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The effect of physiological arousal on item and associative memory consolidation

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Declaration

This research has complied with ethical guidelines throughout. The study description on sign-up outlined the two-parts of the experiment's itinerary, and fully expressed the fact that every participant would endure either a cold or warm water treatment. The cold-pressor stress procedure often causes discomfort, but this was overruled by the participant's control over immersion. Participants were informed by the experimenter of the associated discomfort, and were notified that they were free to remove their hand before the 3-minute ceiling time at any point. There was a first aid medic on standby who was aware of the study's activity. All participants provided written informed consent upon arrival and were informed that they could withdraw from the session at any point without penalty. Each participant was fully debriefed on the full intentions at the end of the second part of the study. Participants were given the opportunity to ask questions or raise any concerns throughout the course of the study. The debrief also included the researcher's email address, in case participants wanted to withdraw their data, or query anything at a later date.

This was a shared data collection project, whereby Sarah-Jane Stowe and myself combined our participant pool to conduct the experiments.
The content of this dissertation is entirely the work of the author.

Introduction

Important events need to be remembered to ensure survival, and given the limitations of cognitive capacity, information that is least relevant must be forgotten. The ways motivational and affective reactions to environmental stimuli modulate memory appear to serve an evolutionary function to separate critical from trivial moments. Arousal, an intensity component of motivation, therefore has a crucial role in modulating and consolidating the process involved in retrieving information. Inducing arousal to measure its subsequent effect on memory has become a well-established procedure, and psychologists continue to investigate whether an elevated state facilitates or inhibits learning and retention.

The Yerkes-Dodson law (Yerkes & Dodson, 1908) posits an empirical relationship between arousal and performance. It dictates that cognitive efficiency increases with arousal to an optimal level, and then beyond this point further increases cause deterioration in performance. Substantial evidence supports this inverted U-shaped curve (Broadhurst, 1959; Hebb, 1955; Watters, Martin, & Schreter, 1997), which further asserts the influence of task difficulty on peak arousal levels. Intellectually demanding and difficult tasks tend to require lower levels of arousal before reaching optimal performance, whereas perseverance tasks involving stamina can be completed well after intensified arousal. However, this negative quadratic relationship has been criticised for being overly simplistic in explaining a complex phenomenon, and for assuming arousal to be an indifferent and one-dimensional concept (Deffenbacher, 1994). Deffenbacher instead proposes an integrative theory where gradual improvements in memory result from cognitive anxiety and incessant increases in physiological excitation. Memory performance will then, at an undefined point, radically plummet.

Easterbrook's cue utilisation theory (1959) suggests that emotionality and arousal leads to the narrowing of attention, by producing a restriction in the number of cues available. Thereby confining memory for the stimuli's periphery, and enhancing memory for its gist. In moderate states of arousal this narrowing of attention can be beneficial when relevant information is attended to and irrelevant cues disregarded. It is when arousal is intensified that the number of accessible cues to consciousness declines, and the narrowing of attentional focus reduces to a degree where task performance is destructively weakened. This is apparent in studies where the level of arousal achieved was potentially too high to facilitate memory functioning (Christianson, Nilsson, Mjörndal, Perris, & Tjelldèn, 1984), and explains why a high arousal group of skydive participants recalled significantly less irrelevant material than controls (Cavenett & Nixon, 2005). Such an effect would explain why there is known to be retrieval failures under conditions of examination stress, and that when relaxation instructions are given immediately prior to recall, performance is significantly improved (Pascal, 1949). It is also not surprising then, that studies that incorporate contextual cues into a learning and test procedure, often find an enhancement at retrieval, an effect that is especially strengthened among participants in the stress condition (Herz, 1997). Specifically, stronger cues have proven to be advantageous for initial memory, whilst weak cues improve delayed performance (Carpenter, 2009).

A series of studies has indicated that arousal has distinct effects on the memory for central (details connected with the source of arousal) and peripheral (details irrelevant to the source of arousal) information. In a comprehensive appraisal, Christianson (1992) concluded that central details are retained in conditions of high arousal, whereas emotion undermines memory for peripheral details. Although numerous studies inspired this assumption (Burke, Heuer, & Reisberg, 1992; Christianson & Loftus, 1987), other findings have reported equal success in recall for both central and peripheral details (Heuer & Reisberg, 1990).

Kleinsmith and Kaplan (1963, 1964) initially reported a cross over interaction of arousal and retention delay on memory, which has since gained further support (Park, 2005; Sharot & Phelps, 2004). That is, that under low arousal memory performance increases immediately and then decreases over time, whereas after high arousal memory increases with delay accordingly. A theoretical account of this effect can be found within the Theory of Action Decrement (Walker & Tarte, 1963), which proposes that elevated arousal generates amplified neural activity, in turn leading to stronger consolidation and an improved durable memory recital. An immediate poor performance is due to the increased temporary inhibition of memory trace during reverberation. Furthermore, low levels of neural activity instigate from minimal arousal, and thus a poorer long-term memory performance occurs because of an ineffective consolidation process and lack of rapid reverberation. This tendency is apparent in other research that has presented time-dependent effects of arousal on memory (Labar & Phelps, 1998). However, in contrast, Buchanan, Etzel, Adolphs, and Tranel (2006) found no difference between immediate and delayed free recall. Similarly, research has found enhanced recall for neutral items among stressed participants in the immediate and 24 hour delayed recall tests (Schwabe, Bohringer, Chatter & Schachinger, 2008). Despite heterogeneous retention patterns, the generality lies coherent with the notion that arousal fortifies recollective experience and interacts with memory retention to hinder the forgetting process (Sharot & Yonelinas, 2008).

This slow consolidation of memories has been suggested to operate as an adaptive function, enabling neurohormonal processes that are activated by an arousing activity to modulate memory strength (McGaugh, 2000). In particular, functional neuroimaging studies have identified a correlation between long-term memory of arousing items and activation in the amygdala (Hamann, Ely, Grafton, & Kilts, 1999).

