The Influence of External Sources of Arousal and Individual Differences on Memory Consolidation

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Abstract

Four experiments examined the hypotheses that arousing and stressful reactions enhance long term memory for associated experiences, and individual differences may modulate this effect. To induce arousal, research participants engaged in a cold pressor task in which they immersed their nondominant arm in ice water. Cortisol and self report measures of arousal confirmed that experiencing the ice water was more stressful than a comparable experience with warm water. Despite varying the stimuli (words, pictures) and their emotional value (positive, negative, neutral), the time between the learning and stress inductions (0 to 1 minute), and the possibility of post-learning mental rehearsal, each experiment produced a significant reversal of the hypothesized effect. That is, in each experiment, exposure to a stressor interfered with, rather than enhanced, long term memory for associated material. This result is qualified by two additional observations. First, when the ice water failed to elevate arousal, it also led to significantly poorer long term memory. Second, individual differences in gender, extraversion, and in hormone-relevant conditions (menstral cycle and oral contraceptive use) significantly affected the stress-memory relationship. For example, both women introverts in the arousal condition and women extaverts in the control condition showed poor recall, whereas the reverse pattern produced good recall, suggesting an inverted U-shaped relationship between arousal and long term memory. I conclude that the relationship between arousal and long term memory is more bounded than previously believed and varies with individual differences in traits and states relevant to gender, extraversion, reactivity, and homone levels.

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Chapter 1

"An impression may be so exciting emotionally as almost to leave a scar upon the cerebral tissues"

–William James, 1890

The idea that emotion can influence memory has been around a long time. Indeed, most of us would assert that our most potent memories are the ones in which we experienced some type of emotional arousal—a heart-stopping car crash, our first public speech, or the excitement of a wedding. Decades of research have shown that emotional arousal typically enhances memory consolidation. Yet, emotional arousal may not always have the same effect on memory for everyone. Past research has assumed that people should all react the same way to arousing situations, but we know this to be untrue. For example, two soldiers in combat situations may undergo the same experience, yet one might develop PTSD, a crippling anxiety disorder characterized in part by memory deficits of the arousing event, while the other suffers no such problems. Why is it that two people might experience the same arousing event, but come away with very different memories? Why might one person remember many details, but another remember very few? The answer may lie in the fact that arousal comes not just from an external source, such as induced arousal from stressful situations, but may also be influenced by individual differences. Two individual differences in particular—extraversion and gender—seem likely to moderate the relationship between arousal and memory.

1.1 Defining and Measuring Arousal

Emotion can be thought of in several different ways; it can be as a mood or a state, a feeling of good or bad. Emotion can also be thought of as comprising two dimensions: valence and arousal. Valence is often defined as how “good” or “bad” (or positive or negative) something is, whereas arousal, which is often quantified through physiological measures such as activation of the autonomic and endocrine systems (for example, increased heart rate or release of stress hormones such as cortisol), can range from very low to very high. But what exactly is it that ranges from low to high? Various researchers have tried to define arousal by proposing different continua. Two of the most popular are that arousal is the inverse probability of falling asleep (Corcoran, 1965), or that arousal is intensity of emotion (Whissell, Fournier, Pelland, Weir, & Makarec, 1986). For the purposes of this project, and following Storbeck and Clore (2008), arousal was defined as a physiological reaction associated with emotional states that involves activation of the sympathetic, autonomic, and/or the endocrine systems.

A satisfactory measure of arousal is difficult to find. Measures of physiological arousal across systems (autonomic nervous system (ANS), electrocortical, somatic, etc.) are often uncorrelated; in fact, even within a system such as the ANS, measures are generally uncorrelated (Cacioppo & Petty, 1983). For example, heart rate may increase but skin conductance may decrease in response to stress in one situation, whereas both may increase in response to stress in other situations. Thus, there is no agreement on a satisfactory measurement of arousal, but hormonal changes or patterns of responses across different measures are generally accepted as a reflection of changes in arousal

(Cacioppo & Petty, 1983). Cortisol in particular has been shown to correlate with observed differences in memory and performance in many studies (e.g., Cahill, Gorski, & Le, 2003), and is perhaps the most widely used measure. For the purposes of this project, arousal was measured in two different ways: self-report and activation of the endocrine system (as measured by change in the stress hormone cortisol).

1.2 Relationship between Arousal and Cognition

Arousal has been shown to influence a number of cognitive processes, such as judgments, decision making, problem solving, perception, attention, and memory, among others. High arousal has the effect of intensifying relevant judgments, attitudes, and responses on a task. For example, compared to low arousal, high arousal can make positive ads seem more positive and negative ads more negative (Gorn, Pham, & Sin, 2001), can intensify evaluations of famous faces (Paulhus & Lim, 1994), and can lead to emotional interpretations of an ambiguous story (Martin, Harlow, & Strack, 1992). Arousal also seems to influence problem solving, not necessarily by influencing accuracy, but by having an effect on speed in these tasks (Lipnicki & Byrne, 2005; McMorris et al., 1999). In addition, others have found that blocking arousal (through administration of a beta blocker) impairs decision making (Rogers, Lancaster Wakeley, & Bhagwagar, 2004).

High arousal can also influence perception of time, wherein high fear can make time seem to pass slowly, but high excitement makes time seem to move more quickly (Campbell & Bryant, 2007). In regard to attention, arousal can guide attention in the sense that it directs attentional resources (such as vision, hearing, and other sensory inputs) toward stimuli that are the apparent source of arousal rather than to stimuli that are not judged to be arousing. For example, the weapon-focus effect (e.g., Loftus, Loftus, & Messo, 1987) is a well known phenomenon where a person's attention is often focused on an arousing stimulus, such as a gun or other weapon, to the exclusion of other details (such as what color shirt the target was wearing).

1.2.1 Arousal and Memory

Perhaps the most studied cognitive process in regard to arousal is memory. Arousal affects memory differently depending on several factors: the type of memory being examined, the emotionality of the to-be-remembered information, and the stage of memory being tested.

The majority of research concerning arousal and memory has concerned item or declarative memory, but there are many other types of memory. Autobiographical memory shows detrimental effects of arousal (Buss, Wolf, Witt, and Hellhammer, 2004); those who receive cortisol before retrieval recall significantly fewer autobiographical memories than those who do not receive cortisol. In the domain of working memory, some researchers have found that arousal does not appear to influence recall in a digit span working memory task (Kuhlmann, Piel, & Wolf, 2005), whereas others have found that digit span working memory is impaired by arousal (Elzinga & Roelofs, 2005; Lupien, Gillin, & Hauger, 1999). Mather et al. (2006) found arousal impaired feature binding in a source monitoring working memory task. Research on feature binding and associative memory has been mixed, with many hypothesizing and finding that arousal impairs associative memory (Touryan, Marain, & Shimamura, 2007; Jacobs & Nadel, 1998; Metcalfe & Jacobs, 1998; Nadel & Jacobs, 1998; Payne, Nadel, Britton, & Jacobs, 2004), but others hypothesizing and finding that it should be enhanced by arousal (Hadley & MacKay, 2006; MacKay, Hadley, & Schwartz, 2005; MacKay et al., 2004; MacKay & Ahmetzanov, 2005). To resolve these conflicting hypotheses, Mather (2007) posited an intriguing theory that because attention is drawn to arousing objects, this attention then facilitates the binding of features within this object (such as color and shape, for example). However, the associations between the arousing object and other contextual information (the object and another object in the background, for example) do not receive such enhancement because the increased attention to the object itself makes maintaining such extra-object associations in working memory difficult.

The affective value of the information to be remembered is important in arousal studies. Information that is positive or negative and arousing is typically more affected by an arousal manipulation than are neutral items. For example, after arousal at encoding, arousing items are remembered better at delayed testing than neutral items (Cahill, Prins, Weber, & McGaugh., 1994; Cahill & McGaugh, 1995; Buchanan & Lovallo, 2001; Kuhlmann & Wolf, 2006; Gore, Krebs, & Parent, 2006; Brignell, Rosenthal, & Curran, 2007). Similarly, when arousal occurs at consolidation, affective items show a memory benefit from arousal, while neutral items do not (Cahill & Alkire, 2003; Cahill et al., 2003; Abercrombie, Speck, & Monticelli, 2006; Liu, Graham, & Zorawski, 2008); however neutral items sometimes also show a memory benefit, typically when no affective items are tested (Nielson, Yee, & Erickson, 2005; Anderson, Wais, & Gabrieli, 2006). Finally, arousal at retrieval impairs memory for positive and negative words but not for neutral words (Domes, Heinrichs, Rimmele, Reichwald, & Hautzinger, 2004; Kuhlmann et al., 2005b; Kuhlmann, Kirschbaum, & Wolf, 2005).

1.2.1.1 Arousal and Consolidation

One of the most studied factors in arousal and memory research is memory stages. Arousal typically enhances memory when it occurs at encoding or consolidation, but impairs memory when it occurs at retrieval (see Roozendaal, 2002 for a review); the key factor to an arousal enhancement of memory appears to be that the participant is aroused close in time to exposure to the to-be-remembered stimuli but is no longer aroused when trying to recall the material. As the research conducted in this dissertation concerns arousal at consolidation, a more in depth review follows.

Consolidation is the stage of memory where information that has been encoded is stored in long term memory. To test the effects of arousal on consolidation, researchers typically arouse participants immediately after a learning episode, and then test memory after a delay that can range from a few hours to months. The majority of the evidence suggests that arousal leads to beneficial effects on memory consolidation (see Roozendaal, 2002, for a review). Interestingly, two sources of external arousal may interact: the valence and/or arousal of the stimuli has been shown to interact with induced arousal at consolidation. For example, Cahill and Alkire (2003) established that participants given epinephrine immediately after viewing slides recalled significantly more of the first slides than those given saline; further investigation revealed that the first slides were the most arousing. Similarly, Cahill et al. (2003) replicated Cahill and Alkire using the cold pressor task to elevate cortisol levels; again, compared to controls, those with elevated cortisol recalled arousing slides better, but no difference was found for neutral slides. However, this relationship between arousal and the arousing qualities of the stimulus may depend on other factors, such as how the participants experience the task. For example, Abercrombie et al. (2006) found that cortisol levels did predict recall after a two day delay, but only for those individuals who experienced high negative affect in relation to the stressor task; furthermore, this relationship was most apparent in enhanced recall for negative pictures.

