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Working memory modules on the threshold to consciousness

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Abstract
Current literature is claiming for an important relationship between conscious experiencing and executive functions (mainly working memory). Since there is still a lack of empirical evidence relating those mental processes, the aim of this research is to continue exploring those relations by finding out how different components of working memory may affect the threshold to consciousness. The experiment contained three groups of people who performed two concurrent computerized tasks. The first one consisted of a replication of a priming and subjective visibility task (de Loof et al., 2013) for all the groups. Both experimental groups differed from the control group in the additional mental load due to the second task and differed between them in the nature of the load (remembering phonological or spatial information). Psychology students participated in the study facing the pc monitor to perform the first task alone if assigned to the control group, or concurrent to a Corsi Block-Tapping Test or a Phonological Maintenance Task if assigned to the experimental groups. The results seem to suggest that the spatial overload group had more trouble when trying to be conscious of the prime number in comparison to the other two. These results show accordance with previous research and could be the first to show a possible working memory module-dependence when it comes to conscious perception. This view could lead to new important reformulations of theories of consciousness and language.

Keywords: Working memory modules, working memory load, mental load, consciousness, conscious experiencing, executive functions, Corsi Block-Tapping Test, Phonological Maintenance Task, psychology

Introduction

Nowadays it seems that everyone in cognitive sciences agrees with the notion of consciousness as a mental function arisen somehow by the interconnection of different brain processes. This apparent shared opinion could be simply explained making some scientific assumptions: first, that everything is made of matter; second, that the brain is causing all sort of behaviours; and, third, that consciousness must be a behaviour that we can therefore study. Such approach goes in line with some of the generic empirical findings on consciousness. Dehaene and Naccache (2001) provide evidence that cognitive processing is possible without consciousness, that attention is an essential precondition for being conscious of something and that there is a necessity of consciousness for some integrative mental operations. These findings must be considered as they are in line with the basic scientific assumptions on consciousness as a brain product serving to an adaptive purpose.
Although there is a common attitude towards its investigation, more than often scientists are not able to share the same conceptualization towards consciousness. This lack of a common theoretical conceptualization could be explained by the ambiguity of the word “conscious”. Dehaene and Changeux (2011) identify two different meanings on this word: on one hand, the intransitive use (e.g., “the patient was still conscious”) can be interpreted as a state that can vary continuously and in which the person is passively perceiving the world; on the other hand, the transitive use (e.g., “I was not conscious of the red light”) can be interpreted as an special integrative type of active processing, defining the contents of consciousness that can be accessed and reported. These two notions are related intimately to two different ways of investigating consciousness. Using electroencephalography and averaging the recordings, it is possible to observe an electrical response (called evoked potential) towards the frontal electrodes (called P3a) when the brain is automatically or unconsciously orienting its selective attention to the stimulus. This signal is different from a late and widely distributed event-related potential wave called P3b, which is strongly linked to consciousness (Del Cul et al., 2007).

Following Purves et al. (2013), the first term described refers to a generalized brain state usually defined as wakefulness and entails a variety of physiological conditions at which there is more or less ability to react towards stimuli. Although wakefulness is a prerequisite, it does not define the subjective contents of awareness. Thus, this second term identifies consciousness as a psychological process whose basic objective is to integrate different brain processes, unifying our experiences into a single and unified story (Broks, 2003). Such a complex mental function cannot be explained easily by a generalized state since most events happening outside and inside us cannot be consciously reported while being awake. Moreover, several findings might be notifying us that consciousness is rather an active brain product serving for an adaptive purpose strongly linked to the highest kind of mental processes (Sterzer et al., 2009). Thus, the Prefrontal Parietal Network (PPN) could be causing the conscious experience, as it seems according to some studies (Rees, 2007; Rees et al., 2002). For instance, Del Cul et al. (2009) have documented patients suffering from damage to the prefrontal cortex and how this relates to a different threshold for subjective visibility. Besides, as Bor and Seth (2012) argue, there seems to be a neural overlap between areas involving attention, executive functions (mainly working memory) and visual awareness. They suggest consciousness as a holistic process carrying on complex and relevant information to achieve a specific adaptive goal in a highly variable environment.

Important methodological questions may arise when trying to investigate such a subjective and ephemeral phenomenon. Is it possible to rely on the reported contents of consciousness? Some authors (Gamez, 2014; Cohen and Dennett, 2011) argue that a conscious report, or a correlate to its activity, is necessary functionally connected to the process of awareness itself. In this sense, it could still be used in experimental psychology as a tool to approach effectively to the thresholds of subjective sensations. For a critic review of the neural correlates of conscious awareness look at De Graaf et al. (2012), and for a deep review of the methods to measure consciousness read Seth et al. (2008).

At this point, as conscious awareness implies attention and the PPN, could it be possible that those mental functions underpinning consciousness are the executive ones? Some authors (Van Gaal et al., 2012) support strong links between these two brain functions, though we still need to understand the directions of those relations.