The amygdala, which is a mediator of stress hormones, is considered one of the most extensively anatomically connected cortical regions of the brain (Amaral, 2003), thus is unlikely to act alone in the modulation and consolidation of memory. Seminal explorations exhibit arousal to activate beta-adrenergic receptors within the amygdala (Cahill, Prins, Weber, & McGaugh, 1994). These receptors are fundamental in allowing the significance of an event to enhance hippocampal-dependent memory consolidation. The valuable effects of arousal on long-term memory are eradicated when the secretion of β-adrenergic receptor antagonists inhibit the β-adrenergic receptors. Such is seen in patients with selective lesions of the amygdala, who have failed to demonstrate stronger memories following arousal (LaBar & Phelps, 1998).

Research suggests that the andrenocortical hormone cortisol, is released in humans during stress, and is a primary manipulator in the effect of stress on memory functions (deKloet, Oitzi, & Joels, 1999). This is apparent in studies where cortisol has shown to increase memory for details of a neutral story (Rimmele, Domes, Mathiak, & Hautzinger, 2003). However, studies have also found improved memory for neutral items independently of cortisol (Schwabe et al., 2008), and even impaired retrieval after cortisol administration (Kuhlmann, Kirschbaum, & Wolf, 2005).

The exact moment that consolidation occurs is unclear. Studies have suggested that when delayed testing is completed within the same experimental session as encoding, the consolidation process has not yet had chance to materialise (Knight & Mather, 2009). Yet others show behavioural affects as soon as 1 hour after encoding (LaBar & Phelps, 1998). Typically, studies have concentrated on testing for retention efficacy after a 24-hour delay (e.g. Cahill et al., 2003; Smeets, Wolf, Giesbrecht, Sijstermans, Telgen, & Joëls, 2009), but some findings have demonstrated superior memory recall even a week after the initial learning phase (Andreano & Cahill, 2006). However, the full potential capacity of the delay has not, to date, been empirically tested. If arousal were to influence memory via the strengthening of hippocampal consolidation, one would only expect to observe better memory after a delay, and not immediately after encoding.

We know from real-life experiences that stressful events are well remembered. As the Poststimulus Elaboration Hypothesis (PSEH; Christianson, 1992) suggests, emotionally arousing situations lead individuals to invest more effort in elaboration of the experience through methods of rehearsal, and thus are processed at a deeper level. An extreme example of this effect, consistent with PSEH, is flashbulb memories (Brown & Kulik, 1977). A flashbulb memory is a personal and vivid account, created in great detail of the circumstances surrounding an emotionally arousing, significant event. Individuals have been able to report specific details such as what they were wearing when they heard about the September 11th terrorist attack (Pezdek, 2003), and more recently the July 7th Bombings in London (Whalley, Farmer, & Brewin, 2007). However, their existence is debatable, as research has demonstrated a decline in consistent details for both everyday and flashbulb memories (Talarico & Rubin, 2005), implying that arousing and everyday events may actually be processed similarly. Moreover, a study into a nuclear accident in Japan that had all the variables needed to produce flashbulb memories, only found evidence for them in a small proportion of the sample (Otani, Kusumi, Kato, Matsuda, Karn, Widner, & Ohta, 2005). This suggests that the consolidation of arousing memories in this way may be exclusive to individualistic cultures, and therefore not an automatic or physiological process.

The beneficial effects of post-learning stress and memory consolidation have been found in studies that only employ neutral material (Andreano & Cahill, 2006; Beckner, Tucker, Delville, & Mohr, 2006). Other studies have shown that negative emotional events are retained poorly compared with neutral events (e.g. Clifford & Hollin, 1981; Clifford & Scott, 1978; Peters 1988). For example, in a 24 hour delayed recall test, the stress group showed an enhanced memory for neutral items only, and not for emotionally arousing positive or negative items (Preuß & Wolf, 2009). Kuehn (1974) found a similar effect in his data analysis of police reports about traumatic events, whereby victims of robberies provided fuller descriptions than victims of rape or assault. Additionally, injured victims always provided less information than non-injured victims. Although findings infer more information is retained in cases of less serious crimes, this may simply reflect the different levels of sensitivity associated with each type of crime. Victims of crimes such as rape and assault may feel vulnerable or embarrassed, and thus disclosing intimate details about the offence could become a gruelling process. Specifically, Knight and Mather (2009) concluded from their research that emotion-induced enhancement is most likely to occur for neutral items that; precede any emotionally arousing stimuli, have a high attentional value at encoding, and are tested after a delay period that is independent of the initial encoding experimental session. They go on to highlight that impairment will occur near the onset of arousal if overshadowed by highly activated competing items. Thus this should only be problem when arousal is induced at encoding. This suggests that arousal selectively enhances memory for neutral items in some instances and not others, imitated in the fact that augmentation for neutral items is not inclusive. Research continues to identify an enhancement for emotional and not neutral material after a 24-hour retention period (Buchanan & Lovallo, 2001; Cahill et al., 2003; Sharot & Yonelinas, 2008). Whereas when a study involving pharmacological manipulations investigated the effect of cortisol on memory, performance did not differ substantially for emotional and neutral material (Abercrombie, Kalin, Thurow, Rosenkranz, & Davidson, 2003).

