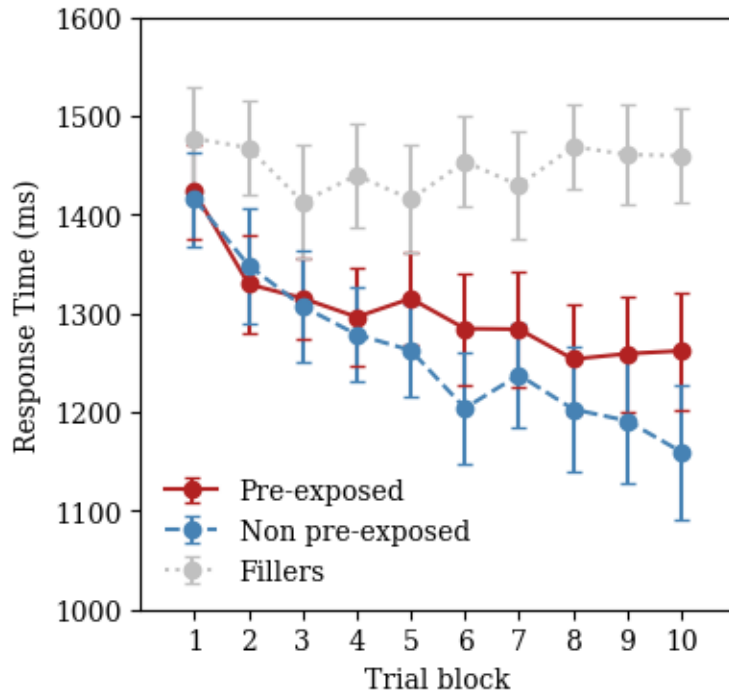


Figure G7.1. Response times across conditions for each 2-trial block where 1000ms marks target onset. Error bars represent 95% confidence intervals.

A mixed ANOVA was performed on mean RT data using within-groups factors of Condition (pre-exposed [PE], non pre-exposed [NPE]) and Trial (10 consecutive trial blocks, 1:10), and between-groups factor of pre-exposure (Order) condition (“S” or “H”) and Ravens group (high, low). The results of the ANOVA are summarized in Table 7.1. Results demonstrated the latent inhibition effect, as the main effect of exposure condition was significant, where mean RTs in the PE condition ( $M=1305\text{ms}$ , 95% CI[1250,1359]) were slower ( $p=.04$ ) than mean RTs in the NPE condition ( $M=1261\text{ms}$ , 95% CI[1201,1321]). A main effect of trial was also found showing that learning increased over time (see Figure 7.1). No between-group effects of Order were observed, however an Order $\times$ Condition interaction was found ( $p=.015$ ), wherein Condition effects differed depending on the stimuli. Specifically, Condition effects were only observed for “H” stimuli,

wherein mean RTs in the PE condition ( $M=1348\text{ms}$ , 95% CI [1278,1408]) were significantly slower than mean RTs in the NPE condition ( $M=1254\text{ms}$ , 95% CI[1180,1326]),  $t(34)=3.08$ ,  $p<.01$ . No differences in condition were observed for “S” stimuli ( $p=.83$ ). Finally, no main effects or interactions were observed with Ravens groups ( $ps>.238$ ). Although the Condition $\times$ Trial interaction was not observed ( $p=.174$ ), the difference between PE and NPE stimuli was larger in the last block than first block (see Figure 7.1). To test for this, the slope for PE and NPE conditions was calculated for each participant using the line of best fit method. The within-subjects ANOVA revealed that the mean slope for the NPE condition ( $M=-25\text{ms}$ , 95% CI[-15,-35]) was significantly steeper,  $F(1,72)=6.41$ ,  $p=.014$ ,  $\eta p.^2=.082$ , than the mean slope for PE condition ( $M=-14\text{ms}$ , 95% CI[-6, 22]), demonstrating a stronger LI effect in PE versus NPE conditions. Overall, these results demonstrate that pre-exposure adversely affects subsequent associative learning as slower response times were observed for PE versus NPE stimuli. Whilst this LI effect was generalized across trial blocks, the analysis of slopes suggested the learning was stronger over time for NPE versus PE conditions thus demonstrating LI, however the overall LI effect was stimulus-specific.

**Accuracy.** Latent inhibition was assessed using the number of correct predictive responses (CPR) for trials in pre-exposed and non pre-exposed stimuli in a mixed measures ANOVA using within-groups factors of test condition (pre-exposed [PE], non pre-exposed [NPE]) and between-groups factor of pre-exposure (Order) condition (“S” or “H”) and Ravens group (high, low). ANOVA results are summarized in Table 7.2. Results demonstrated latent inhibition, as a main effect of test condition was significant ( $p=.022$ ), wherein PE stimuli ( $M=3.53$ , 95% CI[2.33,4.7]) produced fewer correct predictive responses than NPE stimuli ( $M=4.64$ , 95% CI[3.27,6.01]) out of the 20 target presentations in each condition. No main effects or interactions were observed with Order ( $ps>.132$ ) or Ravens group ( $ps>.297$ ). Overall, these results demonstrate that pre-exposure

adversely affects associative learning, as demonstrated by fewer correct predictive responses for PE versus NPE stimuli. In summary, both response time and accuracy demonstrated latent inhibition.

### **Latent Inhibition and Sensitivity**

**Response times.** Sensitivity group differences in latent inhibition were not observed for ATQ-OS, or when negative affect was partialled out in ATQ-OS (E,N) residuals ( $ps > .17$ ). For HSPS (E,N) residuals, a Condition×Trial×Sensitivity×Ravens interaction approached significance,  $F(7,496)=1.81$ ,  $p=.081$ ,  $\eta_p^2=.026$ . Figure 7.2 shows that the 4-way interaction reflects larger LI effects as learning progresses in the HSP low Ravens group compared with all other groups, whereas the non-HSP low Ravens group shows the least LI effects. Note, the HSPS (E,N) residuals group sizes for HSP ( $n=13$ ) versus non-HPS ( $n=22$ ) when Ravens scores are high, and HSP ( $n=9$ ) versus non-HSP ( $n=29$ ) when Ravens scores are low. The small HSP low Raven's group may explain why results did not reach significance.

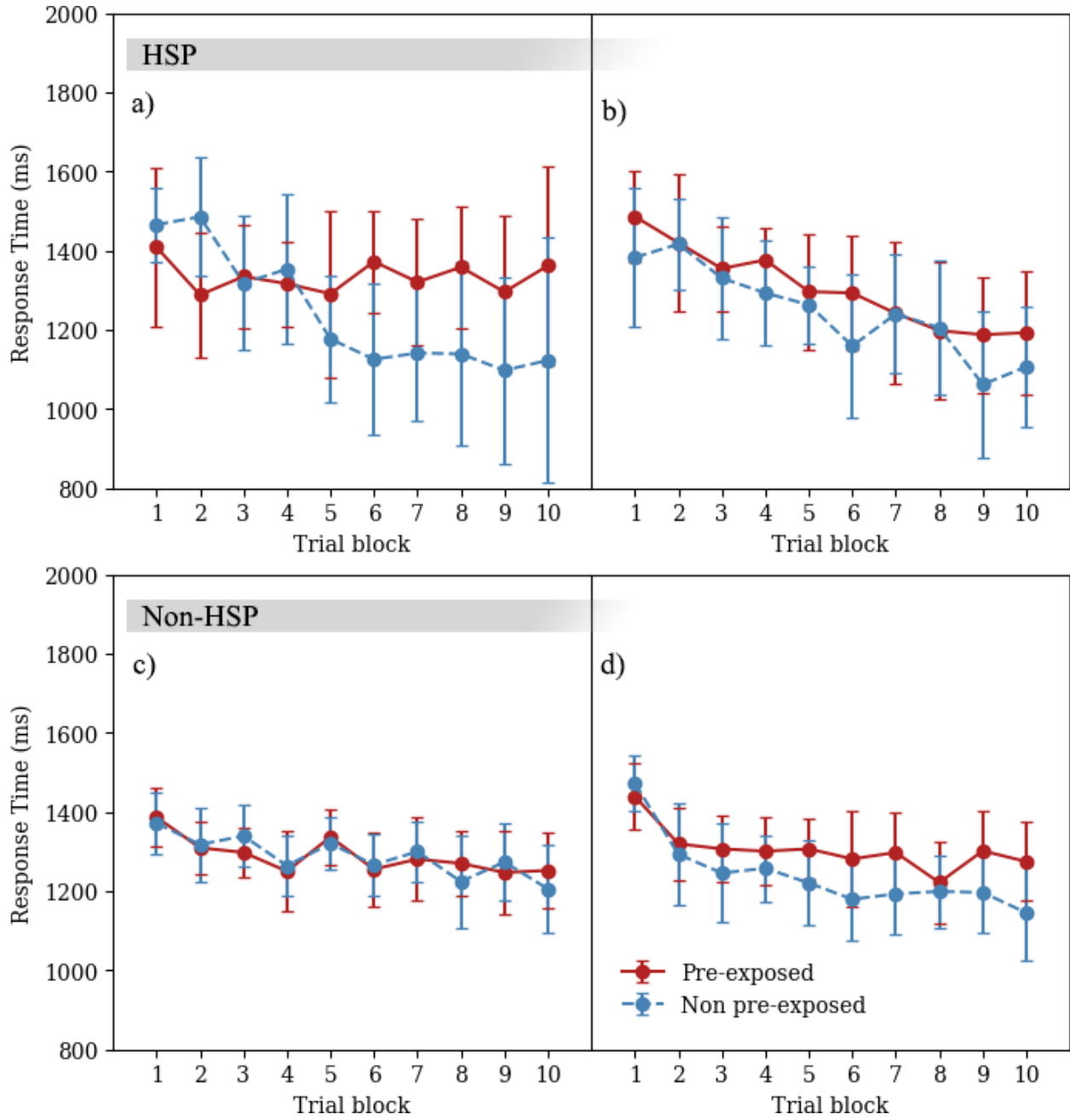


Figure G7.2. Condition×Trial×Sensitivity×Ravens interaction for HSPs (E,N) residuals groups. a) and b) are HSPs in low and high Ravens groups, c) and d) are non-HSPs in low and high Ravens groups, respectively. Error bars show 95% confidence intervals.

## Latent Inhibition and Creativity

**Response times.** The mixed ANOVA results are presented in Table 7.3. No effects were found for RIBS or ATTA measures ( $ps > .05$ ). For the CAQ, the Condition×Creativity×Ravens interaction was significant ( $p = .027$ ). Figure 7.3 shows the core LI effect collapsed across trial blocks. LI is greater for high versus low CAQ groups when Ravens scores are low as mean response times are slightly faster for PE versus NPE in low Ravens and low CAQ groups, whereas LI is greater for low versus high CAQ groups when Ravens scores are high. Thus LI is low in groups high in both CAQ and Ravens or low in both. However, the Condition×Trial×Creativity×Ravens interaction was also significant, visualized in Figure 7.4, which shows how LI effects change across trials depending on level of creative achievement and intelligence. The LI effect increases across trials in groups with high CAQ and low Ravens and groups with low CAQ and high Ravens. Thus LI learning is low in groups high in both CAQ and Ravens or low in both. Note, the group sizes for high ( $n = 24$ ) versus low ( $n = 11$ ) creative achievement when Ravens scores are high, and high ( $n = 15$ ) versus low ( $n = 23$ ) creative achievement when Ravens scores are low.