Executive Functions (EFs) or cognitive control are names given to a group of top-down mental processes allocated primarily in the prefrontal cortex that are used when it is impossible to rely on automatic or conditioned responses and therefore it is needed to pay attention (Diamond, 2013). There are there elemental or core cognitive controllers: inhibition (controlling of one's attentional resources and stopping other processes or actions), working memory (holding information in mind while working with it) and shifting (flexibly changing the focus of our attention and perspectives). From these three basic EFs, other higher-order EFs can be built, such as reasoning or planning (Collins and Koechlin, 2012).

Bearing in mind that working memory and attention seem to be independent mental functions from consciousness itself (Soto et al., 2011; Dutta et al., 2014; Koch and Tsuchiya, 2007), it should be introduced that there is a promising relation between working memory and consciousness in different cognitive theories (Soto and Silvanto, 2014). For instance, in the Global Workspace theory (Dehaene et al., 1998) some preconscious highly specialized functions compete among themselves to get access to a global workspace, which has been conceptualized as with the same contents as those held in working memory. In the Attended Intermediate-level Representations theory of Prinz (2000) it is suggested that a stimulus is consciously perceived when its preconscious representation enter the working memory system thanks to the focus of attention. Finally, if consciousness is theorized as "the remembered present" in a Dynamic Core (Edelman and Tononi, 2000; Edelman et al., 2011), the continuous maintenance and activation of memories correspond to working memory, which would be causing consciousness itself in an eventual neuronal group selection process. In addition to this theoretical overlap, both mental functions are limited in their processing capacity to some extent (Crick and Koch, 1990; Miller, 1956), as well as it is known that their main focus of action is the integration of multimodal information (Zeki and Bartels, 1999).

It seems, then, that the current literature is claiming for an important relationship between conscious experiencing and executive functions, but since there is still a lack of empirical evidence relating those mental processes, some have started to explore the relations between working memory and subjective visibility. De Loof et al. (2013) importantly suggest that when the working memory span is narrowed overloading it, the subjective visibility (the conscious report) on a cognitive task is consequently impoverished as these two processes share the same neural

resources. Also, they observed that a higher working memory load reduces the amount of cognitive resources causing an increment in the congruency effect (less mental ability to shift between tasks). It was concluded consciousness to depend on the available working memory resources.

Nowadays working memory (WM) is conceptualized in a multi-component theory as an integrated system fusing at least two basic types of subsystems depending on the content held (Baddeley, 2011). The phonological loop is the module processing verbal information, whilst the visuo-spatial sketchpad is the module processing visual nonverbal information. Both subsystems of WM hold their respective information "on line" until that piece of information reaches the long-term memory system or is replaced by new perceived stimuli.

As De Loof et al. (2013) enquire: "to what extent do working memory and consciousness overlap? Is it complete?". In this sense, the aim of this research is to continue exploring those relations by finding out how different aspects of working memory may contribute to our experiencing. This research runs the same experiment but comparing the effects of two different module-specific tasks, one targeting the visuo-spatial memory load and one targeting the phonological memory load. At that point we might be able to differentiate and attribute the effects of working memory load in visual awareness to one specific information path. Thus, specifically, three groups are needed. One control group compared to two experimental groups differentiated by adding some mental load (factor) to the dependent variable (the same priming and subjective visibility task used in De Loof et al., 2013). These two experimental groups should differentiate between them in the nature of the load using a Corsi Block-Tapping Test to increase the visuo-spatial WM load and a Phonological Maintenance Task to increase the verbal WM load.

A between-subjects design has been chosen because although it requires of more time and higher sample sizes (important limitations in an undergraduate research project), it will also provide a more conservative and humble approach as well as a clearer differentiation between possible effects observed. As Charness et al. (2012) argue, one of the most important limitations from a within-subjects design arises from the possible contamination of an effect because of the previous task. In this research project, it would not be a good idea to engage the participants in different working memory tasks as they could increase the general short-term memory load occulting the specific ways in which every module interacts with the awareness network. So, in order to avoid a possible process of summation or redundancy gain from one module to the other (Roser & Corballis, 2002), a between-subjects design seems to be the best experimental option in this research.

The priming task replicated consists of a presentation of a prime number appearing and disappearing very quickly before the presentation of a target number inserted in a mask. The latter needs to be categorized as larger or smaller than five while it is needed to consciously report whether the first number had been seen or not.

The Corsi Block-Tapping Test is a widely used tool to assess the visuo-spatial module of working memory in a wide range of settings. It was developed by Corsi (1972) and consists of a layout of nine cubes above a board. The experimenter taps a sequence of cubes and asks the participant to repeat that sequence. As the length of sequences increases, the difficulty of the task increases and the span of the visuo-

spatial working memory can be measured. There have been studies trying to find new computerized ways of administration (Claessen et al., 2015) as well as normative data, showing preferential activation in the right hemisphere (Kessels et al., 2000).