The empirical picture becomes more complex when stressor and learning task are not directly associated and the arousal procedure is detached from the learning episode. This is the case when the stressor (e.g. public speaking or cold water immersion) is typically unrelated to the memory tests conducted. Some research has implied that when to-be-learned information is conceptually related to the source of arousal, learning under stressful circumstances results in improved memorability afterwards (Smeets et al., 2009). Additionally, Varner and Ellis (1998) highlight that the arousal source must be semantically associated with memoranda. Other research, however, has found memory consolidation effects without stressor-material relatedness (Cahill et al., 2003). Thus when reviewing such studies, pre-learning and post-learning stress exposures need to be differentiated. Stress effects on memory parameters depend critically on the timing of the stressor relative to the memory phases of encoding, consolidation, and retrieval. The direction seems to particularly depend on the direction and interval between contact with the stressor and learning episode. One study that examined the timing of stress exposure versus learning phase found that when stress is dispensed 2 hours prior to, or coincides with learning, then both learning and delayed recall is selectively enhanced (Smeets, et al.). On the other hand, when stress is applied 1 hour after learning, recall is not affected; however, 1 hour is considerably longer than in typical consolidation stress studies (e.g. Cahill et al.). Conversely, pre-learning stress has found to have a detrimental consequence on subsequent memory examination compared to post-learning stress (deQuariain, Roozendaal, & McGaugh, 1998; Elzinger, Bakker, & Bremner, 2005; Kuhlman, Piel, & Wolf, 2005). This is supported by previous studies that have found enhancement in delayed retrieval when arousal was induced soon after learning (Neilson & Bryant, 2005; Roozendaal, 2000). A study focusing on this phenomenon in particular, found that arousal induced up to 30 minutes after learning, but not after 45 minutes, significantly enhanced retrieval one-week later (Nielson & Powless, 2007). What’s more, manipulating the duration of retention interval does not appear to influence associative information, but may affect the familiarity of the individual items (Hockley 1991, 1992), insinuating that performance may fluctuate depending on the type of memory tested.

Memory theorists believe that recognition memory judgements are underpinned by two qualitatively different sources of information. Item information is the memory for individual items, and associative information is the shared context for multiple items. Typically, in tests of associative recognition, participants must remember which items were paired together in a previous study list. Compelling evidence has suggested that associative-recognition decisions are based on both associative retrieval and item familiarity (Kelley & Wixted, 2001). Predominately, research to date has only explored arousal’s influence on memory using item information, incorporating words (LaBar & Phelps, 1998), pictures (Li Juan Liu, Graham, & Zorawski, 2007), film clips (Cahill & Mcgaugh, 1995), and stories (Andreano & Cahill, 2006). The documented enrichment of item memory that occurs after arousal provokes the assumption that the same effect may manifest for associative memory. However, of the limited research conducted thus far that has tested associative memory, the results are mostly inconsistent. Whilst some researchers have failed to find this facilitatory effect (Sharot & Yonelinas, 2008), others report that arousal enhances an individual’s ability to discriminate the colour of the word presented (Kensinger & Corkin, 2003) from imagined items (Kensinger & Schacter, 2005).

It has been well documented that cortisol levels are increased by the cold-pressor stress (CPS; Cahill et al., 2003), and thus this task has been used considerably to modulate memory consolidation. The present study separated stimuli from the procedure used to induce arousal in this way. Cold water was documented as an experimental pain stimulus over 60 years ago (Wolf & Hardy, 1941). Since then, the technique has reliably shown to produce a robust stress response (Lovallo, 1975), and has therefore been effective in modulating memory (Cahill et al.). More often than not, studies using the CPS have only found this effect with emotional slides (Cahill et al.); however, similar effects have also been reported for neutral items (Andreano & Cahill, 2006).

The CPS was administered to all participants immediately following exposure to a memory list containing neutral words and images. It is noteworthy to mention that because the CPS was administered after learning, any effect on memory cannot be accredited to actions on attentional, emotional, perceptual, or encoding processes during slide presentation, and must only be the result of some action on memory storage process. Everyday stimuli were used to measure the CPS as an arousal inducer independent of emotional items. Incorporating customary material additionally allows for presumptions about memory for daily information. After water immersion, an index of arousal was obtained through a questionnaire designed to detect features of participants' experience. According to previous research, the awareness or interpretation of one's arousal state should not contribute to memory modulation efficacy (Nielson & Meltzer, 2009). Immediately, and 24 hours after exposure, recognition for the words seen in the memory list were tested using a context reinstatement procedure. To do this a word was presented onscreen and participants had to determine whether the word was old or new. In no context trials, only the test word was presented. An image was shown before the test word in context trials. The contribution of arousal on both item and associative memory was therefore assessed immediately and after a 24-hour delay.

Understanding the influence of arousal on memory performance at two retention intervals could have utility in treating disorders such as depression and post-traumatic stress disorder, in which emotion may influence all phases of memory. Furthermore, comprehending this effect with neutral everyday items allows applications to be made to direct learning environments, potentially offering guidance to methods for increasing long-lasting memory for learnt information. The primary goal of the present research was to examine whether physiological arousal effects long-term consolidation and subsequent recognition accuracy for peripheral associative information. It was hypothesized that arousal enhances the modulation of memory, and this will boost recognition scores after a 24-hour delay. Furthermore, it was predicted that providing a contextual cue facilitates recollection as individuals can draw on both item and associative information.

Method

Participants

Twenty-six male (n = 6) and female (n = 20) psychology undergraduates from the University of Plymouth between 18 and 24 years of age participated in this study. Participants were tested individually, and received course credit for their participation. An ethics committee approved the study, and all participants provided written informed consent.

Stimuli

The 91 words and images used in this study were from our own set of material, and were chosen based on their everyday and neutral quality. Slides were presented in four blocks, to offer participants a breather, on a standard computer screen, and each slide was displayed for several seconds, with no intervening blank screen in-between.