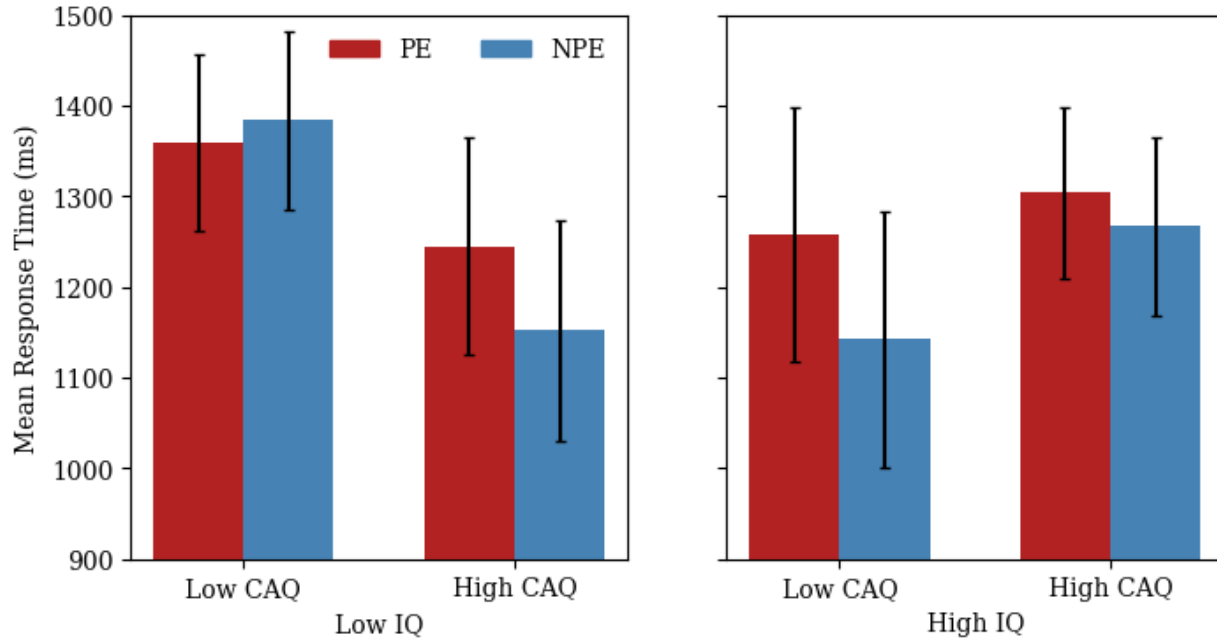
To interpret the 3-way Condition×Creativity×Ravens interaction, planned contrasts were performed by splitting data by Ravens groups in a Condition×Creativity mixed ANOVA using CAQ group as a between-groups factor. The mixed ANOVA revealed that the Condition×Creativity interaction approached significance for low Ravens groups,  $F(1,36) = 3.94$ ,  $p = .055$ ,  $\eta^2 = .099$ , but was not significant for high Ravens groups ( $p = .224$ ). For low Ravens groups, the overall LI RT effects (PE minus NPE condition RTs) are marginally greater in the high ( $M = 94\text{ms}$ , 95% CI[2,195]) versus low ( $M = -25\text{ms}$ , 95% CI[-96,41]) CAQ groups,  $t(36) = 1.99$ ,  $p = .055$ . For high Ravens, the overall LI effects are lower for high ( $M = 38\text{ms}$ , 95% CI[-11, 87]) versus low ( $M = 117\text{ms}$ , 95% CI[-17, 269]) CAQ groups, but not significantly so ( $p = .224$ ). Note,

positive values for LI RTs indicate latent inhibition was present, whereas zero or negative scores indicate an absence of latent inhibition (Evans et al., 2007). Thus our analysis shows that CAQ group differences in LI are only observed in low Ravens groups, and within low Ravens groups, LI is lower in low versus high CAQ groups, however there is a trend towards lower LI in high CAQ high Ravens groups.

To interpret the 4-way Condition×Trial×Creativity×Ravens interaction, planned contrasts were performed by splitting data by Ravens groups. To interpret the condition×trial block×creativity interaction, each trial block (vs. baseline trial block 1) within the interaction was assessed (with no correction). For high Ravens groups, the mixed ANOVA revealed a significant 3-way interaction,  $F(6,191)=2.15$ ,  $p=.052$ ,  $\eta p.^2=.061$ . For low Ravens groups, the interaction was not significant ( $p=.13$ ). The Hochberg method of adjustment for family-wise error revealed that for high Ravens groups, the LI effect was significantly different between CAQ groups for trial blocks 9, 5, 6, and 10, in descending order of significance ( $ps<.01$ ). Figure 7.4 shows that in high Ravens groups, low versus high CAQ groups show stronger LI with a greater decrease in reaction times in trial blocks 9, 5, 6, and 10 (vs. trial block 1) for NPE versus PE conditions.

Overall, when response time performance by condition is collapsed across trials, CAQ group differences in LI are only observed in low Ravens groups, and within low Ravens groups, LI is lower in low versus high CAQ groups, although when Ravens scores are high, response times trend towards lower LI in high versus low CAQ groups. However, further analysis by trial block suggests that LI RT effects are observable between high versus low CAQ groups when Ravens is high. Specifically, when Ravens scores are high, lower LI is observed in high versus low CAQ groups over 4 trial blocks, thus suggesting that high versus low CAQ groups have lower LI and stronger LI, when Ravens scores are high and low, respectively.





*Figure G7.3.* Condition×Creativity×Ravens (IQ) interaction with mean response times for the CAQ. PE and NPE are pre-exposure and non pre-exposure conditions, respectively. Error bars show 95% confidence intervals.

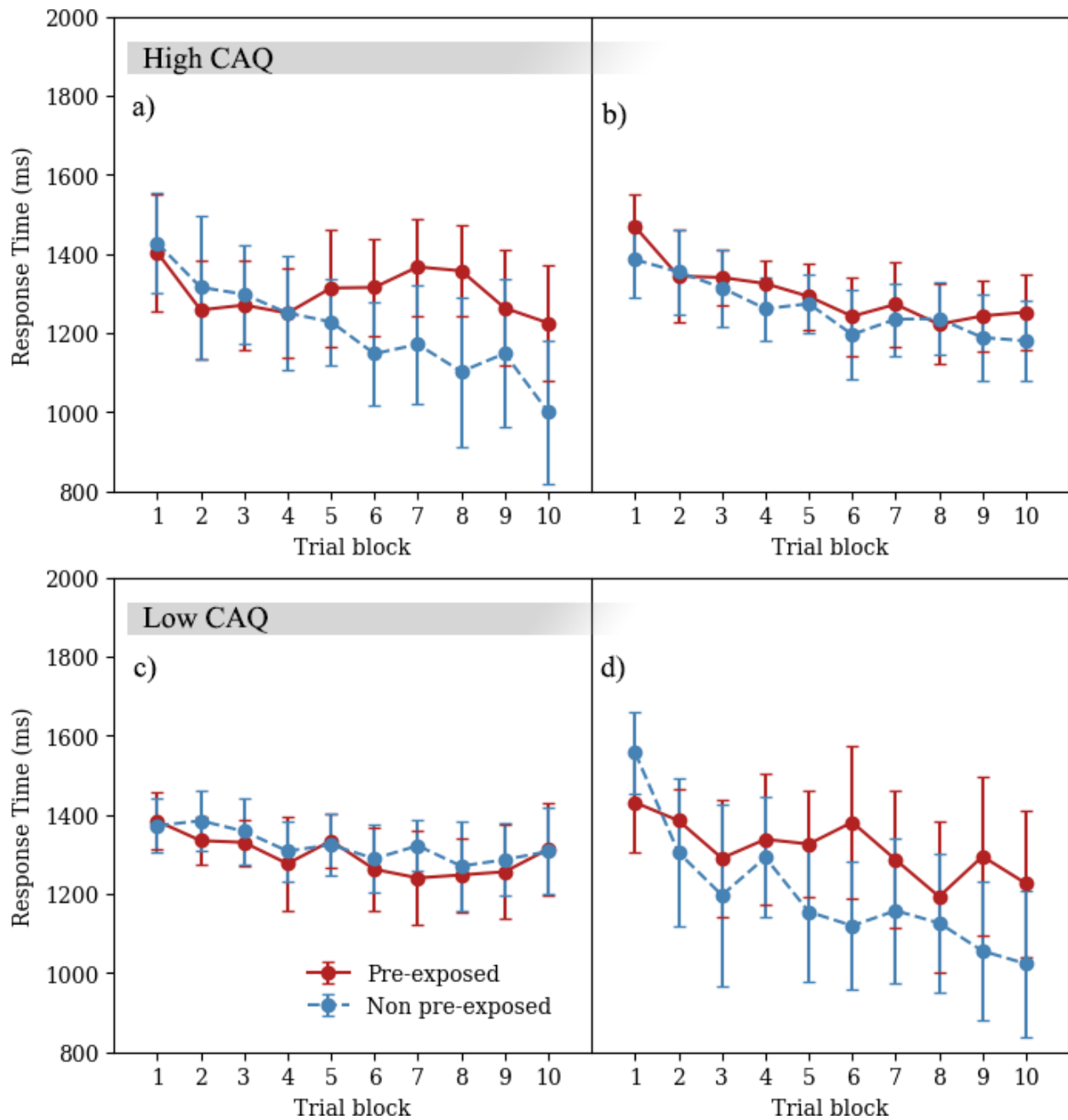


Figure G7.4. Condition×Trial×Creativity×Ravens interaction for CAQ groups. a) and b) are low and high Ravens groups with high CAQ scores, c) and d) are low and high Ravens groups with low CAQ scores. Error bars show 95% confidence intervals.

**Correct predictive responses.** The mixed ANOVA did not reveal any effects for RIBS or ATTA ( $p_s > .05$ ). For the CAQ, a significant Condition×Creativity×Ravens interaction was found

( $p=.016$ ). Figure 7.5 shows the LI CPR effect where CAQ group differences in LI CPR emerge across Ravens group. Specifically, when Ravens scores are low, LI is stronger in high versus low CAQ groups. Conversely, when Ravens scores are high, LI is lower in high versus low CAQ groups.

To interpret the 3-way Condition×Creativity×Ravens interaction, planned contrasts were performed by splitting data by Ravens groups in a Condition×Creativity mixed ANOVA using CAQ group as a between-groups factor. For low Ravens groups, LI CPR effects (NPE minus PE condition CPRs) across conditions are significantly different across CAQ groups,  $F(1,36)=5.32$ ,  $p=.027$ ,  $\eta^2=.129$ , whereas for high Ravens groups, no significant Condition×CAQ interaction emerges ( $p=.214$ ). When Ravens scores are low, high CAQ groups have stronger mean LI CPR effects ( $M=2.73$ , 95% CI[.6,5.25]) than low CAQ groups ( $M=-.22$ , 95% CI[.84,-1.29]),  $t(36)=2.31$ ,  $p=.027$ . When Ravens scores are high, high CAQ groups trend towards lower mean LI CPR effects ( $M=.71$ , 95% CI[-.32,1.87]) than low CAQ groups ( $M=2.55$ , 95% CI[-.2,5.8]),  $p=.214$ . Note, positive values for LI CPR indicate latent inhibition was present, whereas zero or negative scores indicate an absence of latent inhibition (Evans et al., 2007).

Overall, these results show that LI CPR effects are stronger in high versus low creative achievement when intelligence is low, but high versus low CAQ groups trend towards lower LI CPR effects when intelligence is high.

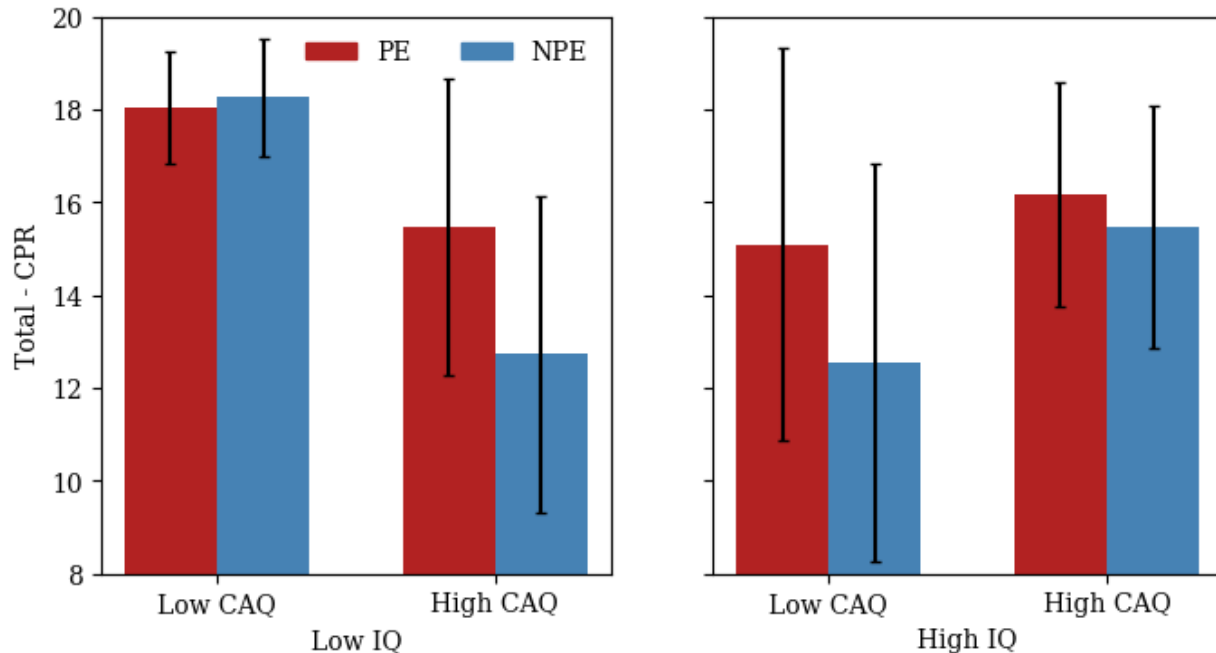


Figure G7.5. Condition×Creativity×Ravens interaction with total trials (n=20) minus correct predictive responses (CPR) for the CAQ groups. PE and NPE are pre-exposure and non pre-exposure conditions, respectively. Error bars show 95% confidence intervals.

### (Alternative) Discussion

In this study, a latent inhibition effect was found where responses were slower and less predictive in PE versus NPE conditions, although order effects were also found for response times, suggesting that the manipulation did not work when “S” was the pre-exposed stimulus. Further, intelligence measured with the Ravens short-form measure (Arthur Jr & Day, 1994) did not interact with the LI effects, or correlate with LI variables, suggesting LI in this within-subjects task is not directly influenced by general intellectual ability.