In order for arousal to effectively benefit memory consolidation, it must happen soon after a learning event so that the arousal can be linked to the learning event. Anderson et al. (2006) found that participants who viewed neutral pictures followed four seconds later by arousing pictures recognized with “remember” responses (rather than “familiar” responses) those neutral pictures better than neutral pictures that were followed by other neutral pictures; this effect, however, was very time dependent, as delays greater than four seconds between pictures did not produce any differences between neutral pictures followed by either neutral or arousing pictures. Thus, arousal from the arousing pictures signified not only that the arousing picture itself was important, but also that what happened immediately before the arousal was also important. Nielson and Powless (2007), however, showed in a list learning task that a delay between encoding and arousal can be much longer than 4 seconds; they demonstrated that arousal (induced in this instance by watching arousing video clips) must take place within 30 minutes of a learning episode to produce a memory benefit in a recognition test. Although the time window for memory benefits was very different in these studies, they utilized different tasks and methods to induce arousal. The unifying factor is that the arousing event is tied to the to-be-remembered event in time; i.e., the participant must think of the events as occurring in the same episode.

The vast majority of studies examining the effect of arousal on memory consolidation have tested only external sources of arousal, such as the cold pressor task or exposure to arousing stimuli. However, as described below, internal variables such as personality and gender may modulate the relationship these external stressors have on memory.

1.2.2 Individual Differences in Arousal: Gender

Gender is an important variable with many well known behavioral and physiological differences between men and women. However, research on gender differences in memory has been mixed. While neither Buchanan and Lovallo (2001) or Liu et al (2008) have found differences in men and women for recall of arousing and neutral pictures after stress, others have found large differences in the type of information recalled. Andreano and Cahill (2006) found that, despite equivalent cortisol elevation, arousal enhanced long term memory for men but not for women. In 2003, Cahill and Van Stegeren found an intriguing interaction between recall of central vs. peripheral information and gender. Participants viewed an emotionally arousing story, but half of the participants received propranolol (a β-adrenergic agonist that blocks arousal). Interestingly, relative to controls, propranolol impaired memory for central but not peripheral information in men, and impaired peripheral but not central information in women. In a related study without propranolol, Cahill, Gorski, Belcher, & Huynh (2004) showed a similar interaction, but with BEM sex-role scores instead of gender. Only those who scored as having masculine traits showed enhanced memory for central information in the arousing portion of the story compared to the non-arousing portion, whereas both BEM groups showed enhanced memory for peripheral information in the arousing portion compared to the non-arousing portion, although the effect was more pronounced for those with feminine traits. Furthermore, BEM scores predicted performance better than actual gender.

There are anatomical sex differences that may explain this processing difference. Cahill and Van Stegeren (2003) suggested that, given that the right hemisphere is associated with central information and the left with peripheral, their findings are consistent with observations that arousal activates the right amygdala more in men and the left amygdala more in women (see also Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004; Cahill et al., 2001; Canli, Desmond, Zhao, & Gabrieli, 2002). In line with this idea, Mackiewicz, Sarinopoulos, Cleven, & Nitschke, (2006) found in an fMRI study that activation of the left ventral amygdala predicted recognition of aversive pictures for women, and activation of the right ventral amygdala predicted the recognition performance of men.

Furthermore, it may be that the menstrual cycle of women plays an important role. HPA (hypothalamic-pituitary-adrenocortical axis) activity, which regulates cortisol release, differs across stages of the menstrual cycle (Schoofs & Wolf, 2009; Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; Kuhlmann & Wolf, 2005; see

Kudielka & Kirschbaum, 2005 for a review) in that females in the luteal stage show comparable responses to stress as men, but females taking oral contraceptives or in the follicular phase show lower increases in cortisol. Moreover, it could be that sex differences in the brain in structures important for memory and emotion play a role; for example, the hippocampus is larger in women than men when adjusted for total brain size, and the amygdala is larger in men than women when adjusted for brain size (Cahill, 2004; 2006). Further evidence comes from studies with rats that indicate that short term stress may facilitate learning in males but reduce it in females, whereas long term stress may leave the male hippocampus more vulnerable to damage (Cahill, 2004; 2006).

Thus, it is likely that sex differences in the brain and in cortisol reactivity play a role in how men and women process information. Under non-arousing circumstances, one would not expect a gender difference. Arousal, however, by activating the amygdala and releasing stress hormones (such as cortisol) that are responded to differently by men and women, may result in sex differences in the processing of information and the type of information that is recalled. If men and women recall not just central and peripheral information, but all types of information (such as simple word lists or pictures) differently under arousal, then this has enormous implications for the study of memory.

1.2.3 Individual Differences in Arousal: Extraversion

Psychologists have long known that extraversion is a personality trait relevant to the study of arousal. In the late 1960's, Eysenck (1967) first proposed that introverts and extroverts differ in cortical arousal. In essence, he believed that introverts have higher cortical activity (and thus a lower threshold of arousal) than extraverts. In support of his theory, numerous studies using EEG, skin conductance, and other measures have found that introverts show greater physiological response to moderate stimulation than extraverts (for reviews, see De Pascalis, 2004; Stelmack, 1990; 2004). Interestingly, however, extraverts do sometimes show greater response to high stimulation than introverts (Stelmack, 1990).

Revelle and Loftus (1992) identify other characteristics that differ between introverts and extraverts; for example, extraverts habituate to arousal faster than introverts. Similar to Eysenck's (1967) hypothesis of higher cortical arousal for introverts, Revelle and Loftus also identify a higher basal level of arousal for introverts. Yet, many (e.g., De Pascalis, 2004; Stelmack, 1990) argue that the majority of physiological evidence indicates that introverts and extraverts do not differ in basal arousal levels in skin conductance, EEG, or heart rate. In contrast to these physiological measures, however, there may be differences in the levels of certain arousal-related hormones. For example, while differences in basal cortisol have not yet been explicitly examined (Netter, 2004), Miller, Cohen, Rabin, Skoner, & Doyl (1999) have found that basal levels of noradrenalin and adrenaline are higher in introverts. By measuring cortisol levels pre- and post-stress, I hope to shed some light on this debate.

While the debate over basal arousal differences between introverts and extraverts may not yet be settled, the evidence that introverts and extraverts differ in sensitivity to and response to arousal is considerable (De Pascalis, 2004; Stelmack, 1990; 2004). Thus, if introverts are indeed more aroused than extraverts and if introverts show a greater response to arousal than extraverts, then one would expect that inducing arousal in introverts should result in high levels of arousal but inducing arousal in extraverts should produce medium levels of arousal.

It is intriguing that while the effects of extraversion on sensitivity to and baseline levels of arousal, and the effect of these differences on many measures of performance have often been hypothesized, there have been few studies on how extraversion mediates the effect of external, induced arousal on long term memory consolidation. The experiments detailed in this dissertation address this surprising lack of research.

1.3 Theories of Arousal

It has been established that arousal typically enhances memory consolidation. But, so far, there has been no unified theory to explain all of the various findings in regard to memory stages, memory for affective vs. neutral information, gender, and extraversion. While theories of arousal, as described below, can account for various pieces of the puzzle, no theory currently accounts for all.

1.3.1 Hormonal and Neurological Mechanisms of Consolidation

The hormonal and neural mechanisms of consolidation are fairly well understood, and concisely explain why arousal may potentiate consolidation. There are several neurotransmitters, amino acids, and hormones that are important in modulating arousal and memory in humans and animals: GABA; catecholamines, which include epinephrine, norepinephrine, and dopamine; CRH, ACTH, corticosterone and cortisol; peptides, particularly opioids such as endorphins, enkephalin, and dynorphins; and vasopressin and oxytocin (see McGaugh & Gold, 1989 for a review). In addition, many brain regions, most notably the amygdala and hippocampus, as well as the nucleus accumbens, caudate nucleus, stria terminalis, and the entorhinal cortex, may be important (McGaugh, 2004). The next section briefly discusses how epinephrine and cortisol, the two stress hormones most commonly studied in humans, influence the consolidation of memory.

When epinephrine is released, it cannot cross the blood brain barrier. It binds to β-adrenoceptors on vagal afferents which project to the nucleus of the solitary tract (NTS) in the brainstem (Cahill & McGaugh, 1998; McGaugh & Roozendaal, 2002; Roozendaal, 2002; LaBar & Cabeza, 2006). This activation of the NTS then stimulates several brain structures, including the amygdala, and results in the release of norepinephrine (noradrenalin), most notably in the basolateral nucleus of the amygdala (BLA) through both a direct projection and indirectly via the locus coeruleus (Joels, Pu, Wiegert, Oitzl, & Krugers, 2006; McGaugh & Roozendaal, 2002). Through these actions, epinephrine also results in a brief but rapid change in neuronal excitability (Joels et al., 2006; Cahill & McGaugh, 1998).

Meanwhile, stress activates the HPA axis, which results in cortisol release. Cortisol also produces changes in excitability, but these changes are slower and longer lasting (Joels et al., 2006; Cahill & McGaugh, 1998). Cortisol, a glucocorticoid, then enters the brain and binds to glucocorticoid receptors in the hippocampus and amygdala (McGaugh & Roozendaal, 2002; Roozendaal, 2002). This binding, particularly in the BLA, intensifies norepinephrine release in the BLA (McGaugh & Roozendaal, 2002). In fact, the BLA has been proposed as a locus for the interaction of glucocorticoids and the noradrenergic system and has also been shown to affect memory consolidation processes in other brain regions, such as the hippocampus (McGaugh & Roozendaal, 2002; Roozendaal, 2002). Consolidation occurs, in part, through norepinephrine binding to adrenoceptors, which activates cAMP (cyclic adenosine monophosphate) and the formation of protein kinases, which can then modulate LTP (long term potentiation), a long term enhancement of synaptic transmission between neurons that is important for memory (McGaugh & Roozendaal, 2002; Roozendaal, 2002). Furthermore, norepinephrine and cortisol facilitate LTP directly in addition to enhancing synaptic responses (Joels et al., 2006). Because the effects of cortisol and epinephrine are reasonably well understood, and because these hormones are typically released under stress, levels of these hormones have been used in many studies as an indicator of arousal.