Procedure

To reduce the impact of diurnal variation in cortisol levels, all testing was performed between 13.00 and 15.00 hours, and the experiment was run across the CPS/control groups. Each participant was tested on 2 consecutive days, with a 24-hour interval. On the first day, participants were first shown the memory list containing the 91 slides of everyday words and images. Immediately after slide presentation the participant immersed his or her arm up to the elbow in either warm (37° – 40°C) or ice-cold (0° - -3°C) water. Although there appear to be no important differences related to the use of the dominant versus the non-dominant hand (Nielson-Joseph, Tsao, Joseph, Zelter, 2001), participants were instructed to place their dominant hand in the water to ensure a standardised method. The procedure of the CPS generally causes discomfort, but this is countermanded by both the participants' control over immersion, and that because the pain amounts steadily the hand can be removed before it becomes too severe. The water treatment was administered after learning to prevent arousal effects on encoding or attention, instead just influencing memory consolidation. Although all participants were informed at outset that they may be asked to place their arm in ice water, they weren't randomly assigned to either a control (n = 13) or arousal condition (n = 13) until just before arm immersion. Because group assignment was based on a random process, it is reasonable to expect that characteristics such as age, IQ, and gender will also be randomly distributed across groups. Thus, the potential for confounding is minimal, as one group should not be systematically older, smarter, or more masculine than the other. Those in the arousal condition were told that because the procedure can be uncomfortable, they should keep their hand in the water for as long as possible, not exceeding three minutes, and they could remove their arm at their own disclosure. Those who kept their arm in the ice-cold water for the full three minutes (n = 8) were instructed at that point to remove their arm from the water. Those in the warm-water condition were instructed to keep their arm in the water until instructed by the experimenter to remove their arm, which occurred pseudorandomly across participants 1, 2, or 3 minutes after immersion.

After the water immersion, participants were given a short rest period to dry their arm with a hand towel. Participants in both conditions were then asked to characterize their experience of the water immersion. To do this, they were first asked to recall the most intense physical pain they had ever experienced by appropriately marking a 0 to 10 scale, with 0 denoted as 'no pain or discomfort' and 10 denoted as 'the worst pain imaginable'. This was done to regulate each subject to the scale. They then had to rate the extent of discomfort experienced in the water immersion on the same scale. Finally, participants were asked to rate how aroused they felt at that moment on a 0 to 10 scale, with 0 denoted as 'drowsy and lethargic' and 10 denoted as 'as mentally aroused as possible'. This was done to compensate for no physiological measures of arousal being taken. Participants then went on to view a further 91 slides as part of the recognition test, of which half were the original slides and half distracters. Using the appropriate keys on the computer's keyboard, participants indicated which of the slides were old and which new. This scale used ran from 1 to 6, with 1 denoted as 'very sure new' and 6 denoted as 'very sure old'. Furthermore some slides were accompanied with a pictorial cue to examine if this helped with remembering. Twenty-four hours after slide presentation, participants returned to complete another identical memory test, representing the delayed trial. Participants' responses for each slide were recorded after both immediate and delayed testing. All participants were fully debriefed before leaving the laboratory for the final time.

A repeated measures analysis of variance (ANOVAs) with time and prompt as within subject factors (2 levels), and condition as the between subject factor was used to analyse the effect of arousal and cue use on recognition accuracy. Another two ANOVAs with familiarity and prompt as within subject factors (2 levels), and condition as the between subject factor was used to analyse the effect of arousal and cue use on identifying old and new items, for both immediate and delayed testing. Independent samples t-tests were used to measure the subjective rating of discomfort and arousal against condition in order to infer whether the water treatment was a successful inducer of arousal.

Results

Descriptive statistics for the two experimental conditions are given in Tables 1, 2 and 3.

Table 1 *Mean and standard deviation of participants' Accuracy scores of Recognition Memory Performance in relation to Time, Prompt, and Condition (n = 13 in each condition)*

	Condition	**Mean**	**Std. Deviation**
Immediate Cue	**Warm**	0.86	0.11
	Cold	0.91	0.09
	Total	0.88	0.10
Immediate No Cue	**Warm**	0.78	0.16
	Cold	0.83	0.09
	Total	0.81	0.13
Delayed Cue	**Warm**	0.80	0.14
	Cold	0.81	0.13
	Total	0.80	0.14
Delayed No Cue	**Warm**	0.68	0.10
	Cold	0.66	0.12
	Total	0.67	0.10

Both groups together recognized more slides in immediate testing. The use of cues enhanced recognition accuracy in both immediate (mean= 0.88, SD= 0.10) and delayed testing (mean= 0.80, SD= 0.14), more than when cues were absent (mean= 0.81, SD= 0.13; mean= 0.67, SD= 0.10). Furthermore, cues seemed to be most beneficial in delayed testing, whereby there is a larger mean difference of 0.13 compared to 0.07 in the immediate trial. The arousal group was more accurate at recognising slides in immediate testing with cues (mean = 0.91, SD = 0.09) and without cues (mean = 0.83, SD = 0.09) than the control group was in immediate testing with (mean = 0.86, SD = 0.11) and without cues (mean = 0.78, SD = 0.16). In delayed testing, arousal also increased recognition accuracy when there were cues (mean = 0.81, SD = 0.13) compared to the control group (mean = 0.80, SD = 0.13). However, the control group was slightly more accurate in delayed testing when no cues were available (mean = 0.68, SD = 0.10) than the arousal group (mean = 0.66, SD = 0.12).

An ANOVA with the factors Time (immediate vs. delayed recognition), Prompt (cue vs. no cue), and Arousal (cold water treatment vs. warm water treatment) was conducted. A significant main effect of Time, $F(1, 24) = 62.52$, $p < .001$, partial $\eta^2 = .72$; and Prompt, $F(1, 24) = 34.24$, $p < .001$, partial $\eta^2 = .59$, were detected. Therefore participants' accuracy decreased over time, and they did better with the aid of a cue (Fig. 1). However, the main effect of Arousal was not significant, $F(1, 24) = 0.34$, $p = .565$, partial $\eta^2 = .01$, thus the condition that participants' were assigned to did not effect their consequent accuracy scores by a significant amount. Fundamentally, being in the cold-water condition did not considerably improve recognition as expected. The Time by Arousal interaction, $F(1, 24) = 3.07$, $p = .092$, partial $\eta^2 = .11$; Prompt by Arousal interaction, $F(1, 24) = 0.34$, $p = .565$, partial $\eta^2 = .01$; and Time by Prompt interaction, $F(1, 24) = 3.18$, $p = .087$, partial $\eta^2 = .12$, were all found not to be significant. Hence, time effects did not depend on which condition participants were in, and the effectiveness of a cue was not determined by condition or time. The three way interaction between Time, Prompt, and Arousal was also not significant, $F(1, 24) = 0.27$, $p = .610$, partial $\eta^2 = .01$.