The purpose of the study was to understand how individual differences in sensitivity and creativity manifest in measures of latent inhibition. We tested the hypothesis that sensitivity and creativity relate to LI RT and LI CPR, treating creativity and sensitivity as dichotomous and

continuous variables with respective ANOVA and regression analysis. Considering the sensitivity and creativity variables as dichotomous, no sensitivity or creativity group differences in LI response times or number of correct predictive responses were found, providing no support for the hypothesis that high sensitivity or high creativity would be associated with low latent inhibition. However, some effects emerge when intelligence is considered as an interactive term.

No evidence was found that higher sensitivity is associated with low LI. With Ravens short-form scores as a between-groups factor in the mixed ANOVA, larger LI RT effects as learning progresses are observed in HSPS (E,N) HSP groups with low Ravens scores versus all other groups, suggesting LI is stronger in HSP groups with lower intelligence and negative affect controlled, although this group difference did not reach conventional levels of significance (i.e.,  $p < .05$ ).

Regarding creativity, previous findings suggest that creative achievement is associated with low LI, especially when intelligence is high (Carson et al., 2003). Thus, we expected to find that ii) high creativity and high intelligence will be associated with the lowest LI effects for both LI response times and correct predictive responses. Consistent with the hypothesis and previous findings (Carson et al., 2003), Figure 7.3, 7.5 and Figure 7.5 shows that LI is reduced in high versus low creative achievement when intelligence is high. Whilst low LI CPR effects in high creative, high intelligence groups is a non-significant trend, convincing evidence of low LI in high creative achievement and high intelligence groups emerges when LI RT effects are analysed by trial block. Specifically, we find that low LI is observed across several mid to late trial blocks in high versus low creative achievers, but only when intelligence is high. Conversely, LI (RT and CPR) is stronger in high versus low creative achievers with low Ravens scores. These results imply that participants high in creative achievement have both lower LI and stronger LI, when Ravens scores are high and low, respectively. On the other hand, low LI is also apparent in people with both low intelligence

and low creative achievement.

Considering sensitivity and creativity as continuous variables with greater power to detect effects (MacCallum et al., 2002), correlation analysis was used to explore relationships between sensitivity, personality and creativity with LI RT and LI CPR variables. Overall, sensitivity, personality and creativity show non-significant weak positive correlations with LI measures, and sensitivity and creative achievement show the highest correlations. Recall that positive values for LI RT and LI CPR (PE minus NPE for RT; NPE minus PE for CPR) indicate latent inhibition was present, whereas zero or negative scores indicate an absence of latent inhibition (Evans et al., 2007). Lack of significant correlations between sensitivity, creativity and LI measures could suggest that LI was attenuated, or not present, providing some evidence consistent with the hypothesis that LI effects should not, or correlate negatively with creativity and sensitivity measures. However, the correlations are positive in direction across all variables, and lack of significance of this relationship could relate to sample size, as stable correlation estimates require a sample size approaching 250 (Schönbrodt & Perugini, 2013) versus  $N=73$  used in this study. Thus, correlations provide no support for the hypothesis that higher sensitivity, openness and creativity are characterized by low LI. Notably, some effects in the dichotomous group analysis went in the opposite direction (e.g., in low intelligence, high sensitivity and creative achievement are associated with higher LI), and LI tends to be lower in groups high or low in both dimensions (i.e., high IQ and CAQ or low IQ and CAQ). Previous research using high IQ groups (Carson et al., 2003) would have captured only the former (LI is lower when CAQ is high in high IQ groups). This finding is most readily interpreted within a multiple intelligence framework (Gardner, 2011b), as insofar as IQ and CAQ capture different aspects of cognition/intelligence, there appears to be a trade-off such that LI occurs when either IQ or CAQ is high but is reduced when IQ and CAQ are both either high or low

(i.e., the extremes).

Further, hierarchical multiple regression analysis was used to test the hypothesis that latent inhibition is one shared underlying mechanism of the sensitive, open creator that can account for unique variance in models predicting creativity, but in the presence of sensitivity and openness measures is made redundant. Moreover, no effects relating to LI were found. In particular, LI RT or LI CPR did not account for unique variance in any creativity measures, nor did LI measures create redundancy of sensitivity and openness coefficients accounting for unique variance in creativity scores (see Chapter 2 for relationship between sensitivity and creativity, including data from this study). Ravens scores accounted for significant unique CAQ variance in the regression models, consistent with previous findings (Carson et al., 2003), but Ravens scores were redundant in the presence of openness to experience. Overall, findings provide no evidence that LI is a common mechanism underlying sensitivity, openness, and creativity.

### **Conclusions**

The key findings from this within-subjects LI task are that a) LI tends to be lower in participants high or low in dimensions of creative achievement and intelligence. Moreover, whenever either CAQ or intelligence is low, LI is higher for groups high than low on the other dimension, suggesting that higher creativity and higher intelligence are qualitatively different processes for dealing with novelty effectively. Results also suggest b) LI is stronger in higher sensitivity with lower intelligence and negative affect controlled. Further, c) LI does not appear to be a unifying mechanism in the relationship between sensitivity, openness and creativity.

In this study, we present evidence that supports the hypothesis, and replicates prior findings (Carson et al., 2003), of low LI in higher creative achievement and higher intelligence. However, evidence reported is not consistent with the hypothesis that sensitivity is characterized by low LI,

or previous observations of low LI in higher openness personality (Peterson & Carson, 2000). One explanation for the lack of evidence for low LI in sensitivity includes the possibility that within-subjects designs of the LI task lack sensitivity to detect individual differences in LI. For example, Figure 7.3 and Figure 7.5 show CAQ group differences in LI effects that differ by Ravens scores in the direction predicted, however those group effects were not significant when trial block was not considered. Consistent with this, Gray et al. (2003) show that within-subjects LI tasks are insensitive to LI effects between high and low schizotypy personality groups which are observed with between-groups LI tasks, wherein the magnitude of effects are larger. In addition, the lack of task sensitivity could be explained by order effects, as LI effects were only observed in half of the participants pre-exposed to “H” stimuli, thus larger group differences would be diminished through averaging across all participants, including those pre-exposed to “S” stimuli. Finally, lack of group differences in the direction predicted could also be explained by inadequate sample sizes per group ( $ns < 30$ ) in the ANOVA analysis (cf. Carson et al., 2003) and overall sample size ( $N < 250$ ) in the correlation and regression analysis (Schönbrodt & Perugini, 2013). Thus, the null hypothesis of normal LI in the sensitive, open creator cannot be rejected in this study using either a) a within-subjects task, or b) inadequate sample sizes.

Nonetheless, significant group differences indicate a more complex picture than previous research. LI is higher for groups high than low on the other dimension (e.g., high intelligence and low CAQ), whereas LI tends to be lower in groups high or low in both dimensions (i.e., high intelligence and CAQ or low intelligence and CAQ). Previous research revealed the former (high intelligence and high CAQ), but we additionally report that LI is also lower in groups low on both IQ and CAQ.



Table G7.1

*Summary output of mixed ANOVA on response times showing main effects and interactions for within-groups factor of condition and trial, and between-groups factors of pre-exposure condition (Order) and Ravens group*

	<i>F</i>	<i>df</i>	$\eta_p^2$
<i>Main effects</i>			
Condition	4.4*	1,69	.06
Trial	10.42***	9,621	.131
Order	.43	1,69	.006
Ravens	.54	1,69	.008
<i>2-way interactions</i>			
Condition×Trial	1.47	9,621	.021
Condition×Ravens	1.42	1,69	.02
Condition×Order	6.18*	1,69	.082
<i>3-way interactions</i>			
Condition×Trial×Ravens	.54	9,621	.008
Condition×Trial×Order	1.06	9,621	.015
<i>4-way interactions</i>			
Condition×Trial×Ravens×Order	.68	9,621	.01

Note. \*  $p < .05$ , \*\*\*  $p < .001$ ;  $\eta_p^2$ =partial eta squared; *df*=degrees of freedom.

Table G7.2

Summary output of mixed ANOVA on accuracy showing main effects and interactions for within-groups factor of condition, and between-groups factors of pre-exposure condition (Order) and

Ravens group

	<i>F</i>	$\eta_p^2$
<i>Main effects</i>		
Condition	5.51*	.074
Order	.43	.006
Ravens	1.11	.016
<i>2-way interactions</i>		
Condition×Ravens	.22	.003
Condition×Order	2.33	.033
<i>3-way interactions</i>		
Condition×Ravens×Order	.68	.01

Note. \*  $p < .05$ ;  $\eta_p^2$ =partial eta squared; degrees of freedom (df1, df2)=(1,69).

Table G7.3

Summary output of mixed ANOVA showing response time main effects and interactions for within-groups factor of condition and trial, and between-groups factors of Ravens group and creativity for CAQ, RIBS and ATTA

	CAQ		RIBS		ATTA	
	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$	<i>F</i>	$\eta_p^2$
<i>Main effects</i>						
Creativity	.66	.009	.65	.009	.88	.013
<i>2-way interactions</i>						
Condition×Creativity	.21	.003	.04	.001	.17	.002
<i>3-way interactions</i>						
Condition×Creativity×Ravens	5.1*	.069	.59	.008	.33	.005
Condition×Trial×Creativity	.84	.012	1.68	.024	.66	.009
<i>4-way interactions</i>						
Condition×Trial×Creativity×Ravens	2.78**	.039	1.44	.02	.61	.009

Note. \*  $p < .05$ , \*\*  $p < .01$ , Ravens=Ravens Advanced Progressive Matrices short-form; CAQ=Creative Achievements Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults

Table G7.4

Summary output of mixed ANOVA showing correct response main effects and interactions for within-groups factor of condition and trial, and between-groups factors of Ravens group and creativity for CAQ, RIBS and ATTA

	CAQ		RIBS		ATTA	
	F	$\eta_p^2$	F	$\eta_p^2$	F	$\eta_p^2$
<i>Main effects</i>						
Creativity	.74	.011	.52	.007	1.4	.02
<i>2-way interactions</i>						
Condition×Creativity	.33	.005	.05	.001	.45	.006
<i>3-way interactions</i>						
Condition×Creativity×Ravens	6.16*	.082	1.59	.023	.01	0

Note. \*  $p < .05$ , Ravens=Ravens Advanced Progressive Matrices short-form; CAQ=Creative Achievements Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults

Table G7.5

Spearman’s correlations between creativity, sensitivity, personality and intelligence variables and latent inhibition response times and number of correct predictive responses

	IQ		Creativity				Sensitivity				Personality				
	Rave	ns	CA	RIB	ATT	HSP		HSP	OS		O	C	E	A	N
			Q	S	A	S	OS	(E,N)	(E,						
LI RT	.072		.134	.057	.068	.125	.12	.127	.123	.07	.04	.04	.10	.04	
LI	-.005		.109	.01	.059	.126	.16	.182	.176	.10	.06	.02	.15	.00	

Note: Ravens=Ravens Advanced Progressive Matrices short-form; CAQ=Creative Achievement Questionnaire; RIBS=Runco Ideational Behaviour Scale; ATTA=Abbreviated Torrance Test for Adults; HSPS=Highly Sensitive Person Scale (full); OS=orienting sensitivity factor of the ATQ; HSPS (E,N)=full HSPS with Big Five Inventory (BFI) extraversion and neuroticism partialled out; OS (E,N)=full ATQ-OS with BFI extraversion and neuroticism partialled out; O=openness to experience factor of the BFI; C=conscientiousness factor of the BFI; E=extraversion factor of the BFI; A=agreeableness factor of the BFI; N=neuroticism factor of the BFI.

Table G7.6

*Hierarchical multiple regression with LI response times, intelligence, sensitivity and personality predicting creativity for CAQ, RIBS and ATTA*

	HSPS			ATQ-OS		
	CAQ	RIBS	ATTA	CAQ	RIBS	ATTA
<b>Model 1</b>						
LI RT	0	0	0	0	0	0
<b>Model 2</b>						
LI RT	0	0	0	0	0	0
Ravens	.217*	.019	.114	.217*	.019	.114
<b>Model 3</b>						
LI RT	0	0	0	0	0	0
Ravens	.204*	-.003	.108	.185*	-.03	.104
Sensitivity	.247*	.389***	.112	.386***	.588***	.116
<b>Model 4</b>						
LI RT	0	0	0	0	0	0
Ravens	.207*	-.024	.111	.193**	-.04	.107
Sensitivity	.254	.412***	.057	.381**	.512***	.092
BFI-E	-.04	.237**	0	-.096	.159*	-.027
BFI-N	-.023	.057	.062	0	.175*	.074
<b>Model 5</b>						
LI RT	0	0	0	0	0	0
Ravens	.118	-.093	.099	.118	-.073	.106
Sensitivity	-.062	.169	.016	-.035	.33*	.086
BFI-E	-.104	.187**	-.022	-.097	.158*	-.027
BFI-N	.068	.126	.074	.042	.177**	.074
BFI-O	.491*	.377***	.063	.487**	.214	.008
<b>Model fit (<math>R^2</math>)</b>						
Model 1	.005	-.01	-.014	.005	-.01	-.014
Model 2	.058*	-.024	.002	.058*	-.024	.002
Model 3	.122*	.2***	.014	.177*	.343***	.008
Model 4	.098	.278*	-.007	.174	.401*	.001
Model 5	.249***	.388***	-.018	.248***	.413	-.014

*Note.* \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; LI RT=Latent inhibition response times (mean PE – mean NPE); HSPS=Highly Sensitive Person Scale (full); ATQ-OS=orienting sensitivity factor of the ATQ; BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory;  $R^2$ =adjusted  $R^2$  for change in model fit.