There is considerable evidence to show that the degree of change in arousal is important for predicting performance. Typically, at higher doses of stress hormones, effects on memory are more pronounced. For example, Cahill and Alkire (2003) found that at 80 ng/kg/min for 3 minutes, epinephrine improved memory consolidation, whereas 40 ng/kg/min of epinephrine and saline showed no such improvement. As mentioned previously, Abercrombie et al. (2006) also found a positive relationship between cortisol increase and memory, but only in those who experienced high negative affect related to the stressor. The degree of arousal is also important at retrieval; those who showed a larger increase in cortisol to stress show greater memory impairment than those with a lower cortisol response (Buchanan, Tranel, & Adolphs, 2006; Tollenaar, Elzinga, Spinhoven, & Everaerd, 2008). However, it is not simply that the higher the cortisol levels, the greater the influence on memory. Elzinga, Bakker, & Bremner (2005) found a surprising negative relationship between cortisol and consolidation, and Cahill et al. (2003) found no relationship between cortisol and memory.

Hormonal theories of consolidation lead to several predictions concerning memory consolidation. First, as described above, the release of stress hormones should correlate with memory, such that those who show an increase in cortisol should also show an increase in memory. Second, if arousal influences HPA activity differently for men and women, and for introverts and extroverts, then this would result in differing rates of consolidation that correspond to cortisol reactivity. However, if men and women, and introverts and extroverts, show the same reactivity to stress, they should have similar consolidation. Hormonal mechanisms cannot, however, explain why arousing items typically are more affected by arousal than neutral items, or why some studies (Abercrombie et al., 2006) have found that cortisol predicts memory only for those who also experienced negative affect and other studies have found no relationship or negative relationships between cortisol and memory (Cahill et al., 2003; Elzinga et al., 2005).

1.3.2 Inverted U vs. Linear Relationships

Many researchers have investigated the relationship between arousal and performance. Evidence for the shape of this relationship, however, is inconclusive, and it is impossible to determine the exact relationship between the degree of arousal and performance at this time. This issue is the subject of considerable debate, going back over 100 years when Yerkes and Dodson (1908) first proposed an inverted u-shaped curve (wherein extremely high and low levels of arousal are either detrimental to or have no effect on performance and a medium level of arousal is optimal). In support of this idea, Jacobs and Nadel and colleagues (Jacobs & Nadel, 1998; Metcalfe & Jacobs, 1998; Nadel & Jacobs, 1998; Payne, Nadel, Britton, & Jacobs, 2004) argue that intense, high arousal associated with trauma is detrimental to memory binding for emotional events.

However, there is much evidence to suggest that an inverted u-shaped curve cannot fully explain the relationship; for example, Nava, Landau, Brody, Linder, & Schächinger (2004) found that mental relaxation, a very low level of arousal, resulted in memory enhancement for visual information. As discussed in the previous section, the degree of arousal typically (but not always) shows a positive correlation with memory enhancement. Others (see Neiss, 1998) have argued that a u-shaped curve does not fit the available data.

The purpose of this dissertation is not to resolve the debate about the relationship between arousal and performance. However, the differing theories do predict different results. If arousal does indeed follow a u-shaped curve, then one would expect that those with very low arousal and very high arousal would do poorly; in terms of extraversion, this would mean that aroused introverts (who would be at a very high level of arousal) and non-aroused extraverts (at a very low level of arousal) would perform worse than non-aroused introverts and aroused extraverts. If, on the other hand, the relationship is more linear, than those who are most aroused should recall the most stimuli; for extraversion, then, aroused introverts should show the best performance. Similarly, these theories may shed light on gender differences-if one gender is found to be more reactive to arousal than the other, and also shows better memory, this might lend support to the linear or u-shaped theory, depending of course on the degree of arousal (an extremely high arousal resulting in memory benefits would support a linear relationship; if it resulted in memory deficits, it would support a U-shaped relationship). If, however, men and women show equivalent reactivity to stress, but different memory effects, then this would result in a problem for either theory. Lastly, the shape of the relationship between arousal and memory can perhaps explain why arousing items are typically recalled more than neutral items; the additional arousal from arousing items might result in an arousal level that is beneficial to memory, but neutral items would not result in arousal sufficient to improve memory.

1.3.3 Arousal as Information

Whereas the evidence for hormonal consolidation of memory may explain what happens biologically, the arousal as information framework seeks to build on that foundation and explain how arousal influences cognition behaviorally. Arousal-as-information can be thought of as a corollary of the more general affect-as-information model (Schwarz & Clore, 2007). Whereas the affect-as-information model accounts for how the valence aspect of affect, as in mood, conveys information about value, arousal-as-information proposes that arousal conveys information about urgency or importance (Clore & Schnall, 2005). In terms of memory, arousal-as-information predicts that the apparent importance or urgency of events triggers arousal, and sets in motion memory consolidation processes. According to this framework, arousal can work to modulate memory in two ways. First, it can guide attention, in the sense that it directs attentional resources (such as vision, hearing, and other sensory inputs) toward stimuli that are the apparent source of arousal rather than to stimuli that are not judged to be arousing. For example, the weapon-focus effect (e.g., Loftus et al., 1987) is a well known phenomenon where a person's attention is often focused on an arousing stimulus, such as a gun or other weapon, to the exclusion of other details (such as what color shirt the target was wearing). But when arousal does not or cannot guide attention to the relevant stimuli (such as when arousal is induced immediately after encoding), the release of stress hormones associated with arousal can lead to memory consolidation effects (Cahill & McGaugh, 1998; LaBar & Cabeza, 2006; McGaugh & Roozendaal, 2002) similar to what might result from increased practice or attention. Accordingly, arousal can also be thought of as a kind of "practice-less practice". Arousal serves as information to the adrenal system that something is important and worthy of remembrance. Thus, arousal is a bodily representation of the apparent importance or urgency of something, with the result that arousal enhances the consolidation of information and events that are linked to the arousal.

This framework predicts that arousal potentiates memory only for that which appears to be a source of or linked to arousal. This is not only because the arousal itself has cognitive consequences, but also because the information or urgency value that arousal conveys is an indicator of what specifically (the source of the arousal) should be remembered. Stimuli that are themselves affective in nature are surely the best candidates for a source of arousal. Thus, post-learning arousal is more likely to be attributed to (associated with) items with some affective value than with neutral items, and thus result in memory benefits for those items. However, when affective items are not present, then the arousal is attributed to the more neutral stimuli, thereby resulting in memory differences for those items.

Arousal as information makes predictions about gender or extraversion similar to that which is already predicted by hormonal theories—as arousal signifies importance or urgency, differing levels of arousal between men and women or extraverts and introverts result in differing consolidation between groups. However, as this theory, being relatively new, includes few predictions about how importance or urgency is evaluated and reflected physiologically and psychologically, it is possible that men, women, introverts, and extraverts may have differing evaluation of urgency or importance that are more psychological and not reflected by cortisol reactivity. Thus, if groups do not differ in reactivity to arousal as measured by cortisol, but still differ in memory consolidation, it is likely that importance evaluations are not reflected hormonally.

Chapter 2

2.1 Study 1: Arousal and Extraversion Interact in DRM True Recall

Study 1 was designed to examine the potential interaction of extraversion and arousal on both true and false memory. As described above, the effects of arousal on long term memory for previously encountered information are fairly well known—arousal typically enhances memory, particularly for emotional items. However, in addition to investigating how extraversion modulates this relationship between arousal and memory, I also investigated the effect of arousal on false memory, or memory for information that has not been previously encountered. Most situations in which accurate memory is extremely important, such as witnessing a crime, also involve fear, stress, and/or arousal. Yet, most studies of false memories have occurred when a participant is in a calm, neutral state in the lab. The experimental induction of arousal allowed me to test false memory scenarios that involve this important aspect of real world instances.

Furthermore, this experiment allowed me to investigate various theories of arousal. If arousal is indeed related to performance as a u-shaped curve, and if introverts are normally more aroused than extraverts and respond more strongly to arousal than extraverts, than those with a very low level of arousal (non-aroused extraverts) and a very high level of arousal (aroused introverts) should perform poorly, whereas those with a medium, optimal level of arousal (non-aroused introverts and aroused extroverts) should perform well. If arousal is related to performance in a linear fashion, then aroused introverts should perform well.

To assess these possibilities, I used the DRM paradigm (Roediger & McDermott, 1995) wherein a number of words all related to a central concept, or lure, are presented. For example, participants may see the words "bed, rest, awake, tired, pillow, snooze, nap, dream, alarm, snore"; they typically remember not only some of the presented words, but also the lure (*sleep*) which was not presented. I used emotional lists (lures: *kill, pain, sad, love, happy, beautiful*) as well as neutral lists (*sleep, needle, chair*) in order to determine how arousal and extraversion influenced memory for emotional as well as neutral items (See Appendix A).

2.1.1 Method

Participants

One hundred and twenty-three undergraduate women volunteered to participate for partial course credit. Table 1 shows the breakdown of extraverts and introverts in the arousal and control conditions.

Table 1.	Arousal (Ice)	No Arousal (Warm)	Total
Extraverts	36	28	64
Intraverts	37	22	59
Total	73	50	123

DRM Task

The DRM word lists were taken from a prior experiment (Palmer & Dodson, 2009). There were three negative word lists, three neutral word lists, and three positive word lists consisting of 10 words each. The lists were blocked by affect (negative, neutral, and positive). The negative, neutral, and positive lists were equated for BAS (backward associative strength, or how strongly each word in the list is associated with the critical lure) and word frequency. Within each list, the order of words ranged from the strongest associate of the critical lure (the first word) to the weakest associate (the last word). Palmer and Dodson found, in multiple experiments, that neutral lists showed the highest rates of both true and false recall.

Cold Pressor Stimulation

Cold pressor stimulation served as the arousal manipulation. The cold pressor task has been reliably shown to induce arousal (Lovallo, 1975). In this task, participants placed their left arm up to the elbow in either a bucket of ice (0-3° C: arousing condition) or warm water (37-40° C: non arousing condition) for one minute. Participants were allowed to remove their arm before the minute was up if they became too uncomfortable, but were encouraged to leave the arm in for the entire minute.

Arousal Questionnaire

A self-report of arousal served as a manipulation check for the arousal manipulation. Participants rated the amount of pain or discomfort they experienced from the arm immersion on a scale of 0 (no pain or discomfort) to 8 (worst pain or discomfort imaginable).

Procedure

During session 1, participants gave informed consent and learned that they would view and recall word lists. Because pilot data showed that the 250ms presentation time used in Palmer and Dodson (2009) resulted in levels of recall near floor (less than 1 word out of 10 recalled on average) two days later, each word was presented for 1 second, with a 100 ms inter stimulus interval between words. After each list was presented, participants had 45 seconds to recall all of the words they could remember from the previous lists. Participants were instructed to recall only words from the just-seen list, and not to recall words from any prior lists.