In its definition, the Phonological Maintenance Task used by Shivde & Thompson-Schill (2004) consists of a delayed judgment task in which participants have to look at a word and maintain it during a delay phase. After waiting, they are shown another non-existing monosyllabic word that has to be judged as with a similar or different rhyme as one of the syllables inside the remembered word. The longer the number of syllables to recognize, the higher the phonological working memory load will be. Phonological WM tasks as this one has shown correlated activations in Broca's Area or inferior frontal gyrus as well as in the left superior parietal lobe (Shivde & Thompson-Schill, 2004; Fiez, 1997; Paulesu et al., 1993).

Following the previous empirical findings, it is hypothesized the experimental groups to show a decrease ratio in the seen responses in comparison to the control group as the amount of information entering the conscious network should be decreased due to the neural overlap and overload of WM. The possible differences between the experimental conditions will be explored.

Methodology

Participants

Thirty-two psychology students from the University of Plymouth (United Kingdom) participated in the experiment separated into three groups using randomization as inclusion criteria. Although there were considerably less men (n = 6) than women (n = 24), the groups did not differ in terms of gender ($\chi^2(2,30) = 5$, $p = .082$), age ($\chi^2(6,30) = 6.857$, $p = .334$) or handedness ($\chi^2(2,30) = 3.36$, $p = .186$). Two participants were excluded because of a technical error and because of an unreliable performance in the working memory task (>75% of error rate). One of the participants presented dyslexia but was not excluded from the analyses as the overall performance was not impaired. None of them had visual deficits. The experiment was set following ethical clearance and participants had to sign a participant consent sheet before starting the experiment and after being given a brief.

Materials

A computerized version of the Corsi Block-Tapping Test and Phonological Maintenance Task were programmed and used in a computer running E-Prime 2.0 software in the laboratory of psychology in the faculty of Human and Health Sciences, as well as a replicated visual categorization and awareness cue task to assess the subjective visibility ratings while manipulating the spatial and phonological working memory loads.

All statistical analyses were performed using Microsoft Excel and SPSS and R statistical softwares.

Procedure

The participants were seated facing the pc monitor. They were explained the instructions of the task in which they had been previously and randomly assigned (brief). Basically, it consisted of a masking task inside one working memory task in

two groups differing in the nature of the latter. A third group performed only the masking task as the control group. Once they expressed their agreement by signing the consent form, they started the experiment immediately. At the end of their participation, they were given a debrief explaining the main purposes of the experiment.

Masking Task: in order to continue exploring deeply the main effect observed in the task developed by De Loof et al. (2013), this one is set following the same principles (please, see the Figure 1). In the most essential respects, this task consisted of a priming task using Arabic digits (1, 4, 6 and 9). Eventually, the prime was presented as a single digit under the fixation cross, whereas the target number was a portion of a mask constituted by three letters and one number following a diamond shape. During the entire trial, a fixation cross was fixed in the centre of the screen.