Table G7.7

*Hierarchical multiple regression with LI correct predictive response, intelligence, sensitivity and personality predicting creativity for CAQ, RIBS and ATTA*

	HSPS			ATQ-OS		
	CAQ	RIBS	ATTA	CAQ	RIBS	ATTA
<b>Model 1</b>						
LI CPR	.005	-.001	0	.005	-.001	0
<b>Model 2</b>						
LI CPR	.005	-.001	0	.005	-.001	0
Ravens	.224*	.019	.114	.224*	.019	.114
<b>Model 3</b>						
LI CPR	.005	-.002	0	.004	-.002	0
Ravens	.209*	-.003	.108	.191*	-.031	.104
Sensitivity	.25*	.392***	.112	.389***	.592***	.116
<b>Model 4</b>						
LI CPR	.005	-.003	0	.005	-.002	0
Ravens	.213*	-.028	.111	.199*	-.042	.107
Sensitivity	.256	.421***	.057	.383***	.515***	.093
BFI-E	-.035	.241**	-.013	-.091	.164*	-.026
BFI-N	-.02	.05	.061	.041	.173*	.074
<b>Model 5</b>						
LI CPR	.004	-.004	0	.004	-.003	0
Ravens	.122	-.098	.099	.122	-.078	.106
Sensitivity	-.06	.175	.016	-.032	.321***	.086
BFI-E	-.099	.191**	-.021	-.093	.162*	-.026
BFI-N	.07	.12	.073	.045	.175**	.074
BFI-O	.49***	.382***	.064	.486**	.227	.008
<b>Model fit (R<sup>2</sup>)</b>						
Model 1	-.001	-.013	-.014	-.001	-.013	-.014
Model 2	.056*	-.027	.002	.056*	-.027	.002
Model 3	.122*	.202***	.014	.177***	.346***	.008
Model 4	.097	.285**	-.007	.174	.405*	.001
Model 5	.248***	.398***	-.018	.247**	.42	-.015

*Note.* \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; RIBS=Runco Ideational Behaviour Scale; LI CPR=Latent inhibition correct predictive responses (NPE-PE); HSPS=Highly Sensitive Person Scale (full); ATQ-OS=orienting sensitivity factor of the ATQ; BFI-N=neuroticism factor of the Big Five Inventory; BFI-E=extraversion factor of the BFI; BFI-O=openness to experience factor of the Big Five Inventory;  $R^2$ =adjusted  $R^2$  for change in model fit.

## References

- Akinola, M., & Mendes, W. B. (2008). The dark side of creativity: biological vulnerability and negative emotions lead to greater artistic creativity. *Pers Soc Psychol Bull*, *34*(12), 1677-1686.
- Ames, M., & Runco, M. A. (2005). Predicting entrepreneurship from ideation and divergent thinking. *Creativity and Innovation Management*, *14*(3), 311-315.
- Andreasen, N. C. (2005). *The Creating Brain*. New York: Dana Press.
- Aron, E. N. (1999). *The highly sensitive person: How to thrive when the world overwhelms you*. London, UK: Harper Collins Publishers Ltd.
- Aron, E. N., & Aron, A. (1997). Sensory-Processing Sensitivity and Its Relation to Introversion and Emotionality. *Journal of Personality and Social Psychology*, *73*(2), 345-368.
- Aron, E. N., & Aron, A. (2013). *TIPS for SPS Research*. [www.hspsperson.com](http://www.hspsperson.com).
- Aron, E. N., Aron, A., & Davies, K. M. (2005). Adult shyness: the interaction of temperamental sensitivity and an adverse childhood environment. *Pers Soc Psychol Bull*, *31*(2), 181-197.
- Aron, E. N., Aron, A., & Jagiellowicz, J. (2012). Sensory processing sensitivity: a review in the light of the evolution of biological responsiveness. *Pers Soc Psychol Rev*, *16*(3), 262-282.
- Arthur Jr, W., & Day, D. V. (1994). Development of a short form for the Raven Advanced Progressive Matrices Test. *Educational and Psychological Measurement*, *54*(2), 394-403.
- Avila, C. (1995). Facilitation and inhibition of visual orienting as a function of personality. *Personality and Individual Differences*, *18*(4), 503-509.
- Barron, F., & Harrington, D. M. (1981). Creativity, Intelligence, and Personality. *Annual review of psychology*, *32*, 439-476.
- Barry, R. J., MacDonald, B., De Blasio, F. M., & Steiner, G. Z. (2013). Linking components of event-related potentials and autonomic measures of the orienting reflex. *Int J Psychophysiol*, *89*(3), 366-373.
- Baruch, I., Hemsley, D. R., & Gray, J. A. (1988). Differential performance of acute and chronic schizophrenics in a latent inhibition task. *J Nerv Ment Dis*, *176*(10), 598-606.
- Batey, M., Chamorro-Premuzic, T., & Furnham, A. (2010). Individual differences in ideational behavior: Can the big five and psychometric intelligence predict creativity scores? *Creativity Research Journal*, *22*(1), 90-97.
- Batey, M., & Furnham, A. (2006). Creativity, intelligence, and personality: A critical review of the scattered literature. *Genetic Social and General Psychology Monographs*, *132*(4), 355-429.
- Beaty, R. E., Benedek, M., Kaufman, S. B., & Silvia, P. J. (2015). Default and Executive Network Coupling Supports Creative Idea Production. *Sci Rep*, *5*, 10964.
- Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative Cognition and Brain Network Dynamics. *Trends Cogn Sci*, *20*(2), 87-95.
- Beaty, R. E., Benedek, M., Wilkins, R. W., Jauk, E., Fink, A., Silvia, P. J., . . . Neubauer, A. C. (2014). Creativity and the default network: A functional connectivity analysis of the creative brain at rest. *Neuropsychologia*, *64C*, 92-98.
- Beaty, R. E., Kaufman, S. B., Benedek, M., Jung, R. E., Kenett, Y. N., Jauk, E., . . . Silvia, P. J. (2016). Personality and complex brain networks: The role of openness to experience in default network efficiency. *Hum Brain Mapp*, *37*(2), 773-779.

- Beck, D. M., Rees, G., Frith, C. D., & Lavie, N. (2001). Neural correlates of change detection and change blindness. *Nat Neurosci*, *4*(6), 645-650.
- Belsky, J., & Pluess, M. (2009a). Beyond diathesis stress: differential susceptibility to environmental influences. *Psychol Bull*, *135*(6), 885-908.
- Belsky, J., & Pluess, M. (2009b). The Nature (and Nurture?) of Plasticity in Early Human Development. *Perspect Psychol Sci*, *4*(4), 345-351.
- Benedek, M., Mühlmann, C., Jauk, E., & Neubauer, A. C. (2013). Assessment of divergent thinking by means of the subjective top-scoring method: Effects of the number of top-ideas and time-on-task on reliability and validity. *Psychology of Aesthetics, Creativity, and the Arts*, *7*(4), 341.
- Benet-Martinez, V., & John, O. P. (1998). Los Cinco Grandes across cultures and ethnic groups: multitrait multimethod analyses of the Big Five in Spanish and English. *J Pers Soc Psychol*, *75*(3), 729-750.
- Benham, G. (2006). The highly sensitive person: Stress and physical symptom reports. *Personality and Individual Differences*, *40*(7), 1433-1440.
- Binder, J. R., & Desai, R. H. (2011). The neurobiology of semantic memory. *Trends Cogn Sci*, *15*(11), 527-536.
- Bo, J., Borza, V., & Seidler, R. D. (2009). Age-related declines in visuospatial working memory correlate with deficits in explicit motor sequence learning. *Journal of Neurophysiology*, *102*(5), 2744-2754.
- Bowers, K. S., Regehr, G., Balthazard, C., & Parker, K. (1990). Intuition in the context of discovery. *Cognitive psychology*, *22*(1), 72-110.
- Bradley, M. M. (2009). Natural selective attention: orienting and emotion. *Psychophysiology*, *46*(1), 1-11.
- Braff, D. L. (1993). Information processing and attention dysfunctions in schizophrenia. *Schizophr Bull*, *19*(2), 233-259.
- Braunstein-Bercovitz, H., & Lubow, R. (1998a). Are high-schizotypal normal participants distractible or limited in attentional resources? A study of latent inhibition as function of masking task load and schizotypy level. *Journal of Abnormal Psychology*, *107*(4), 659-670.
- Braunstein-Bercovitz, H., & Lubow, R. (1998b). Latent inhibition as a function of modulation of attention to the preexposed irrelevant stimulus. *Learn Motiv*, *29*(3), 261-279.
- Bridges, D., & Schendan, H. E. (2018). Sensitive individuals are more creative. *Personality and Individual Differences*.
- Brindle, K., Moulding, R., Bakker, K., & Nedeljkovic, M. (2015). Is the relationship between sensory - processing sensitivity and negative affect mediated by emotional regulation? *Australian Journal of Psychology*, *67*(4), 214-221.
- Brodsky, P., & Brodsky, M. (1981). A model integrating risk variables involved in the development of the schizophrenia spectrum. *J Nerv Ment Dis*, *169*(12), 741-750.
- Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: anatomy, function, and relevance to disease. *Ann N Y Acad Sci*, *1124*, 1-38.
- Cabeza, R., Mazuz, Y. S., Stokes, J., Kragel, J. E., Woldorff, M. G., Ciaramelli, E., . . . Moscovitch, M. (2011). Overlapping parietal activity in memory and perception: evidence for the attention to memory model. *J Cogn Neurosci*, *23*(11), 3209-3217.

- Callejas, A., Lupiáñez, J., & Tudela, P. o. (2004). The three attentional networks: On their independence and interactions. *Brain Cogn*, *54*(3), 225-227.
- Carson, S. (2014a). Leveraging the "mad genius" debate: why we need a neuroscience of creativity and psychopathology. *Front Hum Neurosci*, *8*, 771.
- Carson, S. H. (2011). Creativity and psychopathology: a shared vulnerability model. *Can J Psychiatry*, *56*(3), 144-153.
- Carson, S. H. (2014b). Leveraging the "mad genius" debate: why we need a neuroscience of creativity and psychopathology. *Front Hum Neurosci*, *8*, 771.
- Carson, S. H., Peterson, J. B., & Higgins, D. M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *J Pers Soc Psychol*, *85*(3), 499-506.
- Carson, S. H., Peterson, J. B., & Higgins, D. M. (2005). Reliability, validity, and factor structure of the creative achievement questionnaire. *Creativity Research Journal*, *17*, 37-50.
- Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. *Journal of Personality and Social Psychology*, *67*, 319-333.
- Cerny, B. A., & Kaiser, H. F. (1977). A study of a measure of sampling adequacy for factor-analytic correlation matrices. *Multivariate Behavioral Research*, *12*(1), 43-47.
- Chen, C., Chen, C., Moyzis, R., Stern, H., He, Q., Li, H., . . . Dong, Q. (2011). Contributions of dopamine-related genes and environmental factors to highly sensitive personality: a multi-step neuronal system-level approach. *PLoS One*, *6*(7), e21636.
- Chica, A. B., & Bartolomeo, P. (2012). Attentional routes to conscious perception. *Front Psychol*, *3*, 1.
- Chica, A. B., Bartolomeo, P., & Valero-Cabre, A. (2011). Dorsal and ventral parietal contributions to spatial orienting in the human brain. *J Neurosci*, *31*(22), 8143-8149.
- Chica, A. B., Lasaponara, S., Chanes, L., Valero-Cabre, A., Doricchi, F., Lupianez, J., & Bartolomeo, P. (2011). Spatial attention and conscious perception: the role of endogenous and exogenous orienting. *Atten Percept Psychophys*, *73*(4), 1065-1081.
- Chica, A. B., Martín-Arévalo, E., Botta, F., & Lupiáñez, J. (2014). The Spatial Orienting paradigm: How to design and interpret spatial attention experiments. *Neuroscience & Biobehavioral Reviews*, *40*, 35-51.
- Chirila, C., & Feldman, A. (2012). Study of latent inhibition at high-level creative personality The link between creativity and psychopathology. *Procedia - Social and Behavioral Sciences*, *33*, 353 – 357.
- Christensen, P., Guilford, J., Merrifield, P., & Wilson, R. (1960). Alternate uses. *Beverly Hills: Sheridan Psychological Services*.
- Claridge, G. (1994). Single indicator of risk for schizophrenia: probable fact or likely myth? *Schizophr Bull*, *20*(1), 151-168.
- Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front. *Trends Cogn Sci*, *2*(10), 406-416.
- Cohen, E., & Eichenbaum, H. (1993). *Memory, amnesia, and the hippocampal system*. London, England: MIT press.
- Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science*, *210*(4466), 207-210.