After the ninth list, participants then immediately underwent the arousal manipulation. After the participant removed his or her arm from the water, the participant was given a towel to dry off with and a minute to rest before continuing. Next, participants filled out the Goldberg (1992) extraversion-neuroticism questionnaire and the self-report measure of arousal. Participants were told to return in 48 hours, ostensibly to view more stimuli. Approximately 48 hours later, participants returned for session 2 and were surprised with a recall test. Participants were instructed to recall, in no particular order and with no time constraint, all of the words they could remember seeing from the word lists two days prior.

2.1.2 Results and Discussion

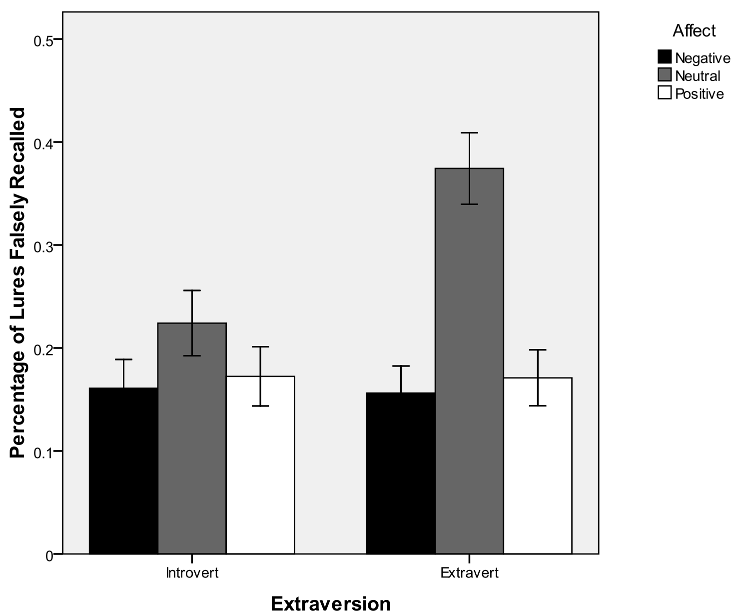
Results

Self-Report Measures of Arousal

The questionnaire data from 25 participants was missing due to computer failure. A univariate ANOVA with the factors of condition and extraversion was conducted on the self-reported value of amount of pain/discomfort experienced for 98 participants. Those in the arousing condition (*M* = 3.52) reported significantly more pain/discomfort than those in the control condition (*M* = .18), F (1, 97) = 169.44, $p < .001$, $\eta^2 = .64$. No effects or interactions were found for extraversion.

Session 1: Immediate Recall

Following the analyses of Palmer and Dodson (2009), who used the same stimuli and similar experimental procedures, I used a binomial logistic generalized estimating equation with extraversion and affect as factors. This analysis is most appropriate for this data, as ANOVA depends on a normal distribution of data—something impossible to achieve with a binary outcome, like false memory, or with low rates of recall, as seen in the delayed recall data (see below). For false recall, replicating Palmer and Dodson (2009) there was a main effect of word type, such that neutral lures (M = .29) were recalled more than positive (M = .17) or negative (M = .16) lures, Wald $\chi 2$ (2, N = 369) = 23.17, p <.001, QICC[1] = 1111.56. Interestingly, an interaction with extraversion revealed that this main effect was significant only for extraverts: Wald $\chi 2$ (5, N = 1102) = 5.76, p = .056, QICC = 1111.56 (see Figure 1a).



[1] Quasi-likelihood under independence criterion, an extension of AIC for choosing the best set of predictors for repeated measures; see Pan, 2001

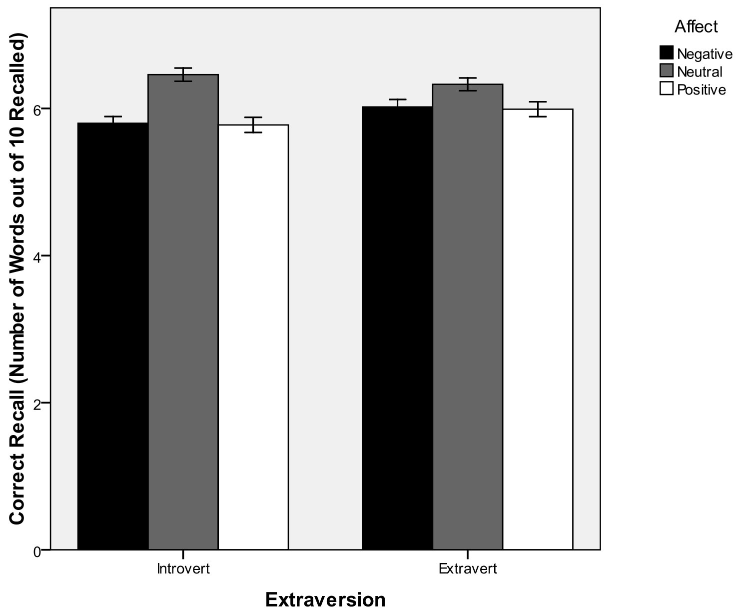


Figure 1. Immediate false and correct recall by affect and extraversion

For correct recall, a normal identity generalized estimating equation revealed a main effect of word type, again replicating Palmer and Dodson (2009): neutral words (*M* = 6.39) were recalled at a higher rate than emotional words (negative *M* = 5.91 and positive *M* = 5.88), Wald $\chi 2$ (2, *N* = 369) = 45.58, *p* <.001, QICC = 1848.33. In contrast to false recall, this effect is marginally stronger in introverts than extraverts: Wald $\chi 2$ (5, *N* = 1102) = 5.63, *p* = .06, QICC = 1848.33 (see Figure 1b). Thus, extraversion appears to be playing a role in recall even before participants are ever aroused.

Session 2: Delayed Recall

For false recall, I conducted a binomial logistic generalized estimating equation with the factors of arousal condition, extraversion, and word type as factors, and with session 1 false recall as a covariate. A main effect of type revealed that participants recalled more neutral (*M* = .25) and positive (*M* = .23) lures than negative lures (*M* = .13): Wald $\chi 2$ (2, *N* = 369) = 20.73, *p* <.001, QICC = 3001.37. No other main effects or interactions were significant.

For correct recall, I conducted a normal identity generalized estimating equation with the factors of arousal condition, extraversion, and affect as factors, and with day 1 correct recall as a covariate. The results revealed a significant condition X extraversion interaction, Wald $\chi 2$ (1, *N* = 1106) = 6.50, *p* = .01, QICC = 2803.58, such that non-aroused introverts (*M* = 1.72) and aroused extraverts (*M* = 1.83) recalled the most words (see Figure 2), and aroused introverts (*M* = 1.44) and non-aroused extraverts (*M* = 1.51) recalled the least. A marginal interaction between condition and type, Wald $\chi 2$ (2, *N* = 1106) = 5.36, *p* = .07, QICC = 2803.58, showed that in the ice condition, neutral (*M* = 1.83) was recalled the most, followed by positive (*M* = 1.59) and negative (*M* = 1.47). In the warm condition, however, neutral words were recalled the least (*M* = 1.52; positive *M* = 1.74, negative *M* = 1.59). A three way interaction with condition, extraversion, and type, Wald $\chi 2$ (2, *N* = 1106) = 7.02, *p* = .03, QICC = 2803.58, revealed that the non-aroused extraverts differed from every other group, in that they are the only group where neutral words were recalled less than emotional words.

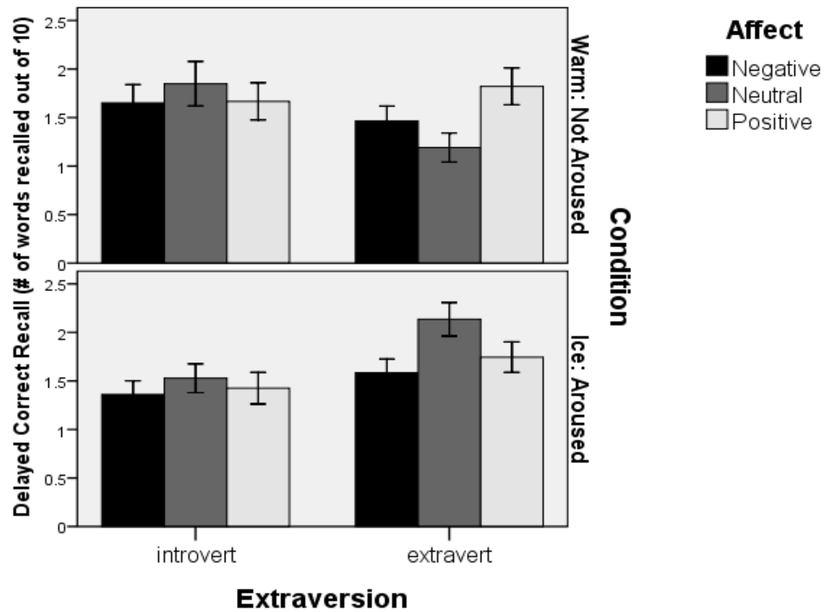


Figure 2. Delayed correct recall as a function of arousal, extraversion, and affect.

Discussion

Even before participants were aroused, it was clear that extraverts and introverts differed in how they recalled neutral and emotional words and lures. Interestingly, non-aroused introverts and aroused extraverts recalled more words in delayed recall. According to an inverted-U shaped theory of arousal and performance, it is likely that non aroused introverts and aroused extraverts recall the most words because they are in their optimal state; introverts may be normally more aroused and more reactive to arousal than extraverts. Thus, arousing introverts further by immersing their arm in ice water produces too much arousal, and so aroused introverts perform poorly. Conversely, arousing extraverts places them in an optimal state of arousal. Thus, these results lend support to an inverted u-shaped relationship between arousal and memory. These results also suggest that the optimal level of arousal for memory recall varies with the amount of chronic or internally generated arousal, which would seem to be relevant to traumatic situations, such as why some individuals develop a crippling response to stress like PTSD while others may emerge from the same situation relatively unscathed.

Interestingly, I did not find much in the way of arousal effects on false memory. There are two related reasons why this might be the case. There are two different mechanisms that can contribute to true and false recall of the studied items in this paradigm (Brainerd, Wright, Reyna, & Payne, 2002). First, participants may remember details about the item itself that leads to its being recalled—this is useful for true memory, but not for false memory. Second, participants may not remember a particular item, but they may remember relational information about all of the items, such as that they are related to a theme of sleep. It is possible that arousal influences memory for details about the item, but not memory for relational information. If that is indeed the case, then there should be no difference in false memory between those aroused and not aroused.