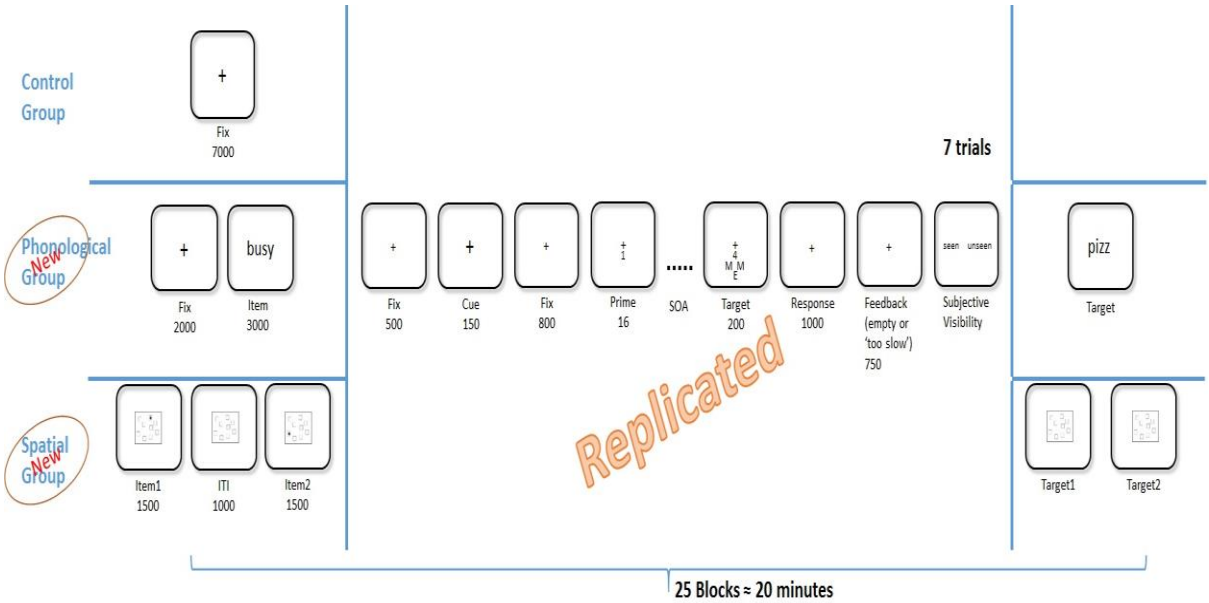

Figure 1: The design of the experiment. SOA = stimulus onset asynchrony; ITI = interstimulus interval.

The start of the trial was announced by a fugacious larger fixation cross for 150 ms just after a period of 500 ms presenting the normal size cross. This cue was followed by a normal size fixation cross during 800 ms and immediately after the target appeared for 200 ms. Between the vanishment of the cue and the appearance of the target, a prime number could be shown under the fixation cross for 16 ms, and the time between the onset of the prime and the target (stimulus onset asynchrony or SOA) varied randomly between 16, 33, 50, 66 and 100 ms. Like in the original, in some trials the prime number was absent (catch trials). After the presentation of the mask, the fixation cross remained in the screen and 1000 ms were given to respond left if the target was smaller than five, and right if it was larger. Afterwards, a feedback screen for 750 ms encouraged participants to respond quicker if no answer was registered. Finally, subjective visibility was measured by asking participants whether they had seen the prime number or not by pressing left (seen) or right (unseen). After the response was registered a new trial started. Importantly, one control group performed this task alone, being presented a blank screen for 7

seconds after which a series of 7 masking trials started. When finished, a new blank screen appeared for 7 seconds and a new 7 trials block started. They repeated 25 series of trials or blocks and performed 10 trials as practice at the beginning. The experiment consisted of 175 trials in total lasting for approximately 18 minutes to complete. Phonological Maintenance Task: as De Loof et al. (2013) found a significant congruency effect in their low-load condition which included 2 letters to memorize, it was decided to use words containing two syllables from the Shivde & Thompson-Schill (2004) "List of stimuli" to set the phonological working memory task (see the Table 1). Containing 28 target items or words, this phonological task was designed following the same rules as the original task. After a fixation cross appeared in the screen for 2 seconds, an item-word was presented to the participant during 3 seconds. Following the experiment of De Loof et al. (2013), in between the presentation of the item and the target, the participant responded to 7 masking task trials in every block. Once completed, a target single-syllable nonsense word sharing a vowel sound with one of the two of the memorized word was presented and it was required to state whether the sound of the target matched any of the syllables of the item presented before the masking task by pressing a button, which terminated the working memory trial and initiated the next. It was decided not to include the final 12 seconds intertrial intervals, changing them to a response-terminate option which appeared to be a conservative change taking into account the technical limitations of this undergraduate study. The whole experiment took 25 working memory trials lasting for approximately 22 minutes, including 2 phonological trials, 4 masking task trials and 5 working memory blocks consecutively as practice at the beginning.

Table 1: List of Stimuli in Phonological Working Memory Task.

Maintained Item		**Phonological Target**	
afraid	honour	kade	dahn
busy	idea	pizz	gee
courage	mankind	der	jine
disgrace	mistake	fiss	riss
display	nothing	fape	pring
embrace	outcome	tase	nowt
endure	permit	byur	rit
enjoy	pity	leb	zee
equal	purchase	deet	wess
exit	quarrel	vip	taw
fever	rascal	teeb	jad
freedom	reject	klebe	bek
happen	succeed	dat	wuck
honest	wander	dest	ver

Note. Adapted from "Dissociating semantic and phonological maintenance using fMRI," by G. Shivde and S. L. Thompson-Schill, 2004, *Cognitive, Affective, & Behavioural Neuroscience*, 4, p. 15.

Corsi Block-Tapping Test: in one of the groups, participants were required to answer a Corsi visual task following the indications extracted from Claessen et al. (2015). The parameters were made simple and as similar as possible to the task used in the

other experimental group. The screen presented a layout with 9 squares in the identical disposition to the original organization developed by Corsi. When the trial started, one square was randomly selected by presenting an asterisk in its centre for 1500 ms. After an interstimulus interval of 1000 ms, a second square was also randomly activated for other 1500 ms. The participants were instructed to remember the pattern of activation while they were performing 7 masking task trials. At the end of these trials, participants switched again to the screen containing the squares and had to select the correct pattern of activation using an optical mouse by left-clicking in the squares. Taking into account that the experiment designed by De Loof et al. (2013) using the Sternberg Task found a significant effect and knowing that this task is not testing the manipulation of the information being remembered but its simple maintenance in the short-term memory system (Diamond, 2013), it was decided to use the forwards version in the Corsi test to make the experiment simple and directly comparable. The experiment consisted of 25 spatial trials and 175 masking task trials lasting for 20 minutes, including 2 spatial trials, 4 masking task trials and 5 working memory blocks consecutively as practice at the beginning.