- Colangelo, N., Kerr, B., Hallowell, K., Huesman, R., & Gaeth, J. (1992). The Iowa Inventiveness Inventory: Toward a measure of mechanical inventiveness. *Creativity Research Journal*, 5(2), 157-163.
- Connor, C. E., Egeth, H. E., & Yantis, S. (2004). Visual attention: bottom-up versus top-down. *Current Biology*, 14(19), R850-R852.
- Conway, A. R., Cowan, N., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychon Bull Rev*, 8(2), 331-335.
- Cooper, N. R., Croft, R. J., Dominey, S. J., Burgess, A. P., & Gruzelier, J. H. (2003). Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *International Journal of Psychophysiology*, 47(1), 65-74.
- Corbetta, M., Kincade, M. J., Lewis, C., Snyder, A. Z., & Sapir, A. (2005). Neural basis and recovery of spatial attention deficits in spatial neglect. *Nat Neurosci*, 8(11), 1603-1610.
- Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nat Rev Neurosci*, 3(3), 201-215.
- Costa, P. T., & McCrae, R. R. (1992). Revised NEO Personality Inventory (NEO-PI-R) and NEO Five-Factor Inventory (NEO-FFI) professional manual. Odessa, FL: Psychological Assessment Resources.
- Costa, R. E., Naylor, E. R., Choles, J. R., Nu, C. S., Halper, N., Rutishauser, S., & Eillis, L. K. (2013). *Individual Differences in Orienting Sensitivity Modulate Event-Related Potentials and Reaction Times in a Modified Attention Network Task*. Poster presentation. Cognitive Neuroscience Society.
- Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior*, 11(6), 671-684.
- Crittenden, B. M., & Duncan, J. (2014). Task difficulty manipulation reveals multiple demand activity but no frontal lobe hierarchy. *Cereb Cortex*, 24(2), 532-540.
- Cropley, A. (2006). In praise of convergent thinking. *Creativity Research Journal*, 18(3), 391-404.
- Csikszentmihalyi, M. (1996). Flow and the psychology of discovery and invention. *New York: Harper Collins*.
- Curran, T. (1997). Higher-order associative learning in amnesia: Evidence from the serial reaction time task. *Journal of Cognitive Neuroscience*, 9(4), 522-533.
- Daselaar, S. M., Huijbers, W., Eklund, K., Moscovitch, M., & Cabeza, R. (2013). Resting-state functional connectivity of ventral parietal regions associated with attention reorienting and episodic recollection. *Front Hum Neurosci*, 7, 38.
- Davis, K. L., Panksepp, J., & Normansell, L. (2003). The affective neuroscience personality scales: Normative data and implications. *Neuropsychanalysis*, 5(1), 57-69.
- De Dreu, C. K., Baas, M., & Nijstad, B. A. (2008). Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. *J Pers Soc Psychol*, 94(5), 739-756.
- De Pauw, S. S., Mervielde, I., & Van Leeuwen, K. G. (2009). How are traits related to problem behavior in preschoolers? Similarities and contrasts between temperament and personality. *J Abnorm Child Psychol*, 37(3), 309-325.
- Deo, P., & Singh, A. (1973). Some personality correlates of learning without awareness. *Behaviorometric*(3), 11-21.

- Depue, R. A., & Collins, P. F. (1999). Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences*, 22(3), 491-517.
- Derryberry, D., & Reed, M. A. (1994). Temperament and attention: Orienting toward and away from positive and negative signals. *Journal of Personality and Social Psychology*, 66(6), 1128-.
- Destrebecqz, A., & Cleeremans, A. (2001). Can sequence learning be implicit? New evidence with the process dissociation procedure. *Psychon Bull Rev*, 8(2), 343-350.
- Deyoung, C. G. (2013). The neuromodulator of exploration: A unifying theory of the role of dopamine in personality. *Front Hum Neurosci*, 7, 762.
- DeYoung, C. G. (2014). Openness/Intellect: A dimension of personality reflecting cognitive exploration. In M. L. Cooper & R. J. Larsen (Eds.), *APA handbook of personality and social psychology: Personality processes and individual differences* (Vol. 4, pp. 369–399). Washington, DC: American Psychological Association.
- Deyoung, C. G., Cicchetti, D., Rogosch, F. A., Gray, J. R., Eastman, M., & Grigorenko, E. L. (2011). Sources of Cognitive Exploration: Genetic Variation in the Prefrontal Dopamine System Predicts Openness/Intellect. *J Res Pers*, 45(4), 364-371.
- DeYoung, C. G., Peterson, J. B., & Higgins, D. M. (2002). Higher-order factors of the Big Five predict conformity: Are there neuroses of health? *Personality and Individual Differences*, 33(4), 533-552.
- DeYoung, C. G., Peterson, J. B., & Higgins, D. M. (2005). Sources of openness/intellect: cognitive and neuropsychological correlates of the fifth factor of personality. *J Pers*, 73(4), 825-858.
- DeYoung, C. G., Peterson, J. B., Séguin, J. R., Mejia, J. M., Pihl, R. O., Beitchman, J. H., . . . Palmour, R. M. (2006). The dopamine D4 receptor gene and moderation of the association between externalizing behavior and IQ. *Archives of General Psychiatry*, 63(12), 1410-1416.
- Diedrich, J., Benedek, M., Jauk, E., & Neubauer, A. C. (2015). Are creative ideas novel and useful? *Psychology of Aesthetics, Creativity, and the Arts*, 9(1), 35-40.
- Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological bulletin*, 136(5), 822.
- Digman, J. M. (1997). Higher-order factors of the Big Five. *Journal of Personality and Social Psychology*, 73(6), 1246.
- Dijksterhuis, A., & Meurs, T. (2006). Where creativity resides: The generative power of unconscious thought. *Conscious Cogn*, 15(1), 135-146.
- Dixon, M. L., Fox, K. C., & Christoff, K. (2014). A framework for understanding the relationship between externally and internally directed cognition. *Neuropsychologia*, 62, 321-330.
- Dreu, C. K. D., Nijstad, B. A., & Baas, M. (2011). Behavioral activation links to creativity because of increased cognitive flexibility. *Social Psychological and Personality Science*, 2(1), 72-80.
- Driver, J., & Vuilleumier, P. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition*, 79(1), 39-88.
- Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: mental programs for intelligent behaviour. *Trends Cogn Sci*, 14(4), 172-179.

- Duncan, J. (2013). The structure of cognition: attentional episodes in mind and brain. *Neuron*, 80(1), 35-50.
- Dunn, L. A., Atwater, G. E., & Kilts, C. D. (1993). Effects of antipsychotic drugs on latent inhibition: sensitivity and specificity of an animal behavioral model of clinical drug action. *Psychopharmacology (Berl)*, 112(2), 315-323.
- Eby, D. (2015). Highly sensitive people: latent inhibition and creativity. Retrieved from <http://highlysensitive.org/64/highly-sensitive-people-latent-inhibition-and-creativity/>
- Eimer, M., & Mazza, V. (2005). Electrophysiological correlates of change detection. *Psychophysiology*, 42(3), 328-342.
- Ellis, B. J., Boyce, W. T., Belsky, J., Bakermans-Kranenburg, M. J., & Van IJzendoorn, M. H. (2011). Differential susceptibility to the environment: An evolutionary–neurodevelopmental theory. *Development and psychopathology*, 23(01), 7-28.
- Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*. Cambridge, UK: Cambridge University Press.
- Erez, Y., & Duncan, J. (2015). Discrimination of Visual Categories Based on Behavioral Relevance in Widespread Regions of Frontoparietal Cortex. *J Neurosci*, 35(36), 12383-12393.
- Evans, D. E., & Rothbart, M. K. (2007). Developing a model for adult temperament. *Journal of Research in Personality*, 41, 868-888.
- Evans, D. E., & Rothbart, M. K. (2008). Temperamental sensitivity: Two constructs or one? *Personality and Individual Differences*, 44(1), 108-118.
- Evans, D. E., & Rothbart, M. K. (2009). A Two-Factor Model of Temperament. *Personality and Individual Differences*, 47(6), 565-570.
- Evans, L. H., Gray, N. S., & Snowden, R. J. (2007). A new continuous within-participants latent inhibition task: examining associations with schizotypy dimensions, smoking status and gender. *Biol Psychol*, 74(3), 365-373.
- Eysenck, H. J. (1993). Creativity and personality: Suggestions for a theory. *Psychological inquiry*, 4(3), 147-178.
- Eysenck, H. J. (1995). *Genius: The natural history of creativity*. Cambridge, UK: Cambridge University Press.
- Fan, J., Fossella, J., Sommer, T., Wu, Y., & Posner, M. I. (2003). Mapping the genetic variation of executive attention onto brain activity. *Proc Natl Acad Sci U S A*, 100(12), 7406-7411.
- Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *Neuroimage*, 26(2), 471-479.
- Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *J Cogn Neurosci*, 14(3), 340-347.
- Fan, J., & Posner, M. (2004). Human attentional networks. *Psychiatr Pract*, 31 Suppl 2, 210-214.
- Fan, J., Wu, Y., Fossella, J. A., & Posner, M. I. (2001). Assessing the heritability of attentional networks. *BMC Neurosci*, 2, 14.
- Fedorenko, E., Duncan, J., & Kanwisher, N. (2013). Broad domain generality in focal regions of frontal and parietal cortex. *Proc Natl Acad Sci U S A*, 110(41), 16616-16621.

- Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Pers Soc Psychol Rev*, 2(4), 290-309.
- Feist, G. J. (2010). The function of personality in creativity: The nature and nurture of the creative personality. In J. C. Kaufman & R. J. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 113-130). United States: Cambridge University Press.
- Fernandez-Duque, D., & Posner, M. I. (1997). Relating the mechanisms of orienting and alerting. *Neuropsychologia*, 35(4), 477-486.
- Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. London: Sage.
- Fink, A., & Benedek, M. (2014). EEG alpha power and creative ideation. *Neuroscience & Biobehavioral Reviews*, 44, 111-123.
- Fink, A., Koschutnig, K., Hutterer, L., Steiner, E., Benedek, M., Weber, B., . . . Weiss, E. M. (2014). Gray matter density in relation to different facets of verbal creativity. *Brain Structure and Function*, 219(4), 1263-1269.
- Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*.
- Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, 45(1), 152-170.
- Förster, J., & Dannenberg, L. (2010). GLOMOsys: A systems account of global versus local processing. *Psychological inquiry*, 21(3), 175-197.
- Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., & Posner, M. I. (2002). Assessing the molecular genetics of attention networks. *BMC Neurosci*, 3, 14.
- Fox, K. C., Spreng, R. N., Ellamil, M., Andrews-Hanna, J. R., & Christoff, K. (2015). The wandering brain: Meta-analysis of functional neuroimaging studies of mind-wandering and related spontaneous thought processes. *Neuroimage*, 111, 611-621.
- Friedman, R. S., Fishbach, A., Förster, J., & Werth, L. (2003). Attentional priming effects on creativity. *Creativity Research Journal*, 15(2-3), 277-286.
- Friedman, R. S., & Förster, J. (2001). The effects of promotion and prevention cues on creativity. *Journal of Personality and Social Psychology*, 81(6), 1001.
- Friedrich, F. J., Egly, R., Rafal, R. D., & Beck, D. (1998). Spatial attention deficits in humans: a comparison of superior parietal and temporal-parietal junction lesions. *Neuropsychology*, 12(2), 193.
- Frischen, A., & Tipper, S. P. (2004). Orienting attention via observed gaze shift evokes longer term inhibitory effects: implications for social interactions, attention, and memory. *Journal of Experimental Psychology: General*, 133(4), 516-533.
- Fugate, C. M., Zentall, S. S., & Gentry, M. (2013). Creativity and working memory in gifted students with and without characteristics of attention deficit hyperactive disorder: Lifting the mask. *Gifted Child Quarterly*, 57(4), 234-246.
- Funes, M. J., Lupiáñez, J., & Milliken, B. (2007). Separate mechanisms recruited by exogenous and endogenous spatial cues: evidence from a spatial Stroop paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, 33(2), 348-362.
- Gardner, H. (2011a). *Creating minds: An anatomy of creativity seen through the lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi*: Basic Books.
- Gardner, H. (2011b). *Frames of mind: The theory of multiple intelligences*: Basic books.
- Gearhart, C. C. (2014). Sensory-Processing Sensitivity and Nonverbal Decoding: The Effect on Listening Ability and Accuracy. *International Journal of Listening*, 28(2), 98-111.