There may be some evidence to support this interpretation, as arousal tends to enhance memory for central (sometimes referred to as “gist”) rather than peripheral (“detail”) information of an event. Based only on this fact, one would think that arousal would enhance false memory, as the false memory can be considered a gist (Brainerd et al., 2002). However, Cahill et al. (2004a) showed that only those participants who scored as having masculine traits on the BSRI (Bem Sex Role Inventory; Bem, 1974) showed enhanced memory for central information (here, analogous to false memory) for an arousing portion of the story compared to the non-arousing portion. In contrast, individuals scoring high on both masculinity and femininity on the BSRI showed enhanced memory for peripheral information (here, analogous to true memory) in the arousing portion compared to the non-arousing portion, although the effect was more pronounced for those with feminine traits. Because this study used only females, I would not expect to see an enhancement for central or gist information (false memory), but I would still expect the enhancement for peripheral or detail information (correct memory). It is possible that if I had used men, I would see an effect of arousal on false memory.

Thus, arousal may still influence the tendency to develop false memories, but it requires further study. Before this question can be answered, it is important to know more about how gender and arousal interact to influence memory consolidation.

2.2 Study 2: Gender Interacts with Arousal and Extraversion in Word Recall

Study 2 was conducted to investigate how gender, extraversion, and arousal interact. The word lists in study 1 were chosen because they had been used in prior false memory research. They were chosen to be emotional (positively or negatively valenced) or neutral in nature, but due to constraints in constructing DRM-type lists, the arousal potential of each word was not taken into account. Since arousing words can also serve as a source of arousal, it is important to equate lists for arousal as well as valence. For this experiment, word lists were created from ANEW (Affective Norms for English Words (Bradley & Lang, 1999), a resource that contains arousal and valence ratings for many words), such that lists still differed in valence (positive, negative, and neutral), but positive and negative lists were equivalently high in arousal, and neutral lists were low in arousal. This experiment did not investigate false recall for three reasons: first, few false memory effects were found in study 1; second, there are significant constraints and difficulties in creating DRM lists equated for arousal as well as backward associative strength and word frequency; and third, it is important to establish the effects of gender, arousal, and extraversion on memory for arousing and neutral words before determining how these effects may transfer to false memory. Predictions concerning gender effects are difficult to make, given the conflicting research on gender and arousal, with some studies showing memory benefits for men only (Andreano & Cahill, 2006), but others showing no effect of gender (Buchanan & Lovallo, 2001; Liu et al., 2008). Effects of arousal and extraversion were expected to replicate study 1.

2.2.1 Method

Participants

97 undergraduate participants volunteered to participate in this study in exchange for partial course credit. See Table 2 for breakdown of participants by gender, extraversion, and condition.

Table 2.	**Ice: Aroused**	**Warm: Not Aroused**	Totals
Women Introvert	**18**	**11**	29
Women Extravert	**12**	**18**	30
Women Total	30	29	59
Men Introvert	**14**	**5**	19
Men Extravert	**9**	**10**	19
Men Total	23	15	38
Introvert Total	32	16	48
Extravert Total	21	28	49
Total	53	44	97

Word Lists

Word lists were created from ANEW (Bradley & Lang, 1999). Three lists (one negative, one neutral, one positive) consisting of 10 words each were matched for word frequency (see Appendix B). An ANOVA revealed that the lists did not differ on word frequency: F (2, 28) = .587, p = .56. The negative (M = 2.26), neutral (M = 5.01), and positive (M = 8.13) differed significantly in valence, F (2, 29) = 417.25, p < .001; post-hoc tests revealed that all 3 differed significantly from each other: all p's < .001. Finally, the lists differed in arousal: F (2, 29) = 190.41, p < .001, such that negative (M = 7.33) and positive (M = 7.48) were equivalent to each other (p = .55), but both were significantly higher in arousal than the neutral list (M = 3.10), all p's < .001.

Procedure

The procedure was exactly the same as in Study 1, except that participants also completed the BSRI (Bem, 1974) during session 1, which measures how stereotypically masculine or feminine a participant is.

2.2.2 Results and Discussion

Results

Self-Report Measure of Arousal

A univariate ANOVA with the factors of condition, gender, and extraversion was conducted on the self-reported value of amount of pain/discomfort experienced. Those in the arousing condition (*M* = 3.91) reported significantly more pain/discomfort than those in the control condition (*M* = .23), $F(1, 96) = 168.93$, $p < .001$, $\eta^2 = .66$. No effects or interactions were found for gender or extraversion.

BSRI

Although others have found the BSRI to predict performance equivalently to or even better than actual gender (e.g., Cahill et al., 2004a), gender was a better predictor for all models than BSRI score. Therefore, all analyses are reported with actual gender and not BSRI.

Session 1: Immediate Recall

Recall was calculated as the number of words out of 10 recalled for each list, and analyzed with the factors of affect, gender, and extraversion in a normal identity generalized estimating equation. The generalized estimating equation revealed a main effect of affect such that negative words (*M* = 6.3) were recalled at a higher rate than both positive (*M* = 5.91, $p = .01$) and neutral (*M* = 5.82, $p = .002$), Wald $\chi 2$ (2, *N* = 291) = 11.85, $p = .003$, QICC = 548.36. There was also a marginal effect of gender, such that women (*M* = 6.19) recalled more words than men (*M* = 5.83), Wald $\chi 2$ (1, 291) = 2.78, *p*

= .06, QICC = 548.36. Finally, an affect by extraversion interaction revealed that introverts recalled more words than extraverts, but only for negative words (see Figure 3): Wald χ2 (2, *N* = 291) = 8.47, *p* = .02, QICC = 548.36.

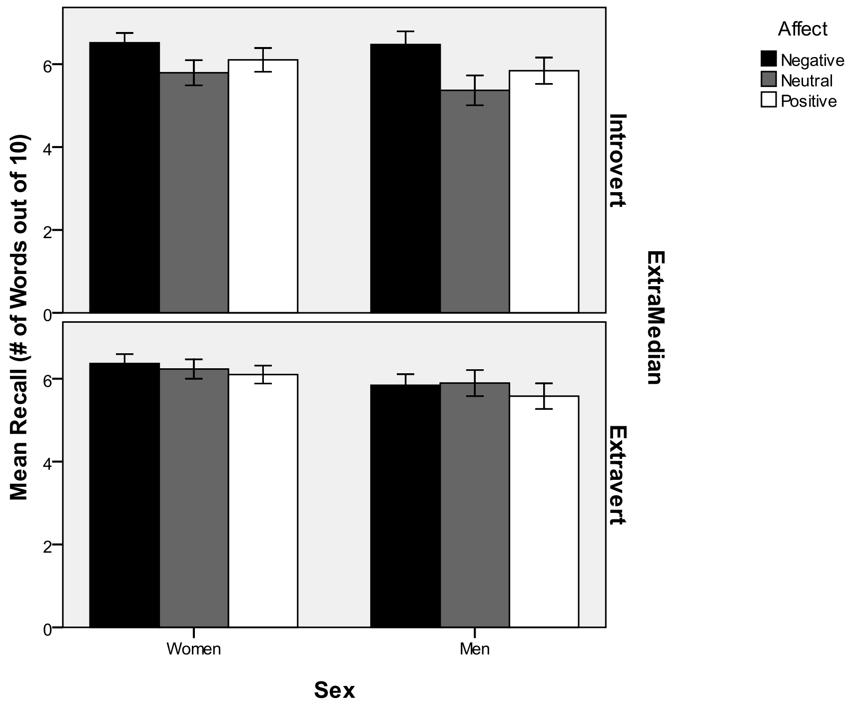
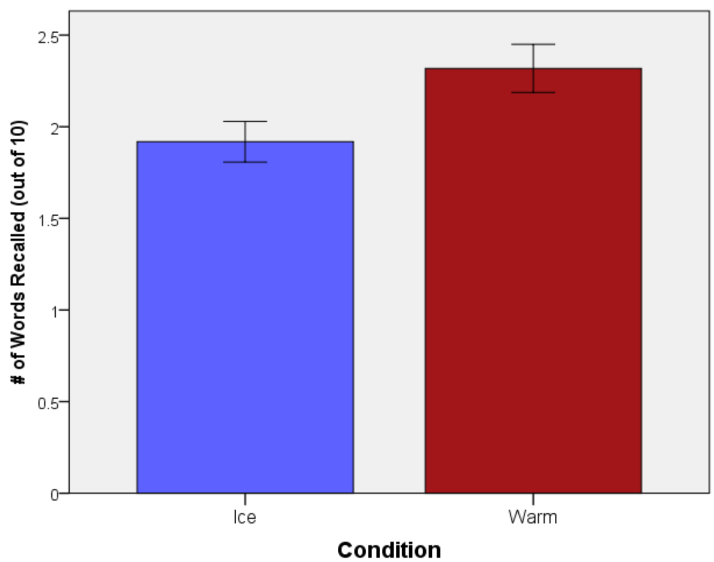


Figure 3. Immediate recall as a function of gender, extraversion, and affect.

Intrusions were calculated as the number of non-presented words that participants recalled. Intrusions on average were very low (less than .4 words per list). A generalized estimating equation with the factors of affect, gender, and extraversion revealed only a main effect for gender, such that men (*M* = .36) listed more intrusions than women (*M* = .22): Wald χ2 (1, *N* = 291) = 4.6, *p* = .03, QICC = 94.99.

Session 2: Delayed Recall

Recall was analyzed with the factors of affect, gender, arousal condition, and extraversion in a normal identity generalized estimating equation. The generalized estimating equation revealed a main effect of affect such that both negative words (*M* = 2.36) and positive words (*M* = 2.17) were recalled at a higher rate than neutral (*M* = 1.59, $p < .001$ and $p = .002$, respectively), Wald $\chi 2$ (2, *N* = 291) = 23.76, $p < .001$, QICC = 539.02. There was also a main effect of gender, such that women (*M* = 2.41) recalled more words than men (*M* = 1.67), Wald $\chi 2$ (1, 291) = 18.65, $p < .001$, QICC = 539.02, see Figure 4b. A main effect of condition also revealed that those who were not aroused (*M* = 2.24) recalled more words than those who had been aroused (*M* = 1.83), Wald $\chi 2$ (1, *N* = 291) = 5.65, $p = .02$, QICC = 539.02, see Figure 4a.