Results

In order to explore how different working memory components might affect the threshold to consciousness, it is needed to analyse the common measure between the groups (the dependent variable), which is the subjective visibility response (seen or unseen). (See the Table 2 for a visual summary of the results.)

The normality tests performed using the Shapiro-Wilk procedure showed significant differences with the normal trend in the control group ($W = 0.8$, $p = .015$), the phonological load condition ($W = 0.73$, $p = .002$) and the spatial load condition ($W = 0.819$, $p = .025$). At this point, analysing the variance between the groups in a non-parametric way (Kruskal-Wallis test), with working memory load as factor (no load in the control group, phonological load and spatial load), did not reveal enough differences in order to reject the null hypothesis, $H(2, 30) = 3.496$, $p = .174$, indicating that the samples could originate from the same distribution.

As the sample sizes are very little and thus more susceptible of big changes due to little measurement errors that can lead to substantial distortions in both parametric and non-parametric tests (Zimmerman, 1995), it was decided to exclude the relevant outliers in an attempt to boost the robustness of the statistical analyses in the subjective visibility variable.

In both experimental conditions, one participant in each group was excluded from the analyses as both were performing two standard deviations under the mean of their groups. In the control group, as both the mean and the median were close to the perfect performance (100% of seen responses) and the standard deviation was very high due to the sample size, two participants' responses were excluded setting the limitation of outliers to 1 standard deviation from the mean.

The normality tests revealed the phonological load group and the spatial load group to follow the normal distribution, $W = 0.947$, $p = .66$ and $W = 0.939$, $p = .572$ respectively. Although the control group did not change its characteristics in comparison to the normal trend ($W = 0.777$, $p = .016$), the Leven's test now showed equality in the error variances, $F(2, 23) = 2.017$, $p = .156$, and the Kruskal-Wallis test showed differences between the groups, $H(2, 26) = 6.112$, $p = .047$, indicating that

the percentage of seen responses varied because of the working memory load factor. (See Figure 2 for a graphic view.)

Table 2: Analyses on the Subjective Visibility Ratings.

	Control (1)	Phonological Load (2)	VisuoSpatial Load (3)	
	Without participants 3 & 17 (eliminated)			
N	10	10	10	
Mean (SD)	.737 (.325)	.812 (.222)	.674 (.231)	
W (*p*)	.800 (.015)	.730 (.002)	.819 (.025)	
Levene F (*p*)				4.766 (.017)
(ranked data)				
H (*p*)				3.496 (.174)
	Without participants 14, 15, 18 & 19 (excluded as outliers)			
N	8	9	9	
Mean (SD)	.871 (.181)	.877 (.089)	.737 (.124)	
W (*p*)	.777 (.016)	.947 (.660)	.939 (.572)	
Levene F (*p*)				2.017 (.156)
(ranked data)				
H (*p*)				6.112 (.047)
	Further analyses with the ranked transformation (the smallest value as 1)			
N	8	9	9	
Mean (SD)	16.625 (9.257)	15.778 (5.832)	8.444 (5.300)	
H (*p*) [h_p^2]				3.721 (.040) [.244]
Contrast (*p*)				
Linear				5.785 (.023)
Quadratic				2.648 (.267)
Dunnett Post-Hoc *p*				
1 vs 2				*p* = .954
1 vs 3				*p* = .042
t test (*p*) 2 vs 3				2.741 (.014)

The analyses of variance with the ranked transformation of the seen responses also showed a significant difference across the conditions ($F(2, 26) = 3.721$, $p = .04$, hp2 = .244) and a linear decrease in the measure of the contrast ($p = .023$). Planned comparisons with Dunnett Post-Hoc test, showed a statistically significant difference between the control group and the spatial load condition ($p = .042$), but not with the phonological load condition ($p = .954$). A two-tailed t test between the experimental

groups also showed enough difference leading to conclude that it is not possible to reject the alternative hypothesis ($t(16) = 2.741$, $p < .014$).