- Gerardi - Caulton, G. (2000). Sensitivity to spatial conflict and the development of self - regulation in children 24 - 36 months of age. *Dev Sci*, 3(4), 397-404.
- Gilbertson, M. W., Shenton, M. E., Ciszewski, A., Kasai, K., Lasko, N. B., Orr, S. P., & Pitman, R. K. (2002). Smaller hippocampal volume predicts pathologic vulnerability to psychological trauma. *Nat Neurosci*, 5(11), 1242-1247.
- Gilhooly, K., Fioratou, E., Anthony, S., & Wynn, V. (2007). Divergent thinking: Strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology*, 98(4), 611-625.
- Goff, K., & Torrance, E. P. (2002). Abbreviated Torrance Test for Adults manual. Bensenville, IL: Scholastic Testing Service.
- Goldberg, L. R. (1990). An alternative" description of personality": the big-five factor structure. *Journal of Personality and Social Psychology*, 59(6), 1216.
- Goldsmith, H. H., Buss, A. H., Plomin, R., Rothbart, M. K., Thomas, A., Chess, S., . . . McCall, R. B. (1987). Roundtable: what is temperament? Four approaches. *Child Dev*, 58(2), 505-529.
- Granger, K. T., Moran, P. M., Buckley, M. G., & Haselgrove, M. (2016). Enhanced latent inhibition in high schizotypy individuals. *Personality and Individual Differences*, 91, 31-39.
- Gray, J. A. (1981). A critique of Eysenck's theory of personality *A model for personality* (pp. 246-276). Berlin Heidelberg: Springer.
- Gray, N. S., Snowden, R. J., Peoples, M., Hemsley, D. R., & Gray, J. A. (2003). A demonstration of within-subjects latent inhibition in the human: limitations and advantages. *Behav Brain Res*, 138(1), 1-8.
- Graybiel, A. M. (1998). The basal ganglia and chunking of action repertoires. *Neurobiol Learn Mem*, 70(1), 119-136.
- Guilford, J. P. (1950). Creativity. *American Psychologist*, 5(9), 444-454.
- Guilford, J. P. (1967). *The nature of human intelligence*. US: McGraw-Hill Inc.
- Hampshire, A., Highfield, R. R., Parkin, B. L., & Owen, A. M. (2012). Fractionating human intelligence. *Neuron*, 76(6), 1225-1237.
- Hennessey, B. A., & Amabile, T. M. (2010). Creativity. *Annu Rev Psychol*, 61, 569-598.
- Hirsh, J. B., & Peterson, J. B. (2008). Predicting creativity and academic success with a "fake-proof" measure of the Big Five. *J Res Pers*, 42(5), 1323-1333.
- Hocevar, D. (1979a). The Development of the Creative Behavior Inventory (CBI). *Paper presented at the annual meeting of the Rocky Mountain Psychological Association (ERIC Document Reproduction Service No.Ed. 170 350)*.
- Hocevar, D. (1979b). Ideational fluency as a confounding factor in the measurement of originality. *Journal of Educational Psychology*, 71(2), 191.
- Hofmann, S. G., & Bitran, S. (2007). Sensory-processing sensitivity in social anxiety disorder: relationship to harm avoidance and diagnostic subtypes. *J Anxiety Disord*, 21(7), 944-954.
- Homberg, J. R., Schubert, D., Asan, E., & Aron, E. N. (2016). Sensory processing sensitivity and serotonin gene variance: Insights into mechanisms shaping environmental sensitivity. *Neurosci Biobehav Rev*, 71, 472-483.

- Hu, L. t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal*, 6(1), 1-55.
- Ivry, R. B., & Robertson, L. C. (1998). *The two sides of perception*. Cambridge, MA: MIT Press.
- Jagiellowicz, J., Xu, X., Aron, A., Aron, E., Cao, G., Feng, T., & Weng, X. (2010). The trait of sensory processing sensitivity and neural responses to changes in visual scenes. *Social cognitive and affective neuroscience*, 6(1), 38-47.
- Jagiellowicz, J., Xu, X., Aron, A., Aron, E., Cao, G., Feng, T., & Weng, X. (2011). The trait of sensory processing sensitivity and neural responses to changes in visual scenes. *Soc Cogn Affect Neurosci*, 6(1), 38-47.
- Jauk, E., Benedek, M., Dunst, B., & Neubauer, A. C. (2013). The relationship between intelligence and creativity: New support for the threshold hypothesis by means of empirical breakpoint detection. *Intelligence*, 41(4), 212-221.
- Jauk, E., Benedek, M., & Neubauer, A. C. (2014a). The Road to Creative Achievement: A Latent Variable Model of Ability and Personality Predictors. *Eur J Pers*, 28(1), 95-105.
- Jauk, E., Benedek, M., & Neubauer, A. C. (2014b). The road to creative achievement: A latent variable model of ability and personality predictors. *European Journal of Personality*, 28(1), 95-105.
- Jauk, E., Neubauer, A. C., Dunst, B., Fink, A., & Benedek, M. (2015). Gray matter correlates of creative potential: a latent variable voxel-based morphometry study. *Neuroimage*, 111, 312-320.
- John, O. P., Donahue, E. M., & Kentle, R. L. (1991). The Big Five Inventory--Versions 4a and 54. . Berkeley, CA: University of California, Berkeley, Institute of Personality and Social Research.
- John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm Shift to the Integrative Big-Five Trait Taxonomy: History, Measurement, and Conceptual Issues. In O. P. John, R. W. Robins, & L. A. Pervin (Eds.), *Handbook of personality: Theory and research* (pp. 114-158). New York, NY: Guilford Press.
- John, O. P., & Srivastava, S. (1999). The Big Five trait taxonomy: History, measurement, and theoretical perspectives. *Handbook of personality: Theory and research*, 2(1999), 102-138.
- Johnson, J. A. (1994). Clarification of factor five with the help of the AB5C model. *European Journal of Personality*, 8(4), 311-334.
- Johnson, M. H., Posner, M. I., & Rothbart, M. K. (1991). Components of visual orienting in early infancy: contingency learning, anticipatory looking, and disengaging. *J Cogn Neurosci*, 3(4), 335-344.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds.), *Attention and performance* (Vol. XI, pp. 187-203). Hillsdale, NJ: Lawrence Erlbaum.
- Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., . . . Kounios, J. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biol*, 2(4), e97.
- Kantor-Martynuska, J. (2012). "The Princess and the Pea" Suggestions for the Revision of Sensory Sensitivity in the Regulative Theory of Temperament. *Journal of Individual Differences*, 33(4), 237-247.

- Kaufman, A. B., Kornilov, S. A., Bristol, A. S., Tan, M., & Grigorenko, E. L. (2010). The neurobiological foundation of creative cognition. In J. C. K. R. J. Sternberg (Ed.), *The Cambridge handbook of creativity* (pp. 216-232). New York, NY: Cambridge University Press.
- Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four c model of creativity. *Review of general psychology, 13*(1), 1.
- Kaufman, J. C., & Sternberg, R. J. (Eds.). (2010). *The Cambridge handbook of creativity*. New York: Cambridge University Press.
- Kaufman, J. C., Waterstreet, M. A., Ailabouni, H. S., Whitcomb, H. J., Roe, A. K., & Riggs, M. (2010). Personality and self-perceptions of creativity across domains. *Imagination, Cognition and Personality, 29*(3), 193-209.
- Kaufman, S. B., DeYoung, C. G., Gray, J. R., Jiménez, L., Brown, J., & Mackintosh, N. (2010). Implicit learning as an ability. *Cognition, 116*(3), 321-340.
- Kaufman, S. B., Quilty, L. C., Grazioplene, R. G., Hirsh, J. B., Gray, J. R., Peterson, J. B., & DeYoung, C. G. (2016). Openness to Experience and Intellect Differentially Predict Creative Achievement in the Arts and Sciences. *J Pers, 84*(2), 248-258.
- Kaufmann, G. (2003). Expanding the mood-creativity equation. *Creativity Research Journal, 15*, 131-135.
- Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and technical innovation: Spatial ability's unique role. *Psychol Sci, 24*(9), 1831-1836.
- Keri, S. (2011). Solitary Minds and Social Capital: Latent Inhibition, General Intellectual Functions and Social Network Size Predict Creative Achievements. *Psychology of Aesthetics, Creativity, and the Arts, 5*(3), 215–221.
- Kihlstrom, J. F. (1987). The cognitive unconscious. *Science, 144*5-1452.
- Kim, K. H. (2005). Can only intelligent people be creative? A meta-analysis. *Prufrock Journal, 16*(2-3), 57-66.
- Kim, K. H. (2008). Meta - analyses of the relationship of creative achievement to both IQ and divergent thinking test scores. *The Journal of Creative Behavior, 42*(2), 106-130.
- King, L. A., McKee Walker, L., & Broyles, S. J. (1996). Creativity and the Five-Factor Model. *J Res Pers, 30*, 189–203.
- Kjellgren, A., Bood, S. A., Axelsson, K., Norlander, T., & Saatcioglu, F. (2007). Wellness through a comprehensive yogic breathing program - a controlled pilot trial. *BMC Complement Altern Med, 7*, 43.
- Klein, R. M. (2000). Inhibition of return. *Trends Cogn Sci, 4*(4), 138-147.
- Klein, R. M., & Dick, B. (2002). Temporal dynamics of reflexive attention shifts: A dual-stream rapid serial visual presentation exploration. *Psychol Sci, 13*(2), 176-179.
- Klimesch, W., Doppelmayr, M., Russegger, H., Pachinger, T., & Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience letters, 244*(2), 73-76.
- Kline, R. B. (2015). *Principles and practice of structural equation modeling*: Guilford publications.
- Knight, R. (1996). Contribution of human hippocampal region to novelty detection. *Nature, 383*(6597), 256-259.
- Koivisto, M., & Revonsuo, A. (2003). An ERP study of change detection, change blindness, and visual awareness. *Psychophysiology, 40*(3), 423-429.

- Kounios, J., Fleck, J. I., Green, D. L., Payne, L., Stevenson, J. L., Bowden, E. M., & Jung-Beeman, M. (2008). The origins of insight in resting-state brain activity. *Neuropsychologia*, *46*(1), 281-291.
- Kozbelt, A., Beghetto, R. A., & Runco, M. A. (2010). Theories of creativity. *The Cambridge handbook of creativity*, *20*, 47.
- Kris, E. (1952). *Psychoanalytic explorations in art*. Oxford, England: International Universities Press.
- Laufs, H., Krakow, K., Sterzer, P., Eger, E., Beyerle, A., Salek-Haddadi, A., & Kleinschmidt, A. (2003). Electroencephalographic signatures of attentional and cognitive default modes in spontaneous brain activity fluctuations at rest. *Proceedings of the national academy of sciences*, *100*(19), 11053-11058.
- Li, Y., Guan, Y., Wang, F., Zhou, X., Guo, K., Jiang, P., . . . Fang, Z. (2015). Big-five personality and BIS/BAS traits as predictors of career exploration: The mediation role of career adaptability. *Journal of Vocational Behavior*, *89*, 39-45.
- Lin, W.-L., Hsu, K.-Y., Chen, H.-C., & Chang, W.-Y. (2013). Different attentional traits, different creativities. *Thinking Skills and Creativity*, *9*, 96-106.
- Liss, M., Mailloux, J., & Erchull, M. J. (2008). The relationships between sensory processing sensitivity, alexithymia, autism, depression, and anxiety. *Personality and Individual Differences*, *45*(3), 255-259.
- Liss, M., Timmel, L., Baxley, K., & Killingsworth, P. (2005). Sensory processing sensitivity and its relation to parental bonding, anxiety, and depression. *Personality and Individual Differences*, *39*(8), 1429-1439.
- Lubart, T. I. (2001). Models of the creative process: Past, present and future. *Creativity Research Journal*, *13*(3-4), 295-308.
- Lubow, R. (1997). Latent inhibition as a measure of learned inattention: some problems and solutions. *Behav Brain Res*, *88*(1), 75-83.
- Lubow, R. (2005a). Construct validity of the animal latent inhibition model of selective attention deficits in schizophrenia. *Schizophr Bull*, *31*(1), 139-153.
- Lubow, R., & Josman, Z. (1993). Latent inhibition deficits in hyperactive children. *Journal of Child Psychology and Psychiatry*, *34*(6), 959-973.
- Lubow, R. E. (1989). *Latent inhibition and conditioned attention theory* (Vol. 9): Cambridge University Press.
- Lubow, R. E. (2005b). Construct validity of the animal latent inhibition model of selective attention deficits in schizophrenia. *Schizophr Bull*, *31*(1), 139-153.
- Lubow, R. E., & Gewirtz, J. C. (1995). Latent inhibition in humans: data, theory, and implications for schizophrenia. *Psychol Bull*, *117*(1), 87-103.
- Lubow, R. E., & Kaplan, O. (2005). The visual search analogue of latent inhibition: implications for theories of irrelevant stimulus processing in normal and schizophrenic groups. *Psychon Bull Rev*, *12*(2), 224-243.
- Lupiáñez, J., Decaix, C., Siéoff, E., Chokron, S., Milliken, B., & Bartolomeo, P. (2004). Independent effects of endogenous and exogenous spatial cueing: Inhibition of return at endogenously attended target locations. *Exp Brain Res*, *159*(4), 447-457.
- MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychol Methods*, *1*(2), 130 - 149.