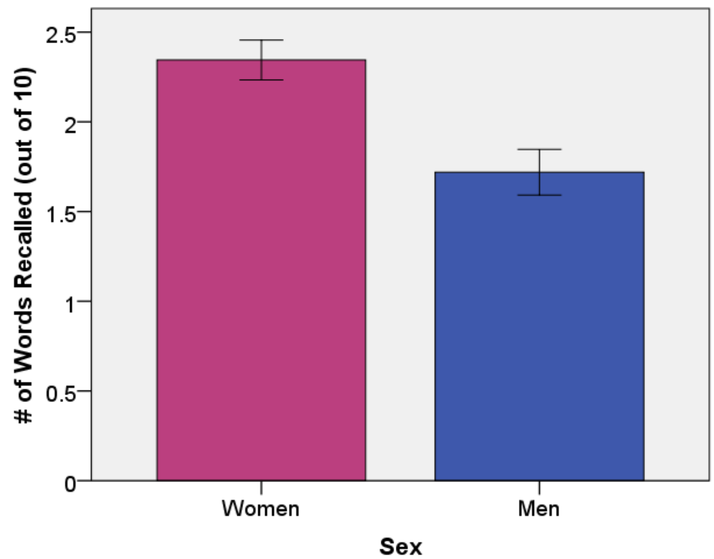


Figure 4. Main effects of arousal and gender.

An interesting three-way interaction between gender, condition, and extraversion (Wald $\chi 2$ (1, N = 291) = 13.83, p <.001, QICC = 539.02; see Figure 5) showed that, similar to study 1, female non-aroused introverts recalled the most words. In direct contrast, however, male aroused introverts recalled more words than aroused extraverts, and non-aroused extraverts recalled more words than aroused extraverts.

A generalized estimating equation with the factors of gender, condition, and extraversion revealed no significant main effects or interactions for intrusions in delayed recall.

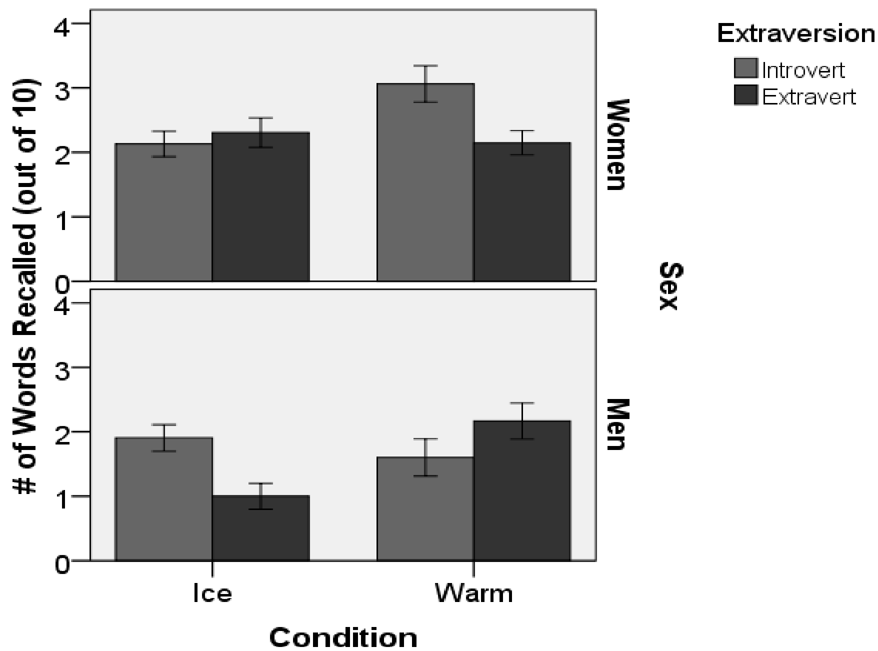


Figure 5. Delayed recall as a function of arousal, gender, and extraversion.

Discussion

Study 2 revealed intriguing results that expand on the results of study 1. The procedures were nearly identical, with the addition of men and the equation of arousal values for the affective word lists. Like extraversion, gender is an important modulator of the relationship between arousal and memory. Interestingly, I replicated the interaction of arousal and extraversion on memory from study 1, but only for women—men showed the opposite pattern. In delayed recall, women appear to follow an inverted U-shaped curve between arousal and memory, wherein non-aroused introverts perform the best, but in men, non-aroused introverts and aroused extraverts recalled the least, demonstrating a U-shaped curve. Thus, it is likely that men and women responded differently to the arousal manipulation. This could explain why inverted U-shaped relationships are often predicted, but rarely observed for arousal and performance effects—such a relationship may hold only for women, while men may show a different relationship.

The change from emotional DRM word lists to arousing and neutral word lists also revealed some interesting results. First, arousing words were recalled at higher rates in session 2 than neutral words—a finding that is consistent with the literature. However, for immediate recall, positive words were recalled less than negative words. Perhaps, even though the positive and negative lists were equated in terms of the arousal value of individual words in the list, there may have been an cumulative effect; in other words, perhaps an entire list composed of 10 negatively arousing words is more arousing than a list composed of 10 positively arousing words, even if individual words in each list are equivalently arousing. In addition, these results may indicate that valence is just as important, or perhaps even more important, than arousal for long-term recall; as countless studies have found, negative words are remembered better.

While we did not find a main effect of arousal in study 1, study 2 showed that those who were not aroused recalled more words than those who were aroused two days later—a finding that at first seems at odd with the typical finding in the literature of enhanced memory for those who were aroused. Recall, however, that the female non-aroused introverts recalled the most words, while the male aroused extraverts recalled the least; thus, the interaction between gender, arousal, and extraversion may explain this surprising main effect.

Thus, the results suggest the possibility that women and men, as well as introverts and extraverts, respond differently to stress. While the arousal questionnaire showed that men and women and extraverts and introverts did not differ significantly in self-reports of arousal, self report has always been a problematic way to measure arousal. Thus, some concrete measure of a physiological response to the arousal manipulation is needed.

2.3 Study 3: Arousal, Gender, and Extraversion in Picture Recall

Study 1 and Study 2 provided evidence that extraversion and gender modulate the relationship between arousal and memory. However, it is impossible to determine from those results whether the effects of extraversion and gender are due to a difference in reactivity to the stress test, due to different basal levels of cortisol, or due to other factors. Thus, study 3 involved three approaches to determining how individual differences modulate the relationship between arousal and memory. First, cortisol was collected at two time points—both before and 15 minutes after stress, which allowed me to determine differences in reactivity and baseline arousal within the factors of gender and extraversion. Second, study 3 also utilized an expanded extraversion questionnaire, which consisted of six subscales (Activity Level, Assertiveness, Cheerfulness, Excitement Seeking, Friendliness, and Gregariousness; Goldberg, 1999), which allowed me to more specifically determine what aspects of extraversion interact with arousal. Third, by asking women to indicate what stage of the menstrual cycle they were in and whether they were taking oral contraceptives, I could determine whether these factors (the importance of which is discussed in Chapter 1) are behind the gender differences observed in study 2.

Finally, it is possible that the surprising finding of better recall under low arousal than high arousal may have reflected the differences between the methods used in studies 1 and 2 and those used in other studies in the literature (using affective DRM word lists and measuring immediate as well as delayed recall). While initial performance was taken into account as a covariate for delayed performance in both studies, it is possible that the experience of recalling the words initially affected subsequent recall of the same items. Thus, memory was tested only at session 2 in study 3. In addition, in order to compare these results with results in the literature, study 3 was a close replication of Cahill et al. (2003), a respected study in the arousal and memory literature.

2.3.1 Method

Participants

One hundred and twenty-three undergraduates volunteered to participate for partial course credit. Table 3 shows the breakdown of men, women, extraverts and introverts (for the purposes of this table, extraversion was defined by a median split of the total extraversion scale) in the arousal and control conditions.

Table 3.	**Ice: Aroused**	**Warm: Not Aroused**	Totals
Women Introvert	**18**	**15**	33
Women Extravert	**14**	**22**	36
Women Total	32	37	69
Men Introvert	**18**	**16**	34
Men Extravert	**13**	**15**	28
Men Total	31	31	62
Introvert Total	36	31	67
Extravert Total	27	37	64
Total	63	68	131

Stimuli

Stimuli consisted of 31 pictures (11 neutral, 10 positive, 10 negative; see Appendix C) taken from IAPS (International Affective Picture System; Lang, Bradley & Cuthbert, 2005). The pictures were chosen so that negative, neutral, and positive pictures differed on valence ($M = 2.28, 4.94, 7.85$ respectively; $F(2, 28) = 707.29$, $p < .001$), but negative ($M = 4.78$) and positive pictures ($M = 4.75$) were equivalently high in arousal and greater than neutral pictures ($M = 2.25$; $F(2, 28) = 113.34$, $p < .001$); in addition, the pictures were chosen to be similar in arousal and valence ratings to Cahill et al. (2003).

Procedure

The procedure is a near replication of Cahill et al. (2003), with 4 differences: 1) Cahill et al. used negative and neutral pictures only; 2) Cahill et al. used a 1 week delay, whereas this study used a 48 hour delay; 3) Cahill's participants placed their arm in water for either 1, 2, or 3 minutes, a duration that was assigned pseudo randomly (this study used 1 minute, as that was shown to be sufficient to induce arousal in studies 1 and 2), and 4) Cahill et al. used a self-report measure of arousal, similar to what was used in Study 1 and 2 described above. This study did not use self-report, because studies 1 and 2 showed the ice water to be arousing, and it is possible that the self report procedure causes participants to associate arousal exclusively to the stress task and not to viewing the experimental stimuli. The mood literature has shown that if participants attribute their mood to a mood manipulation procedure, typical experimental findings disappear or even reverse (Schwarz & Clore, 1983). If giving self-reports of arousal causes participants to associate or attribute their arousal to the ice water task, it is possible that an analogous effect would occur; in fact, this may explain why the findings from study 2 (that non-aroused participants recall more) differ from the typical findings. This possibility is discussed further in chapter 3.

To reduce variability due to diurnal cortisol variation, all participants were tested between the hours of 12 and 5 pm. Participants were contacted via email the evening before the experiment was scheduled to begin, and asked to refrain from drinking alcohol for 12 hours prior to the experiment, from eating a large meal or consuming products with high dairy, acidity, or caffeine 60 minutes prior to the experiment, as these factors have been shown to influence cortisol samples (Salimetrics, 2009) . After signing the consent form, participants washed their hands and rinsed out their mouths with water. The participant then placed a synthetic salivette swab under their tongue for one to two minutes to saturate the swab with saliva. The participant then placed the swab in the salivette tube, which was stored at -20° C until it was assayed.