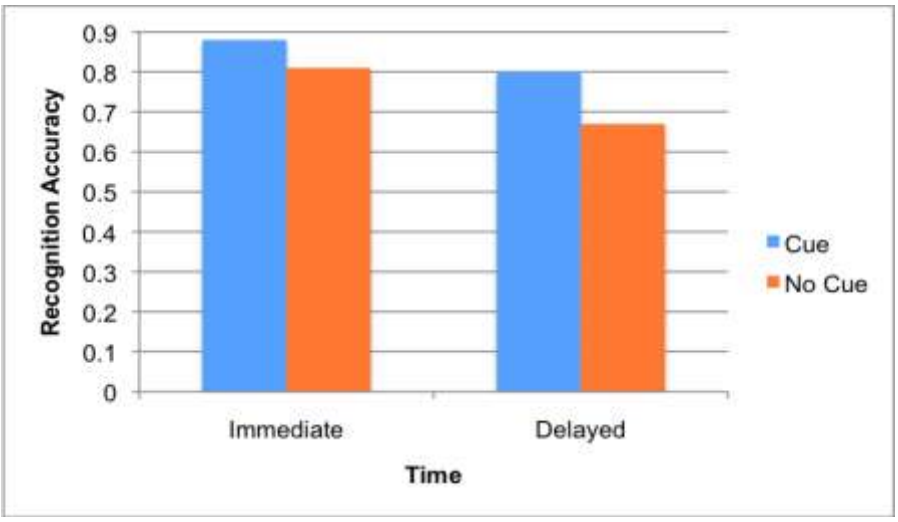

Fig. 1. *Recognition judgments of neutral stimuli; whereby data are compiled from all participants regardless of condition (n = 26), in immediate and delayed testing, and in context and no context trials. Analysis of variance revealed significant main effects of Time and Prompt.*

Table 2 *Mean and standard deviation of participants' Proportion (%) response "old" scores in relation to Familiarity, Prompt, and Condition in immediate testing (n = 13 in each condition)*

	Condition	Mean	Std. Deviation
Immediate Old Cue	**Warm**	0.84	0.13
	Cold	0.89	0.14
	Total	0.87	0.14
Immediate Old No Cue	**Warm**	0.70	0.22
	Cold	0.72	0.17
	Total	0.71	0.19
Immediate New Cue	**Warm**	0.22	0.17
	Cold	0.12	0.15
	Total	0.17	0.17
Immediate New No Cue	**Warm**	0.21	0.17
	Cold	0.16	0.16
	Total	0.18	0.16

Both groups together were more likely to correctly recognise old slides than mistakenly recognise new slides. Being in the arousal condition helped participants to correctly identify old items when there were cues (mean = 0.89, SD = 0.14) and when there weren't (mean = 0.72, SD = 0.17), more than those in the control condition, who had a higher false alarm rate (mean = 0.84, SD = 0.13; mean = 0.70, SD = 0.22). Participants in both groups were less likely to mistakenly report a new item when cues were provided (mean = 0.17, SD = 0.18) than when there were no cues (mean = 0.18, SD = 0.16).

An ANOVA with the factors Familiarity (old items vs. new items), Prompt (cue vs. no cue), and Arousal (cold water treatment vs. warm water treatment) was conducted. A significant main effect of Familiarity $F(1, 24) = 164.07$, $p < .001$, partial $\eta^2 = .87$, and Prompt $F(1, 24) = 10.20$, $p < .005$, partial $\eta^2 = .30$ were detected. Therefore, participants were significantly better at recognising old items correctly than they were at mistakenly identifying old items that were actually new items. Furthermore, participants attained a higher hit rate with the aid of a cue. The Familiarity by Prompt interaction $F(1, 24) = 24.35$, $p < .001$, partial $\eta^2 = .50$ was also significant. Hence, the likelihood that participants correctly distinguished old from new items depended upon whether a contextual cue was provided. However, the main effect of Arousal was not significant $F(1, 24) = 0.43$, $p = .518$, partial $\eta^2 = .02$, thus the condition that participants' were assigned to did not effect their consequent proportion of "old" responses by a significant amount. Fundamentally, being in the cold-water condition did not considerably improve hit rates or reduce false alarm rates. The Familiarity by Arousal interaction $F(1, 24) = 1.43$, $p = .243$, partial $\eta^2 = .06$ and Prompt by Arousal interaction $F(1, 24) = 0.12$, $p = .732$, partial $\eta^2 = .00$, were both found not to be significant. Therefore, the proportion of "old" responses given and the effectiveness of a cue did not depend on which condition participants were in. The three way interaction between Familiarity, Prompt, and Arousal was also not significant $F(1, 24) = 1.14$, $p = .296$, partial $\eta^2 = .05$.

Table 3 *Mean and standard deviation of participants' Proportion (%) response "old" scores in relation to Familiarity, Prompt, and Condition in delayed testing (n = 13 in each condition)*

	Condition	Mean	Std. Deviation
Delayed Old Cue	**Warm**	0.78	0.20
	Cold	0.87	0.16
	Total	0.83	0.18
Delayed Old No Cue	**Warm**	0.57	0.13
	Cold	0.58	0.11
	Total	0.58	0.12
Delayed New Cue	**Warm**	0.36	0.19
	Cold	0.35	0.16
	Total	0.36	0.17
Delayed New No Cue	**Warm**	0.31	0.12
	Cold	0.33	0.19
	Total	0.32	0.15

Both groups together were more likely to correctly recognize old slides than mistakenly recognise new slides. Being in the arousal condition helped participants to correctly identify old items when there were cues (mean = 0.87, SD = 0.16) and when there weren't (mean = 0.58, SD = 0.11), more than those in the control condition, who had a higher false alarm rate (mean = 0.78, SD = 0.20; mean = 0.57, SD = 0.13). Participants in both groups were less likely to mistakenly report a new item when cues were provided (mean = 0.36, SD = 0.17) than when there were no cues (mean = 0.32, SD = 0.15). In comparison to immediate testing, hit rates had decreased and false alarm rates had increased for both groups in delayed testing, suggesting their performance had deteriorated over time.