- MacCallum, R. C., Zhang, S., Preacher, K. J., & Rucker, D. D. (2002). On the practice of dichotomization of quantitative variables. *Psychol Methods*, 7(1), 19-40.
- MacLeod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, R. M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical considerations of the Attention Network Test. *Neuropsychology*, 24(5), 637.
- Martindale, C. (1977). CREATIVITY, CONSCIOUSNESS, AND CORTICAL AROUSAL. *Journal of Altered States of Consciousness*, 3(1), 69-87.
- Martindale, C. (1989). Personality, situation, and creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 211-232). New York: Plenum.
- Martindale, C. (1999). Biological bases of creativity. In R. J. Sternberg (Ed.), *Handbook of Creativity* (pp. 137-152). Cambridge, UK: Cambridge University Press.
- Martindale, C., Anderson, K., Moore, K., & West, A. N. (1996). Creativity, oversensitivity, and rate of habituation. *Personality and Individual Differences*, 20(4), 423-427.
- Martindale, C., & Armstrong, J. (1974a). Relationship of creativity to cortical activation and its operant control. *Journal of Genetic Psychology*, 124(2), 311-320.
- Martindale, C., & Armstrong, J. (1974b). The relationship of creativity to cortical activation and its operant control. *J Genet Psychol*, 124(2d Half), 311-320.
- Matthews, G., & Zeidner, M. (2012). Individual differences in attentional networks: Trait and state correlates of the ANT. *Personality and Individual Differences*, 53(5), 574-579.
- McCrae, R. R. (1987). Creativity, divergent thinking, and openness to experience. *Journal of Personality and Social Psychology*, 52(6), 1258.
- McCrae, R. R. (2007). Aesthetic Chills as a Universal Marker of Openness to Experience. *Motiv Emot*, 31, 5-11.
- McCrae, R. R., Costa Jr, P. T., Ostendorf, F., Angleitner, A., Hřebíčková, M., Avia, M. D., . . . Woodfield, R. (2000). Nature over nurture: temperament, personality, and life span development. *Journal of Personality and Social Psychology*, 78(1), 173-186.
- McCrae, R. R., & Costa, P. T. (1997). Conceptions and correlates of openness to experience. In R. Hogan, J. A. Johnson, & S. R. Briggs (Eds.), *Handbook of personality psychology* (pp. 825-847). Orlando, FL: Academic Press.
- Mednick, S. (1962). The associative basis of the creative process. *Psychological review*, 69(3), 220.
- Mednick, S. A., & Mednick, M. T. (1967). *Examiner's manual, Remote Associates Test: College and adult forms 1 and 2*: Houghton Mifflin.
- Meltzer, H. Y., & Stahl, S. M. (1976). The dopamine hypothesis of schizophrenia: a review. *Schizophr Bull*, 2(1), 19.
- Mendelsohn, G. A. (1976). Associative and attentional processes in creative performance. *J Pers*, 44(2), 341-369.
- Meyer, B., & Carver, C. S. (2000). Negative childhood accounts, sensitivity, and pessimism: A study of avoidant personality disorder features in college students. *Journal of Personality Disorders*, 14(3), 233-248.
- Monroe, S. M., & Simons, A. D. (1991). Diathesis-stress theories in the context of life stress research: implications for the depressive disorders. *Psychological Bulletin*, 110(3), 406.
- Moore, S. R., & Depue, R. A. (2016). Neurobehavioral foundation of environmental reactivity. *Psychol Bull*, 142(2), 107-164.

- Mueller, S. T. (2011). PEBL's Change Detection Task. Computer software retrieved from <http://pebl.sf.net/battery.html>.
- Mueller, S. T., & Piper, B. J. (2014). The psychology experiment building language (PEBL) and PEBL test battery. *Journal of neuroscience methods*, 222, 250-259.
- Muller, H. J., & Rabbitt, P. M. (1989). Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interruption. *J Exp Psychol Hum Percept Perform*, 15(2), 315-330.
- Neal, J. A., Edelmann, R. J., & Glachan, M. (2002). Behavioural inhibition and symptoms of anxiety and depression: is there a specific relationship with social phobia? *Br J Clin Psychol*, 41(Pt 4), 361-374.
- Necka, E., & Hlawacz, T. (2013). Who has an Artistic Temperament? Relationships Between Creativity and Temperament Among Artists and Bank Officers. *Creativity Research Journal*, 25(2), 182-188.
- Nelson, B., & Rawlings, D. (2010). Relating schizotypy and personality to the phenomenology of creativity. *Schizophr Bull*, 36(2), 388-399.
- Nijstad, B. A., De Dreu, C. K., Rietzschel, E. F., & Baas, M. (2010). The dual pathway to creativity model: Creative ideation as a function of flexibility and persistence. *European Review of Social Psychology*, 21(1), 34-77.
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive psychology*, 19(1), 1-32.
- Norman, E., Price, M. C., & Duff, S. C. (2006). Fringe consciousness in sequence learning: The influence of individual differences. *Conscious Cogn*, 15(4), 723-760.
- Norman, E., Price, M. C., Duff, S. C., & Mentzoni, R. A. (2007). Gradations of awareness in a modified sequence learning task. *Conscious Cogn*, 16(4), 809-837.
- O'Gorman, J. (2016). 4 Habituation and Personality *Individual Differences and Psychopathology: Physiological Correlates of Human Behaviour* (Vol. 3, pp. 45).
- O'Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change-blindness as a result of 'mudsplashes'. *Nature*, 398(6722), 34-34.
- O'Connor, B. P. (2000). SPSS and SAS programs for determining the number of components using parallel analysis and Velicer's MAP test. *Behavior Research Methods*, 32(3), 396-402.
- Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. *Journal of neuroscience methods*, 162(1), 8-13.
- Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual review of neuroscience*, 35, 73-89.
- Peterson, J. B., & Carson, S. H. (2000). Latent Inhibition and Openness to Experience in a high-achieving student population. *Personality and Individual Differences*, 28, 323-332.
- Pitman, R. K., Rasmusson, A. M., Koenen, K. C., Shin, L. M., Orr, S. P., Gilbertson, M. W., . . . Liberzon, I. (2012). Biological studies of posttraumatic stress disorder. *Nature reviews. Neuroscience*, 13(11), 769.
- Plucker, J. A. (1999). Is the proof in the pudding? Reanalyses of Torrance's (1958 to present) longitudinal data. *CREATIVITY RESEARCH JOURNAL*, 12(2), 103-114.
- Plucker, J. A., Beghetto, R. A., & Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educational psychologist*, 39(2), 83-96.

- Plucker, J. A., & Makel, M. C. (2010). Assessment of creativity. *The Cambridge handbook of creativity*, 48-73.
- Plucker, J. A., Runco, M. A., & Lim, W. (2006). Predicting ideational behavior from divergent thinking and discretionary time on task. *Creativity Research Journal*, 18(1), 55-63.
- Pluess, M. (2015a). Individual Differences in Environmental Sensitivity. *Child development perspectives*, 9(3).
- Pluess, M. (2015b). Vantage Sensitivity: Environmental Sensitivity to Positive Experiences as a Function of Genetic Differences. *J Pers.*
- Pluess, M. (2017). Vantage Sensitivity: Environmental Sensitivity to Positive Experiences as a Function of Genetic Differences. *J Pers*, 85(1), 38-50.
- Pluess, M., & Bartley, M. (2015). Childhood conscientiousness predicts the social gradient of smoking in adulthood: a life course analysis. *J Epidemiol Community Health*, 69(4), 330-338.
- Pluess, M., & Belsky, J. (2009). Differential susceptibility to rearing experience: the case of childcare. *J Child Psychol Psychiatry*, 50(4), 396-404.
- Pluess, M., & Belsky, J. (2013). Vantage sensitivity: individual differences in response to positive experiences. *Psychol Bull*, 139(4), 901-916.
- Pluess, M., & Boniwell, I. (2015a). Sensory-Processing Sensitivity predicts treatment response to a school-based depression prevention program: Evidence of Vantage Sensitivity. *Personality and Individual Differences*, 82, 40-45.
- Pluess, M., & Boniwell, L. (2015b). Sensory-Processing Sensitivity predicts treatment response to a school-based depression prevention program: Evidence of Vantage Sensitivity. *Personality and Individual Differences*, 82 40-45.
- Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology*, 118(10), 2128-2148.
- Posner, M., Rothbart, M. K., Vizueta, N., Levy, K. N., Evans, D. E., Thomas, K. M., & Clarkin, J. F. (2002). Attentional mechanisms of borderline personality disorder. *Proc Natl Acad Sci U S A*, 99(25), 16366-16370.
- Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, 32(1), 3-25.
- Posner, M. I. (1994). Attention: the mechanisms of consciousness. *Proceedings of the national academy of sciences*, 91(16), 7398-7403.
- Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. *Attention and performance X: Control of language processes*, 32, 531-556.
- Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual review of neuroscience*, 13(1), 25-42.
- Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive neuropsychology*, 2(3), 211-228.
- Posner, M. I., & Rothbart, M. K. (1980). The development of attentional mechanisms. *Nebraska Symposium on Motivation. Nebraska Symposium on Motivation*, 28, 1-52.
- Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annu Rev Psychol*, 58, 1-23.
- Posner, M. I., Rothbart, M. K., & Tang, Y. (2015). Enhancing attention through training. *Current Opinion in Behavioral Sciences*, 4, 1-5.

- Poy, R., del Carmen Eixarch, M., & Ávila, C. (2004). On the relationship between attention and personality: Covert visual orienting of attention in anxiety and impulsivity. *Personality and Individual Differences, 36*(6), 1471-1481.
- Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General, 118*(3), 219-235.
- Reber, A. S. (1992). The cognitive unconscious: An evolutionary perspective. *Conscious Cogn, 1*(2), 93-133.
- Reber, A. S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconscious*. New York, NY: Oxford University Press.
- Reber, P. J. (2013). The neural basis of implicit learning and memory: a review of neuropsychological and neuroimaging research. *Neuropsychologia, 51*(10), 2026-2042.
- Reber, P. J., & Squire, L. R. (1998). Encapsulation of implicit and explicit memory in sequence learning. *Journal of Cognitive Neuroscience, 10*(2), 248-263.
- Reed, J., & Johnson, P. (1994). Assessing implicit learning with indirect tests: Determining what is learned about sequence structure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(3), 585-594.
- Rees, G., & Lavie, N. (2001). What can functional imaging reveal about the role of attention in visual awareness? *Neuropsychologia, 39*(12), 1343-1353.
- Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychol Sci, 8*(5), 368-373.
- Rizzo-Sierra, C. V., Duran, M. C., & Leon-Sarmiento, F. E. (2011). Highly sensitive trait and ectomorphism: another link on creativity and psychopathology. *Can J Psychiatry, 56*(11), 702; author reply 702-703.
- Rothbart, M., Derryberry, D., & Posner, M. (1994). A psychobiological approach to the development of temperament. *Temperament: Individual differences at the interface of biology and behavior, 83-116*.
- Rothbart, M. K. (2007). Temperament, development, and personality. *Current Directions in Psychological Science, 16*(4), 207-212.
- Rothbart, M. K. (2011). *Becoming Who We Are: Temperament and Personality in Development*. New York, NY, USA: The Guildford Press.
- Rothbart, M. K., Ahadi, S. A., & Evans, D. E. (2000). Temperament and personality: origins and outcomes. *J Pers Soc Psychol, 78*(1), 122-135.
- Rothbart, M. K., Ellis, L. K., Rueda, M. R., & Posner, M. I. (2003). Developing mechanisms of temperamental effortful control. *J Pers, 71*(6), 1113-1143.
- Rothbart, M. K., & Posner, M. (2001). Mechanism and variation in the development of attentional networks. . In C. A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience*. (pp. 353-363). Cambridge, MA: MIT Press.
- Rothbart, M. K., Sheese, B. E., & Posner, M. I. (2007). Executive attention and effortful control: Linking temperament, brain networks, and genes. *Child development perspectives, 1*(1), 2-7.
- Runco, M. A. (1998). Suicide and creativity: the case of Sylvia Plath. *Death Stud, 22*(7), 637-654.
- Runco, M. A. (2014). *Creativity: Theories and Themes: Research, Development, and Practice* (Second ed.): Elsevier, Inc.