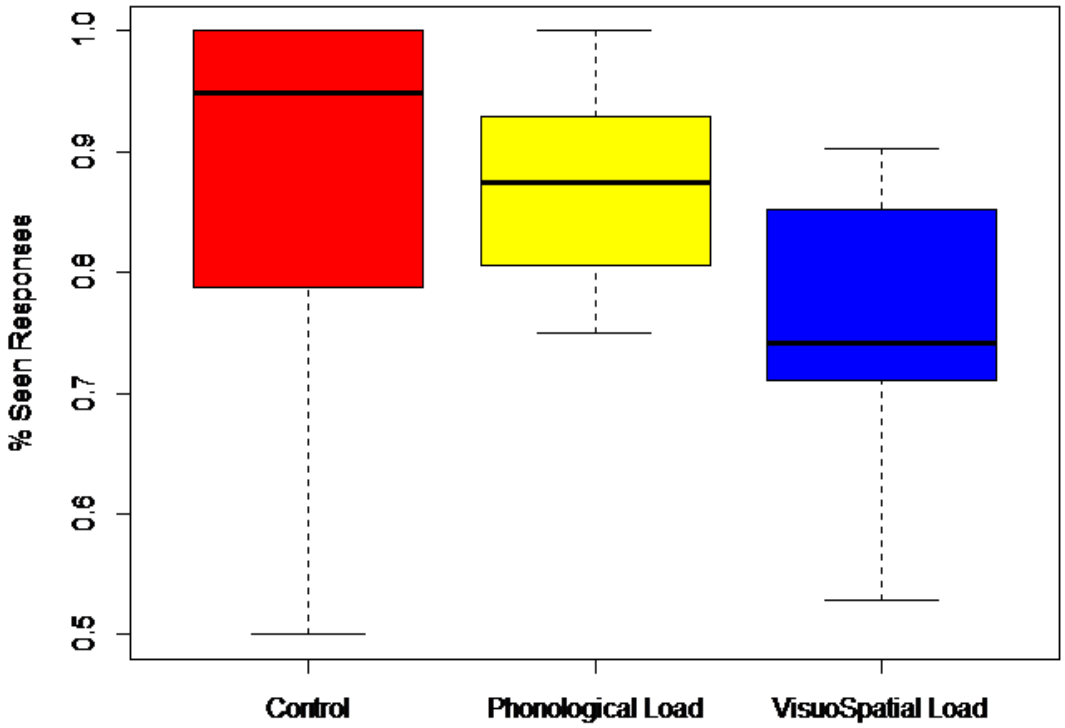

Figure 2: Boxplots of the distributions without outliers.

Further analyses

Although the priority analyses are already explained, some other results must be taken into account in order to draw a complete and critical picture about this study.

As other previous investigations using the same methodology (De Loof et al., 2013; Charles et al., 2013), the data in the present study is showing a sigmoidal function in the percentage of seen responses which can be attributed to the main effect of SOA, $F(2.271, 56.773) = 12.819$, $p < .001$, hp2 = .358. (See Figure 3 for a graphic observation.)

Furthermore, a 2 (congruency: repeated measures) x 5 (SOA: repeated measures) x 3 (groups: independent factor) mixed ANOVA on the means of correct reaction times (RTs) design was analysed in order to observe the possible interactions between conditions.

As previous studies (Vorberg et al., 2003), the presence of a main effect of SOA ($F(2.603, 5.205) = 3.06$, $p = .04$, hp2 = .102), congruency ($F(1, 27) = 30.327$, $p < .001$, hp2 = .529), and their interaction ($F(4, 108) = 2.662$, $p = .036$, hp2 = .09) indicate that, again, these two processes are strongly linked, although the orientation of the effect across the different SOA conditions is the opposite (RTs decreased with increasing SOA). The grouping factor did not show a main effect (p = .216). No

tertiary effect or three-way interaction was observed, $F(8, 50) = 1.031$, $p = .426$, hp2 = .142.