An ANOVA with the factors Familiarity (old items vs. new items), Prompt (cue vs. no cue), and Arousal (cold water treatment vs. warm water treatment) were conducted. A significant main effect of Familiarity $F(1, 24) = 96.03$, $p < .001$, partial $\eta^2 = .80$ and Prompt $F(1, 24) = 37.03$, $p < .001$, partial $\eta^2 = .61$ were detected. Therefore, similarly to in immediate testing, participants were significantly better at recognising old items correctly than they were at mistakenly identifying old items that were actually new items. Furthermore, participants attained a higher hit rate with the aid of a cue. The Familiarity by Prompt interaction $F(1, 24) = 20.63$, $p < .001$, partial $\eta^2 = .46$ was also significant. Hence, the likelihood of recognizing an old item as an old item correctly, and successfully distinguishing a new item as a new item, depended upon whether a cue was provided. However, the main effect of Arousal was not significant $F(1, 24) = 0.38$, $p = .544$, partial $\eta^2 = .02$, thus the condition that participants were assigned to did not effect their consequent proportion of "old" responses by a significant amount. Fundamentally, being in the cold-water condition did not considerably improve hit rates or reduce false alarm rates. The Familiarity by Arousal interaction $F(1, 24) = 0.35$, $p = .560$, partial $\eta^2 = .01$ and Prompt by Arousal interaction $F(1, 24) = 0.31$, $p = .583$, partial $\eta^2 = .01$ were both found not to be significant. Therefore, the proportion of "old" responses given, and the effectiveness of a cue, did not depend on which condition participants were in. The three way interaction between Familiarity, Prompt, and Arousal was also not found to be significant $F(1, 24) = 1.22$, $p = .279$, partial $\eta^2 = .05$.

The subjective rating of discomfort and arousal due to the stressor was examined using an independent samples t-test. As expected, participants in the arousal condition reported a far higher rating of discomfort (mean = 4.31, SD = 2.10) than in the control condition (mean = 0.15, SD = 0.38). This difference was significant, $t(24) = -7.03$, $p < .001$, $d = -.803$. Surprisingly, both participants in the arousal condition (mean = 6.46, SD = 1.76) and the control condition (mean = 6.31, SD = 1.32) reported similar levels of perceived arousal, $t(24) = -0.25$, $p = .803$.

Discussion

Building up on recent findings, the present study was conducted to further clarify the influence of arousal on memory consolidation. Additionally, the effect of providing a contextual cue was explored. Arousal was induced with the cold pressor stress procedure, and memory for neutral words and images was measured at two stages by recognition accuracy scores.

The relationship between memory and arousal was not consistent with the experimental hypothesis that physiological arousal would improve memory performance over a delay. The sum of correctly recognised slides between the arousal and control conditions failed to achieve statistical significance. Thus recognition performance was not significantly improved in CPS participants over controls. This teamed with a main effect of time, whereby participants' performance deteriorated in delayed testing, demonstrates the main finding of this study; that this research failed to find an effect for long-term facilitation of memory caused by arousal. This was somewhat unexpected, as the beneficial effects of arousal on memory for neutral items have been repeatedly confirmed (Rimmele, Domes, Mathiak, Hautzinger, 2003), even when in comparison to emotive material (Preuß & Wolf, 2009). In addition, various studies support the process whereby arousal inhibits retrieval in the short term (e.g. Nielson & Jenson, 1992), whilst consolidation effects appear later in time (e.g. Nielson, Yee, & Erikson, 2005). Moreover, this retention enhancement for neutral items has been found after the CPS specifically (Andreano & Cahill, 2006). However, Andreano and Cahill only found an enhancing effect in their male participants, which may explain why this female dominated sample failed to align. Several studies have indicated gender differences in the processing of memories in arousing situations (Cahill & van Stegeren, 2003; Shors, 1998). The present study was not designed to evaluate gender differences, but would nonetheless find it problematic to do so. The demographic properties of enrolment for psychology courses makes it difficult to recruit enough male participants to be representative of the larger population. Hence, the imbalanced sex ratio of the current study (23% male and 77% female); was not optimal for a true assessment of possible sex effects. This is a recurrent problem that often emerges in studies that recruit psychology undergraduate participants (e.g. Li Juan Liu, Graham, & Zorawski, 2007), despite recommendations that possible sex differences should be considered (Cahill, 2006; Wolf, 2008). The evidence at minimum suggests that identical effects of memory retention on males and females should not be assumed, and is therefore an area that merits attention in future studies.

Alternatively, such a direction of relationship may have been observed before, but under-reported due to the “file drawer problem” described by Park (2005). This is where the probability of publication depends on the statistical significance of the results. Hence, studies such as the present, which report non-significant outcomes, are less likely to be broadcast.

However, it is undeniable that this null effect replicates previous studies that specify recognition accuracy for neutral items decreases over time (Sharot & Phelps, 2004). Such as when memory has not been affected for non-arousing slides after a CPS procedure (Cahill et al., 2003). The same pattern of results has been found for memory accuracy for neutral items previously paired with arousing items (e.g. Baddeley, 1982; Kleinsmith & Kaplan, 1963; Walker & Tarte, 1963). The failure to establish consolidation effects may have resulted from the absence of emotional items. Perhaps after exposure to a certain emotion-evoking stimuli, the viewing causes concern amongst participants, and ultimately increases post stimulus elaboration. Neutral items are then associated with shallow maintenance processing. This is supported by Christianson’s (1992) review of existing literature, which states that high levels of arousal are associated with poorer memory for peripheral information. Therefore, it may be true that emotional words form a more cohesive semantic category and receive some preferential processing over neutral words (Phelps & LaBar, 1997), which would explain why, in this case, neutral test words were forgotten. Such findings can be understood in terms of adaptive value. Most peripheral details are not important for predicting future events, and may not ensure survival. However, accessibility to emotional items that’s core features associate with the stressor may be critical for guiding behavior in future scenarios. This explains why studies where the to-be-learned information is conceptually related to its stressor, and considered important by the individual often observe improved memorability (Smeets et al., 2009).