Next, participants viewed each picture in random order, with the exception that the same neutral picture always appeared first. Each picture was presented for 15 seconds total with a 0 ms inter stimulus interval; In order to ensure participants were paying attention, 5 seconds into the presentation of each picture, the computer prompted them to generate a name or short phrase for that picture. Immediately afterwards, participants underwent the cold pressor stimulation arousal manipulation described in study 1. Lastly, participants completed a computerized International Personality Item Pool extraversion scale (Goldberg, 1999), and additional questions for women (such as the date of their last menstruation, typical menstrual cycle length, and oral contraceptives use) that were used to determine menstrual cycle stage.

Participants were told to return in 48 hours, ostensibly to view more stimuli. Approximately 48 hours later, participants returned for session 2 and were surprised with a recall test. Participants were instructed to recall, in no particular order and with no time constraint, all of the pictures they could remember seeing two days prior. They were instructed to recall the pictures using the name or phrase they had generated, and to also record any details they could recall about each picture.

2.3.2 Results and Discussion

Results

Cortisol

The saliva samples were sent to the General Clinical Research Center (GCRC) lab at the University of Virginia, where they were stored at -20 °C until analysis. After thawing, saliva samples were centrifuged at 1500 g for 15 minutes, which resulted in a clear supernatant of low viscosity. Cortisol levels were determined employing Enzyme-Linked Immunosorbent Assay (ELISA) methodology. 96-well-Maxisorb microtiterplates were coated with monoclonal mouse anti-cortisol antibodies. All reagents were brought to room temperature and mixed before use. Plates were brought to room temperature and prepared for use with NSB (non-specific binding) cells. Each tube was prepared with 24 mL of assay diluents, and 25 mL of standards, controls, and saliva samples were pipetted into the appropriate wells. The assay diluents were pipetted into zero and NSB wells. A final 1:1600 dilution of conjugate (15 mL into 24mL assay) was mixed and 200mL were added into each well. Each plate was mixed for 5 minutes at 500rpm, and was incubated for 55 minutes at room temperature. The plates were then washed 4 times with 1X wash buffer (100 mL of 10X wash buffer concentrate mixed with 900 mL of deionized H2O), and blotted. 200mL of TMB substrate solution was added to each well, and plates were mixed for 5 minutes at 500rpm. They were then incubated in dark at room temperature for 25 minutes. 50mL of stop solution was then added to each well, and mixed for 3 minutes at 500rpm. With a computer-controlled program a standard curve was generated and the cortisol concentration of the samples was calculated. The intra-assay coefficient of variation was 8 and the corresponding inter-assay coefficient of variation was 2.7.

The samples of three participants were not able to be assayed due to insufficient saliva. There was no difference between the ice water (M = 5.56 nmol/L) and warm water (M = 5.89) groups in baseline cortisol, but the increase in cortisol 15 minutes after the CPS task was significantly higher in the ice water group (M = 1.99) compared to the warm water group (M = .01), t (129) = 3.52, p = .001. As others (e.g., Elzinga & Roelofs, 2005), have done, I divided the ice water group into non-responders (ice water participants with little or no cortisol response to stress) and responders (ice water participants with a cortisol response to stress) by a median split of cortisol response. A median split was used, as about one half of the ice participants showed a response to stress. This analysis also resulted in a significant effect of condition, F (2, 128) = 42.26, p <.001, such that the non-responders actually showed a decrease in cortisol in response to stress (M = -.72) and did not differ significantly from the warm (M = .01) group; the responders, however (M = 4.54) showed a change in cortisol significantly greater than both warm and non-responders (p's < .001; see Figure 6).

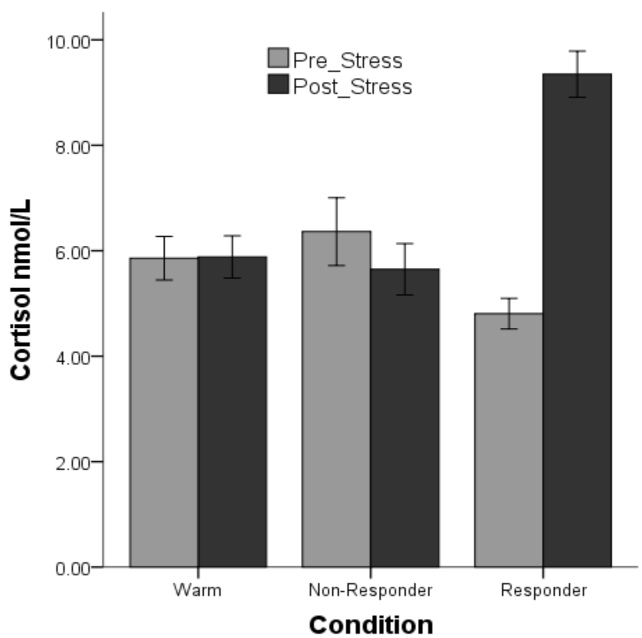
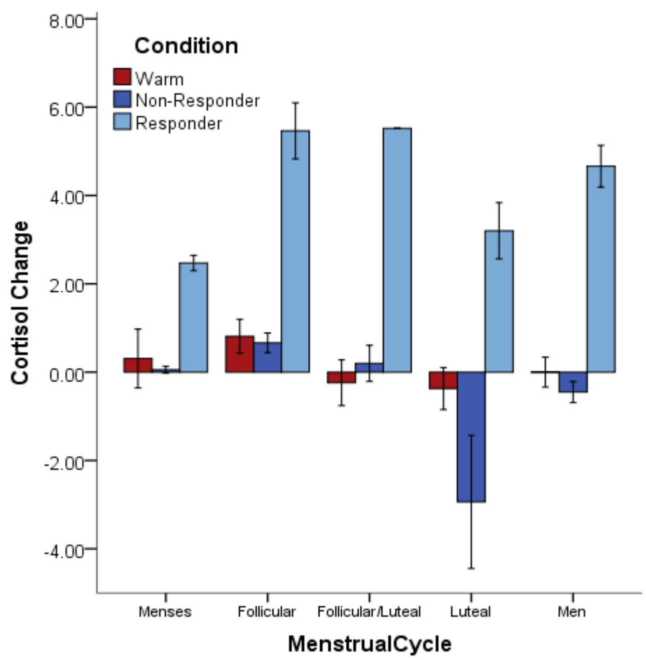


Figure 6. Cortisol as a function of arousal and time.

Cortisol did not differ at baseline or after stress as a function of gender or extraversion. However, menstrual cycle stage was a significant predictor of the change in cortisol from baseline to post-stress, F (4, 126) = 6.18, p < .001, such that women in the follicular phase had the largest increase in cortisol (*M* = 2.74), and women in the luteal phase actually showed a decrease in cortisol (-.888) compared to men (*M* = 1.01), women in menses (*M* = .99) and women in the follicular/luteal phase (*M* = .42); see Figure 7. Oral contraceptive use (see Figure 7) was a marginally significant predictor of change in cortisol, F (2, 126) = 2.37, p = .095; post-hoc tests revealed that those who were taking oral contraceptives (*M* = .35) showed significantly less increase in cortisol than those who were not taking contraceptives (*M* = 1.59, p = .03).



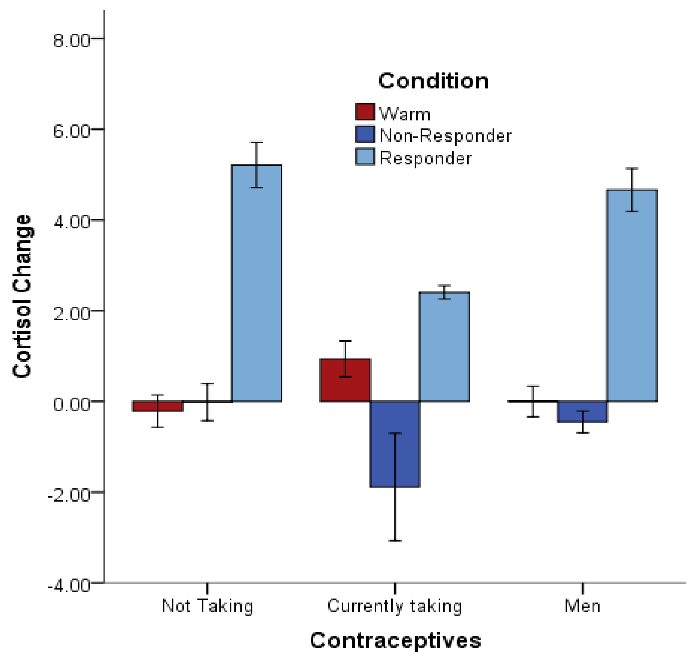
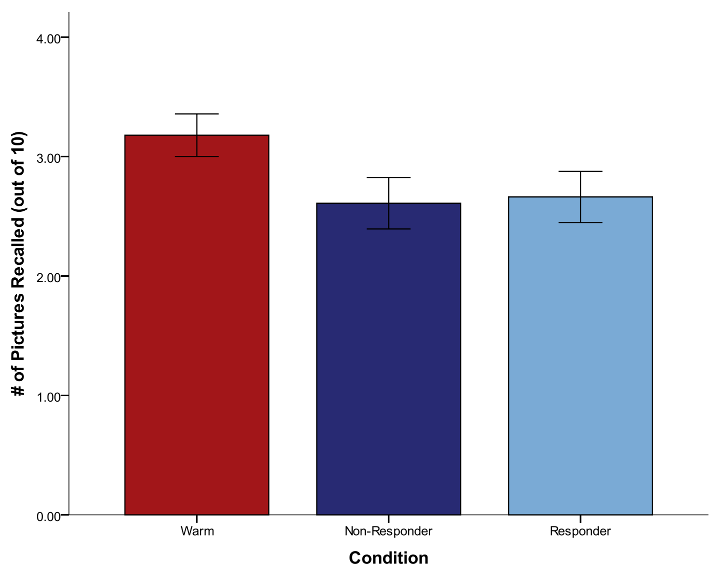


Figure 7. Cortisol as a function of menstrual cycle and oral contraceptive use.