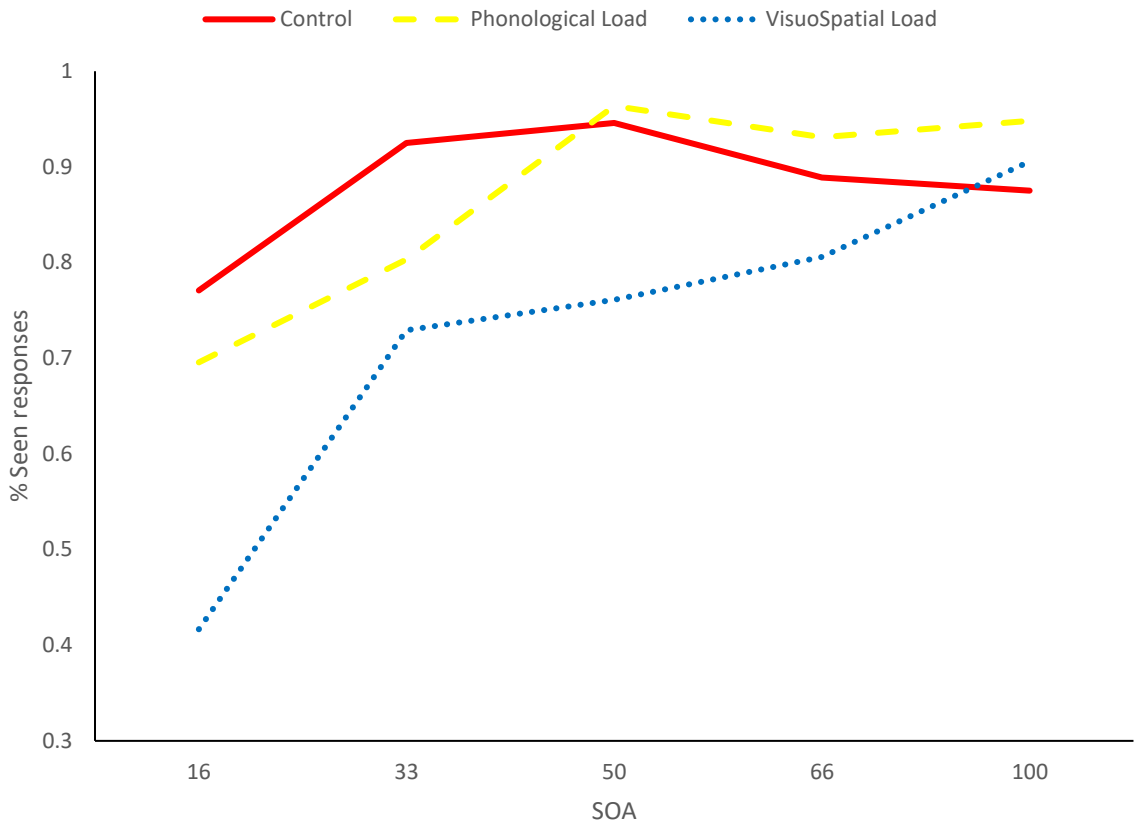

Figure 3: A sigmoidal relation between the subjective visibility rating and the SOA shows accordance with previous studies.

Repeating the same analyses on the error rates, a principal effect of congruency ($F(1, 27) = 19.067$, $p < .001$, hp2 = .414) and a secondary effect with SOA ($F(4, 108) = 4.426$, $p = .002$, hp2 = .141) were revealed. However, no main effect of SOA was observed, $F(4, 108) = 1.764$, $p = .141$, hp2 = .061. A tertiary effect or three-way interaction was found, $F(8, 48) = 2.156$, $p = .043$, Wilk's $\Lambda = .541$, hp2 = .264. A main independent measures effect of the working memory conditions was also found, $F(2, 27) = 4.076$, $p = .028$, hp2 = .232, showing that the experimental groups were committing considerably less errors than the control group.

Discussion

The aim of this research was to investigate what differences could there be between specific WM modules in the recently tested overlap with subjective visibility. It was expected both experimental conditions to differ in the overall ratio of seen responses in comparison to the control group. The results partially supported this hypothesis showing that the performance in the spatial load condition was less accurate than in the control, although there was no effect caused by the phonological load condition. This might suggest importantly that some specific aspects or pathways of WM are

more strongly linked to the conscious network than others and, indeed, that there might be a module-dependence.

Some ideas must be introduced with respect to the data obtained. First, the absence of effect produced by the phonological load condition on the subjective visibility ratings could imply that those brain areas processing the material in that specific task could not be an active part of the conscious network. If we interpret the results not only as an overlapping between both functions but as a recruitment of brain areas, then the conscious network could simply have more resources as the phonological WM would not be operating at its full capacity (as this recognition task does not involve necessarily the production of speech).

Second, the observed effect by the spatial load condition could reveal some insight of a specific module-dependence of consciousness. It could be argued that consciousness needs the visuo-spatial sketchpad free in order to fully operate. The effect found in the spatial load condition goes in line with previous findings. As De Loof et al., 2013 used the Sternberg task to increase the WM load in a recognition basis, they could have also targeted not the verbal WM module, but the visuo-spatial sketchpad (Corbin & Marquer, 2013).

Finally, the differences also observed between the experimental groups could imply several things. As the phonological task was targeting mainly the left parietal lobe and the visuo-spatial task was targeting mainly the right hemisphere, it could be drawn from these results that the right parietal lobe could be more crucial in the conscious span than it is the left parietal lobe (Kessels et al., 2000).