It should be emphasized that although the CPS has been widely used in medical research for more than 50 years (Lovallo, 1975), and has proved to be an effective experimental tool to investigate memory modulation by stressful experiences (Cahill et al., 2003), it remains confined by individual arrangement. For example, differences in water temperature, apparatus, and procedure might contribute to conflicting results (von Baeyer, Piira, Chambers, Trapanotto, & Zeltzer, 2005). It has previously been documented that temperature variations of as little as 2°C can cause significant alterations in pain response (Mitchell, MacDonald, & Brodie, 2004). Essentially, the intensity of cold pressor pain increases as water temperature decreases (Hilgard, 1969). Thus, it is important to maintain strict standardisation across research in order for comparisons to be made. Furthermore, in the present study 62% of participants in the arousal condition immersed their hand until the ceiling time. This means that the true tolerance time is unknown for these participants. The variation of pain threshold among participants may be a direct result of a range of psychosocial factors (e.g. coping style, motivation, and expectations). In addition, those who chose to remove their arm before the ceiling time imposed constraints on data analysis. This could count as one of the reasons it has been argued that studying traumatic events as they naturally occur is the best way to accurately investigate the impact of strong emotion on memory (Yuille & Cutshall, 1986; Yuille & Tollesrup, 1992). This is primarily because laboratory studies cannot adequately stimulate a real meaningful situation. Nevertheless, the laboratory-based CPS has the advantage of allowing greater control over details of intensity, duration and location than is possible with other stressors.

The type of memory tested for may account for some of the variation. Indeed, various studies (e.g. Andreano & Cahill, 2006; Preuß & Wolf, 2009) have found a facilitating effect for neutral items after a delay, but this was in a free-recall scenario. Thus, it is possible that teasing participants with further novel items and a multiple choice answering system causes reservation, which is otherwise avoided in free-recall tests. Therefore, emotional items may well be processed at a deeper level, which would explain why this effect is not apparent when testing for them.

As previously discussed, the retention delay, conceptual relatedness between stimuli and stressor, and the timing of stress exposure versus learning, may all be critical factors in deciding whether consolidation effects are observed. It is plausible that the 24-hour delay adopted was insufficient to generate a significant enhancing effect for non-emotive items, given that other studies have waited a week to test for such a response (e.g. Andreano & Cahill, 2006). In the present analysis the stressor was unrelated to the to-be-learned material, and this has been suggested to have an inhibitory impact on consequent performance, especially in the case of low-arousing items (Smeets et al., 2009). Smeets et al. additionally investigated the timing of arousal inducement, and found that memory was dependent on a pre-learning or coinciding stressor. Thus, arousal may modulate memory via effects of attention during encoding (Christianson & Loftus, 1991) and by altering retention (McGaugh, 2000). Although Sharot and Phelps (2004) disagree, instead proposing that arousal can facilitate slower forgetting, even when attention is not focused on the to-be-learned material. Nevertheless, if the encoding phase had required participants to indicate certain features about each item (e.g. whether the image was artificial or natural), then it could be ensured that everyone attended to each item, a technique applied by Knight and Mather (2009). This may have increased recognition rates, as otherwise participants' attention could privately deflect to any number of physical or psychological distractions.

As expected, providing a contextual cue assisted recognition memory, this shows that participants relied on memory for the association between the picture and word, which is similar to other studies' findings (Kelley & Wixted, 2001). This provides compelling evidence that associative-recognition decisions are based on both associative retrieval and item familiarity. When participants retrieve one member of a pair, they can successfully accept (if intact) or reject (if novel) the associates. Further, if recognition fails, participants can draw on knowledge about the familiarity of the pair to distinguish previously studied from novel items. The combined effort of associative retrieval and item familiarity explains why repeated word and image pairs on a list will increase the hit rate without affecting the false alarm rate. Therefore, a simple idea is that recognition, like other forms of memory is cue dependent; in situations where participants can draw on both item and associative information, their memory functioning progresses. This is not surprising given that the recollection component of recognition is considered to motivate both "remembering" and memory for context (Yonelinas, 2002).

Perhaps incorporating a weaker cue would have improved delayed memory even further (Carpenter, 2009), and then a significant Time by Prompt interaction may have been found. One reason for this may be that stronger cues fail to encourage the activation of elaborative information, which promotes prolonged retrieval through spreading activation. On the other hand, previous studies suggest that the time-dependent effects of emotion do not necessarily benefit memory for contextual information (Sharot & Yonelinas, 2008). This partially supports the current findings, as the enhancing effect of cue contribution was not considerably exaggerated among participants in the arousal condition, unlike how previous studies have described (Herz, 1997).

To characterize the response to the CPS, subjective ratings of discomfort were assessed. The results revealed significantly higher ratings of discomfort in the stressed group compared to the warm water control condition. These findings are well in line with previous studies (Schoofs, Wolf, & Smeets, 2009) and indicate the successful induction of an affective response.