- Runco, M. A., & Acar, S. (2012). Divergent Thinking as an Indicator of Creative Potential. *Creativity Research Journal*, 24(1), 66-75.
- Runco, M. A., & Albert, R. S. (1985). The Reliability and Validity of Ideational Originality in the Divergent Thinking of Academically Gifted and Nongifted Children. *Educational and Psychological Measurement*, 45(3), 483-501.
- Runco, M. A., & Albert, R. S. (1986). The threshold theory regarding creativity and intelligence: An empirical test with gifted and nongifted children. *Creative Child and Adult Quarterly*, 11(4), 212-218.
- Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity Research Journal*, 24(1), 92-96.
- Runco, M. A., Plucker, J. A., & Lim, W. (2000-2001). Development and psychometric integrity of a measure of ideational behavior. *Creativity Research Journal*, 13(3 & 4), 393-400.
- Runco, M. A., Walczyk, J. J., Acar, S., Cowger, E. L., Simundson, M., & Tripp, S. (2014). The incremental validity of a short form of the Ideational Behavior Scale and usefulness of distractor, contraindicative, and lie scales. *The Journal of Creative Behavior*, 48, 185-197.
- Sapolsky, R. M., Uno, H., Rebert, C. S., & Finch, C. E. (1990). Hippocampal damage associated with prolonged glucocorticoid exposure in primates. *Journal of Neuroscience*, 10(9), 2897-2902.
- Sawyer, R. K. (2012). *Explaining creativity: The science of human innovation* (Second ed.). New York: Oxford University Press, Inc.
- Schacter, D. L. (1997). The cognitive neuroscience of memory: perspectives from neuroimaging research. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 352(1362), 1689-1695.
- Schendan, H., Searl, M., Melrose, R., & Stern, C. (2003a). Sequence? What Sequence?: the human medial temporal lobe and sequence learning. *Mol Psychiatry*, 8(11), 896-896.
- Schendan, H. E. (2012). Implicit memory. In V. S. Ramachandran (Ed.), *Encyclopedia of Human Behavior* (Vol. 1-10). Oxford, United Kingdom: Elsevier.
- Schendan, H. E., Searl, M. M., Melrose, R. J., & Stern, C. E. (2003b). An FMRI study of the role of the medial temporal lobe in implicit and explicit sequence learning. *Neuron*, 37(6), 1013-1025.
- Schendan, H. E., Tinaz, S., Maher, S. M., & Stern, C. E. (2013). Frontostriatal and mediotemporal lobe contributions to implicit higher-order spatial sequence learning declines in aging and Parkinson's disease. *Behav Neurosci*, 127(2), 204-221.
- Schmajuk, N., Aziz, D. R., & Bates, M. J. B. (2009). Attentional–Associative Interactions in Creativity. *CREATIVITY RESEARCH JOURNAL*, 21(1), 92–103.
- Schönbrodt, F. D., & Perugini, M. (2013). At what sample size do correlations stabilize? *J Res Pers*, 47(5), 609-612.
- Schooler, J. W., & Melcher, J. (1995). The ineffability of insight. *The creative cognition approach* (Cambridge, MA, US: The MIT Press), (pp. 97-133).
- Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of neurology, neurosurgery, and psychiatry*, 20(1), 11.
- Shamay-Tsoory, S. G., Adler, N., Aharon-Peretz, J., Perry, D., & Mayseless, N. (2011). The origins of originality: the neural bases of creative thinking and originality. *Neuropsychologia*, 49(2), 178-185.

- Shanks, D. R. (2005). Implicit learning. In K. L. R. Goldstone (Ed.), *Handbook of cognition* (pp. 202-220). London, UK: Sage.
- Shanks, D. R., & Johnstone, T. (1999). Evaluating the relationship between explicit and implicit knowledge in a sequential reaction time task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25(6), 1435-1451.
- Shiner, R. L., Buss, K. A., McClowry, S. G., Putnam, S. P., Saudino, K. J., & Zentner, M. (2012a). What Is Temperament Now? Assessing Progress in Temperament Research on the Twenty-Fifth Anniversary of Goldsmith et al. (1987). *Child development perspectives*, 6(4), 436-444.
- Shiner, R. L., Buss, K. A., McClowry, S. G., Putnam, S. P., Saudino, K. J., & Zentner, M. (2012b). What Is Temperament Now? Assessing Progress in Temperament Research on the Twenty-Fifth Anniversary of Goldsmith et al. (). *Child development perspectives*, 6(4), 436-444.
- Shiner, R. L., & DeYoung, C. G. (2013a). The Structure of Temperament and Personality Traits: A Developmental. In P. D. Zelazo (Ed.), *The Oxford Handbook of Developmental Psychology, Vol. 2: Self and Other* (Vol. 2, pp. 113). New York: New York: Oxford University Press, Inc.
- Shiner, R. L., & DeYoung, C. G. (2013b). The structure of temperament and personality traits: A developmental perspective. In P. D. Zelazo (Ed.), *The Oxford Handbook of Developmental Psychology* (Vol. 2, pp. 113-141). Oxford: Oxford University Press.
- Silvia, P. J. (2008). Creativity and intelligence revisited: A latent variable analysis of Wallach and Kogan (1965). *CREATIVITY RESEARCH JOURNAL*, 20(1), 34-39.
- Silvia, P. J., Kaufman, J. C., Reiter-Palmon, R., & Wigert, B. (2011). Cantankerous creativity: Honesty–Humility, Agreeableness, and the HEXACO structure of creative achievement. *Personality and Individual Differences*, 51(5), 687-689.
- Silvia, P. J., Nusbaum, E. C., Berg, C., Martin, C., & O'Connor, A. (2009). Openness to experience, plasticity, and creativity: Exploring lower-order, high-order, and interactive effects. *Journal of Research in Personality*, 43(6), 1087-1090.
- Silvia, P. J., Wigert, B., Reiter-Palmon, R., & Kaufman, J. C. (2012). Assessing creativity with self-report scales: A review and empirical evaluation. *Psychology of Aesthetics, Creativity, and the Arts*, 6(1), 19.
- Silvia, P. J., Winterstein, B. P., Willse, J. T., Barona, C. M., Cram, J. T., Hess, K. I., . . . Richard, C. A. (2008). Assessing creativity with divergent thinking tasks: Exploring the reliability and validity of new subjective scoring methods. *Psychology of Aesthetics, Creativity, and the Arts*, 2(2), 68.
- Simonton, D. K. (2012a). Quantifying creativity: can measures span the spectrum? *Dialogues Clin Neurosci*, 14(1), 100-104.
- Simonton, D. K. (2012b). Taking the US Patent Office criteria seriously: A quantitative three-criterion creativity definition and its implications. *Creativity Research Journal*, 24(2-3), 97-106.
- Simonton, D. K. (2016). Defining Creativity: Don't We Also Need to Define What Is Not Creative? *The Journal of Creative Behavior*, 1-15.
- Smith, S. M., Ward, T. B., & Finke, R. A. (1995). *The creative cognition approach*.
- Smits, D. J., & Boeck, P. (2006). From BIS/BAS to the big five. *Eur J Pers*, 20(4), 255-270.

- Smolewska, K. A., McCabe, S. B., & Woody, E. Z. (2006). A psychometric evaluation of the Highly Sensitive Person Scale: The components of sensory-processing sensitivity and their relation to the BIS/BAS and “Big Five”. *Personality and Individual Differences*, *40*, 1269–1279.
- Sobocko, K., & Zelenski, J. M. (2015). Trait sensory-processing sensitivity and subjective well-being: Distinctive associations for different aspects of sensitivity. *Personality and Individual Differences*, *83*, 44-49.
- Sokolov, E. N. (1963). Higher nervous functions: The orienting reflex. *Annual review of physiology*, *25*(1), 545-580.
- Sokolov, E. N. (1990). The orienting response, and future directions of its development. *Integrative Physiological and Behavioral Science*, *25*(3), 142-150.
- Solomon, P. R., Crider, A., Winkelman, J., Turi, A., Kamer, R., & Kaplan, L. (1981). Disrupted latent inhibition in the rat with chronic amphetamine or haloperidol-induced supersensitivity: relationship to schizophrenic attention disorder. *Biol Psychiatry*.
- Spreng, R. N., Mar, R. A., & Kim, A. S. (2009). The common neural basis of autobiographical memory, prospection, navigation, theory of mind, and the default mode: a quantitative meta-analysis. *J Cogn Neurosci*, *21*(3), 489-510.
- Spreng, R. N., Sepulcre, J., Turner, G. R., Stevens, W. D., & Schacter, D. L. (2013). Intrinsic architecture underlying the relations among the default, dorsal attention, and frontoparietal control networks of the human brain. *J Cogn Neurosci*, *25*(1), 74-86.
- Squire, L. R. (1992). Memory and the hippocampus: a synthesis from findings with rats, monkeys, and humans. *Psychological review*, *99*(2), 195-231.
- Squire, L. R., & Zola-Morgan, S. (1991). The medial temporal lobe memory system. *Science*, *253*(5026), 1380-1386.
- Sternberg, R. J., & Lubart, T. I. (1991). An investment theory of creativity and its development. *Human development*, *34*(1), 1-31.
- Sternberg, R. J., & Lubart, T. I. (1999). The concept of creativity: Prospects and paradigms. *Handbook of creativity*, *1*, 3-15.
- Strelau, J. (1998). *Temperament: A psychological perspective*. New York: Plenum Press.
- Strelau, J., & Zawadzki, B. (1993). The Formal Characteristics of Behavior—Temperament Inventory (FCB—TI): Theoretical assumptions and scale construction. *European Journal of Personality*, *7*, 207–229.
- Takeuchi, H., Taki, Y., Hashizume, H., Sassa, Y., Nagase, T., Nouchi, R., & Kawashima, R. (2011). Failing to deactivate: the association between brain activity during a working memory task and creativity. *Neuroimage*, *55*(2), 681-687.
- Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., & Kawashima, R. (2010). Regional gray matter volume of dopaminergic system associate with creativity: evidence from voxel-based morphometry. *Neuroimage*, *51*(2), 578-585.
- Tape, T. G. (2006). The area under an ROC curve. *Interpreting diagnostic tests*.
- Tipples, J. (2002). Eye gaze is not unique: Automatic orienting in response to uninformative arrows. *Psychon Bull Rev*, *9*(2), 314-318.
- Trofimova, I. (2018). Functionality versus dimensionality in psychological taxonomies, and a puzzle of emotional valence. *Philos Trans R Soc Lond B Biol Sci*, *373*(1744).

- Trofimova, I., & Robbins, T. W. (2016). Temperament and arousal systems: A new synthesis of differential psychology and functional neurochemistry. *Neurosci Biobehav Rev*, *64*, 382-402.
- Tulving, E. (1972). Episodic and semantic memory. *Organization of memory*, *1*, 381-403.
- VanVoorhis, C. W., & Morgan, B. L. (2007). Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology*, *3*(2), 43-50.
- Von Stumm, S., Chung, A., & Furnham, A. (2011). Creative ability, creative ideation and latent classes of creative achievement: What is the role of personality? *Psychology of Aesthetics, Creativity, and the Arts*, *5*(2), 107-114.
- Wallach, M. A., & Kogan, N. (1965). *Modes of thinking in young children: A study of the creativity-intelligence distinction*. New York: Holt, Rinehart, & Winston.
- Wallas, G. (1926). *The Art of Thought*. New York: Franklin Watts.
- Wan, L., Crawford, H. J., & Boutros, N. (2007). Early and late auditory sensory gating: moderating influences from schizotypal personality, tobacco smoking status, and acute smoking. *Psychiatry Res*, *151*(1-2), 11-20.
- Weijters, B., Baumgartner, H., & Schillewaert, N. (2013). Reversed item bias: An integrative model. *Psychol Methods*, *18*(3), 320 - 334.
- Wilson, K. E., Lowe, M. X., Ruppel, J., Pratt, J., & Ferber, S. (2016). The scope of no return: Openness predicts the spatial distribution of Inhibition of Return. *Atten Percept Psychophys*, *78*(1), 209-217.
- Zabelina, D. L., Colzato, L., Beeman, M., & Hommel, B. (2016). Dopamine and the Creative Mind: Individual Differences in Creativity Are Predicted by Interactions between Dopamine Genes DAT and COMT. *PLoS One*, *11*(1), e0146768.
- Zabelina, D. L., O'Leary, D., Pornpattananangkul, N., Nusslock, R., & Beeman, M. (2015). Creativity and sensory gating indexed by the P50: selective versus leaky sensory gating in divergent thinkers and creative achievers. *Neuropsychologia*, *69*, 77-84.
- Zabelina, D. L., & Robinson, M. D. (2010). Creativity as flexible cognitive control. *Psychology of Aesthetics, Creativity, and the Arts*, *4*(3), 136-143.
- Zabelina, D. L., Saporta, A., & Beeman, M. (2016). Flexible or leaky attention in creative people? Distinct patterns of attention for different types of creative thinking. *Mem Cognit*, *44*(3), 488-498.
- Zahn, T. P., Kruesi, M. J., Leonard, H. L., & Rapoport, J. L. (1994). Autonomic activity and reaction time in relation to extraversion and behavioral impulsivity in children and adolescents. *Personality and Individual Differences*, *16*(5), 751-758.
- Zentner, M., & Bates, J. E. (2008). Child temperament: An integrative review of concepts, research programs, and measures. *International Journal of Developmental Science*, *2*(1-2), 7-37.