However, it could also be argued that the effect observed in comparison to the phonological load is not revealing a quality-dependence (what system is used), but instead a quantity-dependence (how many systems are used) as the Corsi task could not only be targeting the visuo-spatial sketchpad, but also the episodic buffer due to the memorization of the sequences of activation in the squares (Ferreira et al., 1998). This can also be explained as the Corsi task leads activations not only in the right parietal lobe, but also in the dorsolateral prefrontal cortex (D'Esposito & Postle, 1999). A second explanation could be drawn as the Corsi task implies a delay recall test and that the participants need to actively recall the items memorized. In comparison to the phonological maintenance task in which it is needed to recognize a sound, the proactive property of the Corsi task could be causing the observed differential. Nonetheless, between the prefrontal cortex and the parietal lobe, clinical evidence may indicate the latter as being more relevant when it comes to producing awareness. Patients suffering from hemispatialanogsias, or deficits in awareness of one side of their bodies or the surrounding environments, tend to show insults in their right parietal lobes (Vallar and Perani, 1986). By contrast, lesions of the prefrontal cortex are commonly related to executive impairments rather to alterations on awareness itself (Burgess, 2000; Silk et al., 2006; Stuss and Alexander, 2007). Finally, it is impossible to simply state that the right parietal lobe, or indeed the right hemisphere, is more important to produce awareness. Gazzaniga (2000) suggests that although each hemisphere works independently of the other, the integrated sensation even observed in split brains gives us some insight about awareness, as it could be intimately and ultimately linked to a process of giving a meaning to the other processes carried out in the brain. This idea has been worked for a long time, with Roser & Gazzaniga (2004)

suggesting the unitary narrative to be produced thanks to a distributed processing or the integration of separated modules. If both modules are imagined as two different RAM memories, as the majority of PCs nowadays use a dedicated graphics-RAM separated from a sound card-RAM, it could actually be happening that the memory related to language is more sophisticated and thus requires of more use (load) in order to significantly affect the general RAM (which would be the conscious network at this point).

A continuation study of De Loof et al. (2015) has recently examined how the visuospatial and the executive aspects of working memory may differ in their impact on visual awareness. They observe that although both WM aspects affect the speed in processing a masking task, there is no effect of the visuospatial load. These results are concluded as visuospatial having a more persistent and stable impact on visual awareness whereas the executive WM presents a more gradual impact. There are two reasons given to understand this apparent lack of interference of visuospatial load on visual awareness. One reason is focusing on the methodology, as their task could have been targeting mainly the object characteristics rather than its spatial locations. The other arises thanks to Rissman et al. (2008) whose evidence suggest that low loadings on memory are using mainly the resources in the PPN, while higher loadings could be using also a special type of cache memory system held mainly in the hippocampal regions.

Bearing all this in mind, it can be interpreted the conscious network to be operating as with the same properties as the higher order executive functions: it requires some degree of activity and is constructed upon WM, inhibition and shifting.

The research explained in this paper shows several limitations that prevent from extrapolating conclusions to the rest of the human population. The sample size as well as the sample characteristics (gender, age…) make it impossible to state whether the observed effects can be understood as a human condition. Only incrementing the size and variability of the sample would it be possible to begin making strong general predictions. The tasks used also need to be interpreted with respect to the theories behind. So, in order to state that there is no mental overlap between the phonological loop and the conscious network, it is first needed to investigate other tasks addressing other aspects of that phonological WM subsystem. Thus, the replication of the priming task taken from De Loof et al. (2013) could have tiny but significant differences to the original, as the time between the onset of the cue and the onset of the target is not fixed to 800ms. In this case, we can only try to be conservative and sceptical towards the results. Also, the groups compared might differ in ways they should not. For instance, participants in the experimental groups tend to show greater RTs and less errors in comparison to the control group. That could be argued as not affecting the conclusions (as they were performing better, the WM tasks were not impairing the overall performance), but that could also be argued as to be affecting the visibility ratios in a way that cannot be easily understood. Opposing the theory, the SOA produced a contradictory (facilitation) effect on RTs and had no effect on the error rates, possibly exposing a lack of concentration among the participants. As executive functions cannot work without attention that could explain the absence of effect observed in the phonological load condition.

Hence, in further research it should be strongly considered to continue doing replications. Adding and changing the WM tasks in an attempt to find different ways of interaction between this executive function and consciousness. This could help us mapping the functional pathways of the conscious contents.

Implementing tasks targeting the inhibitory control could lead to indirect interactions between consciousness and WM, as inhibition has been conceptualized as a shield protecting WM while the latter is enabling the transfer of the information to the long-term memory system (Diamond, 2013). Moreover, future research projects should investigate deeply the possible interactions between different executive functions. Consciousness might imply a process of 'Executive Fusion' in which some EFs are fusing and, thus, using the same neural resources, in order to create the holistic active representations of the conscious world we all perceive.

Finally, transcortical magnetic stimulation (TMS) can be useful in the future as it could allow the experimenters better handling when selecting specific brain areas associated to specific WM modules. Pascual-Leone et al. (1994), for instance, observed important impairments in double stimulus tasks when administered to the parietal lobe.

Conclusion

Based upon the findings it could be said that not all the WM modules seem to overload in the same way the conscious network. Whereas the spatial and possibly the temporal aspects of WM seem to share the same resources as the conscious network (presumably in the right parietal lobe and the prefrontal cortex), the phonological rehearsal WM processing could be out of the conscious network. This could reveal that language related information processed in WM might not be overlapping to the same extent as spatial information when it comes to producing conscious perception of visual stimuli.

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