According to the Yerkes-Dodson law (Yerkes & Dodson, 1908) and Easterbrook's cue-utilization theory (1959), the stressor in this study may have therefore produced a level of arousal that was too high to successfully increase memory performance. If this were the case, the memory task would present as an intellectually demanding and difficult task presuming only minimal arousal to enhance remembering. This would also explain why the use of contextual cues was so beneficial to participants. However, the possibility that the CPS evoked a physiological response that was beyond obligatory is unlikely given that when previous studies have incorporated this method, evidence for memory consolidation has been found (e.g. Cahill et al., 2003). What's more, studies that continue to define arousal as either 'high' or 'low' can be problematic, as little clarification of the arousal-memory relationship can be achieved when so few points along the continuum are considered.

Alternatively, the Theory of Action Decrement would explain these results in terms of neural activity. Specifically, the CPS must have triggered a small amount of nonspecific neural activity that conveyed the fixation of the reverberating memory trace. This then resulted in a weak consolidation and subsequently poor long-term memory performance. However, this is difficult to certify because no significant Time by Arousal interaction was found. Therefore, our results simply demonstrated that memory performance deteriorated over time, irrelevant of arousal. This would consequently suggest that water immersion did not have the desired effect on participants. This may be a plausible explanation, given that there were no significant differences of memory performance between conditions, and that subjective ratings of arousal were also similar for both groups. Thus participants who underwent the cold-water immersion did not feel any more stimulated per se than controls. If it were the case that these personal evaluations accurately mirrored participants' physiological activation, then despite the cold-water immersion being rated as more uncomfortable, it would not be deemed in this case as an arousing device. This is similar to research that has found no interaction between cortisol and arousal (Abercrombie, Kalin, Thilrow, Rosenkranz, & Davidson, 2003). Nevertheless, the awareness or interpretation of one's arousal state should not have interfered with subsequent memory modulation efficacy (Neilson & Meltzer, 2009).

Stressors that typically lead to a more pronounced cortisol stress response compared with the CPS, such as the Trier Social Stress Test (TSST, Kirshbaum, Pirke, & Hellhammer, 1993) have shown enhanced memory for neutral items (Preuß & Wolf, 2009). Furthermore, incorporation of social-evaluative elements has shown to increase HPA axis responses to the CPS (Schwabe, Haddad, & Schachinger, 2008). Such a suitable modification of the water immersion may have heightened physiological activation and thus served to increase the probability of memory consolidation for neutral items.

However, self-report measures of stress provide only meager evidence for differential levels of arousal amongst the two experimental conditions. This was particularly an issue for the present project as no supplementary physiological measures were taken such as galvanic skin response, pupil dilation, or salivette collection, all which would have provided a more scientific basis for considering the CPS' success. Pain tolerance, rating, and behavior expressive of pain, can be shaped by the presence of an audience such as an experimenter (Sullivan, Adams, & Sullivan, 2004). An effect that may be apparent in the current findings, as this was the only way safety and compliance with study protocol could be monitored without resources such as a one-way mirror or video monitoring. Moreover, the present CPS procedure could be criticised for its failure to circulate the water, a factor found to allow heat to build up around the arm and consequently enhance the likelihood of longer tolerance (Mitchell et al., 2004).

Various studies on context effects have shown that people recollect more accurately when they are in the same internal state at test as study (see Balch, Myers, & Papotto, 1999 for a review). This was partially achieved as participants were tested on both days in the same room, and even at the same desk. However, investigators in future studies could consider incorporating a direct reinstatement procedure, whereby the water treatment is administered for a second time just before delayed testing to demonstrate the utmost beneficial effects of the stressor. This effect could be down to the neural regions necessary for online emotional processing that also influence emotional memory retrieval, perhaps through the re-experience of emotion during the retrieval process.

There are several methodological limitations to be confronted in the current experiment. Firstly, the conclusions reached must only be considered as preliminary given the small sample size. Although this study accounted for type I and type II errors, it is still possible that extreme outliers influenced the overall statistical output, compromising the extent to which findings can be generalised. Small sample sizes can also result in the neglect of real differences between groups, and when this occurs, false conclusions may be reached. Consequently, these findings may actually be supportive of Kleinsmith and Kaplan's (1963, 1964) cross over interaction, whereby memory performance increases immediately and then decreases over time. As such is representative for the general pattern of current results, which may have become significant with a larger sample size. Still, at least the young sample should not be problematic, as similar patterns of performance have been found between younger and older age groups in direct comparison studies (e.g. Waring & Kensinger, 2009). Encompassing additional emotional items within the study list could have enabled direct comparisons between memory for emotional and neutral items. This could then aid clarification to whether memory consolidation was not exhibited because of the stimulus or stressor. Importantly, the words and images presented and tested for in the present experiment had not previously been rated for their arousal or valence, a measure that other studies have enforced (e.g. Sharot & Yonelinas, 2008). Therefore, it cannot be assured that the 'everyday' items used definitely had neutral qualities in anyone's opinion other than the researcher.

It seems apparent that it is not justified to assume that all details are well retained just because they are exposed during an arousing scenario. Post-learning stress activation doesn't appear to uniformly modulate memory consolidation for all recently required information; rather, it interacts with the intensity of arousal and components of stimuli. In accordance with the wealth of current research, it seems likely that emotional items are remembered differently, and possibly preferentially over neutral or ordinary items. Furthermore, the incorporation of cues into a study procedure generally seems helpful in facilitating memory storage, however, these effects are not necessarily manipulated by arousal inducement. Based upon the results of this study, it would be expected that sufficient arousal inducement does generally improve recognition. Yet it remains debatable whether this is true for immediate or delayed memory and is further dependent upon the type and emotionality of information tested for. Previous studies suggest immediate testing may be temporarily impaired for applicable and meaningful information. This could be helpful to police investigations, which may wish to bare such tendencies in mind when questioning victims and witnesses. In educational settings, ensuring students are alert and connected before any presentation of information is likely to profit their performance. Recreating the context of the event or providing any cues from learning may also be helpful. Hence, lessons and lectures that are taught in consistent environments, and incorporate cues into presentations, may be beneficial for retrieval in later testing. At the very least, the pattern of results from this, and previous studies, proves that the way emotion and memory interact is a very complex matter that is far from fully understood.

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