Picture Recall

Recall was analyzed with the factors of picture type (affect), gender, arousal, and extraversion in a normal identity generalized estimating equation. As positive and negative pictures did not differ from each other in recall, they were collapsed into an "arousing" picture category. Extraversion was measured in seven ways—overall extraversion (a combination of the six subscales), and six subscales (activity level, assertiveness, excitement seeking, cheerfulness, friendliness, gregariousness). Gender was also measured in three different ways—men vs. women, menstrual cycle stage, and use of oral contraceptives. Lastly, arousal was conceptualized in two different ways—by condition (ice vs. warm) and by response to stress—warm vs. nonresponders (ice water participants with little or no cortisol response to stress) vs. responders (ice water participants with a cortisol response to stress).

Condition: Those who were not aroused (*M* = 3.13) recalled more pictures than those who had been aroused (*M* = 2.66), Wald $\chi 2$ (1, *N* = 254) = 4.04, *p* = .04, QICC = 751.57. When divided into responders vs. nonresponders vs. warm, there was also a significant effect (Wald $\chi 2$ (1, *N* = 254) = 5.86, *p* = .05, QICC = 750.54). Estimated marginal means revealed that those in the warm water condition (*M* = 3.13) recalled more pictures than those who did not respond to ice water (*M* =2.53, p = .02), but did not differ from those who responded to arousal (*M* = 2.78); responders also did not differ from non-responders (see Figure 8a).



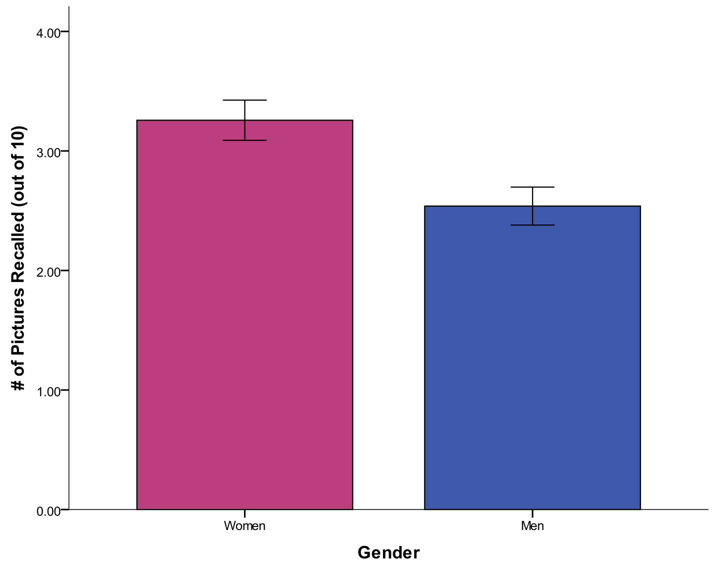


Figure 8. Picture recall as a function of condition and as a function of gender.

Gender: As in study 2, women (*M* = 3.28) recalled more pictures than men (*M* = 2.51), Wald $\chi 2$ (1, *N* = 254) = 10.53, *p* < .01, QICC = 751.57, see Figure 8b. When gender is examined by menstrual cycle, women in the luteal phase (*M* = 3.66) recalled more pictures than men (*M* = 2.51, *p* < .01), those in menses (*M* = 2.85, *p* = .04), and those in the follicular stage (*M* = 2.92, *p* =.08), but did not differ from the follicular/luteal phase (*M* = 3.30): Wald $\chi 2$ (4, *N* = 254) =14.41, *p* <.01, QICC = 723.12; this finding is interesting given that those in the luteal phase actually showed a cortisol decrease, as described above. For oral contraceptive use, there was a significant condition by contraceptive interaction in estimated marginal means, Wald $\chi 2$ (8, *N* = 254) =19.57, *p* =.01, QICC = 748.60, such that for responders, those taking oral contraceptives (*M* = 2.6) and men (*M* = 2.38) recalled fewer pictures than those not taking (*M* = 3.4, *p* = .08, *p* = .02, respectively); in the warm and non-responder conditions, women, regardless of contraceptive use, recalled more pictures than men.

Extraversion: There were no main effects of overall extraversion or the 6 subscales on memory.

Affect: Arousing pictures (*M* = 4.0) were recalled more than neutral pictures (*M* = 1.79), Wald $\chi2$ (1, *N* = 254) = 200.16, *p* <.001, QICC = 751.57.

Interactions: Depending on the measure of extraversion used, interactions with arousal and gender change. In examining activity level (see Figure 9a), marginal means reveal that results are consistent with studies 1 & 2—warm female introverts perform better than all other groups (all *p*'s less than .1); Wald $\chi2$ (11, *N* = 254) = 22.26, *p* = .02, QICC = 690.60. When examining the interaction between arousal, gender, and friendliness (Wald $\chi2$ (11, *N* = 254) = 23.49, *p* = .02, QICC = 681.35) or arousal, gender, and gregariousness (Wald $\chi2$ (11, *N* = 254) = 25.98, *p* <.01, QICC = 696.25; see Figure 9b), however, warm female extraverts perform better than all others except responder female introverts (friendliness: *M* = 4.24, all *p'*s ≤ .03; gregariousness: *M* = 4.1, all *p'*s ≤ .07). Males in the ice water condition (particularly non-responding male introverts and responding male extraverts) consistently demonstrate the worst memory regardless of extraversion measure used.

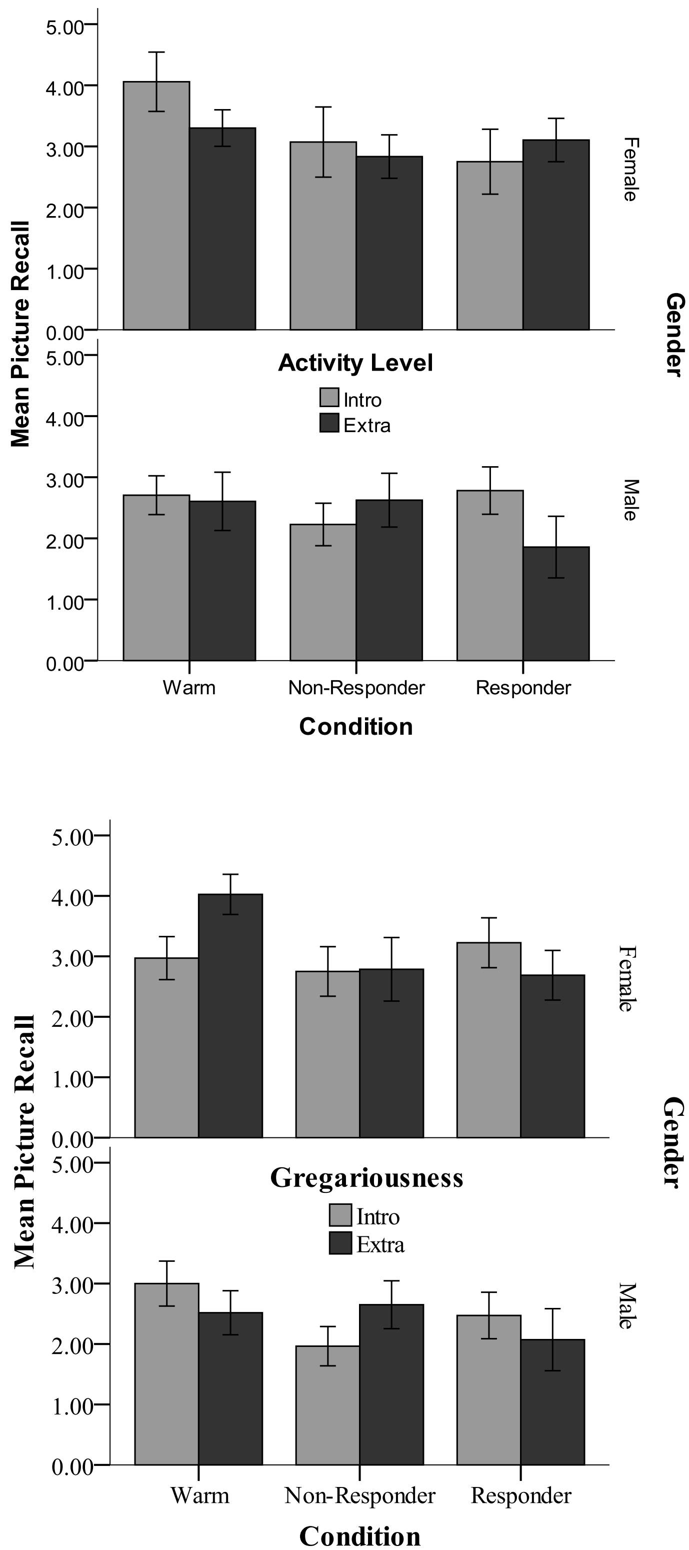


Figure 9. Picture recall as a function of arousal, gender, and extraversion (activity level and gregariousness).

Detail Recall

The measure of details recalled was simply the total of the number of details recalled for each picture. Like picture recall, detail recall was analyzed by condition, gender, affect, and extraversion.

There were no main effects for condition (either ice vs. warm or responders vs. non-responders vs. warm) or gender (either men vs. women, menstrual cycle stage, or oral contraceptive use). There was a main effect for affect, such that arousing details (M = 2.6) were recalled more than neutral details (M = 2.25), Wald $\chi 2$ (1, N = 254) = 11.16, p =.001, QICC = 360.85.

For extraversion, a model with the factors of condition (warm vs. non-responders vs. responders), gender, affect, and activity level revealed a significant main effect of activity level on detail recall, Wald $\chi 2$ (1, N = 254) = 4.67, p =.03, QICC = 324.72. Estimated marginal means showed that extraverts (M = 2.66) recalled more than introverts (M = 2.22). Assertiveness (p = .09) was also a marginal predictor of detail recall, Wald $\chi 2$ (1, N = 254) = 2.8, p =.09, QICC = 325.98, such that those high in assertiveness (M = 2.6) recalled more details than those low in assertiveness (M = 2.26).

There were numerous interactions between arousal and extraversion. As all subscales of extraversion showed similar effects, only the results for overall extraversion (an average of the six subscales) are given here. A model with the factors of condition (warm vs. non-responders vs. responders), gender, affect, and overall extraversion revealed an interaction between arousal and extraversion, Wald $\chi 2$ (2, N = 254) = 11.48, *p* =.003, QICC = 358.27, such that introverts (*M* = 3.8) and extraverts (*M* = 3.68) did not differ in the warm condition, introverts (*M* = 4.05) recalled more details than extraverts (*M* = 2.6, *p* = .001) in the non-responder condition, but extraverts (*M* = 4.35) recalled marginally more than introverts (*M* = 3.27, *p* = .07) in the responder condition (see Figure 10).

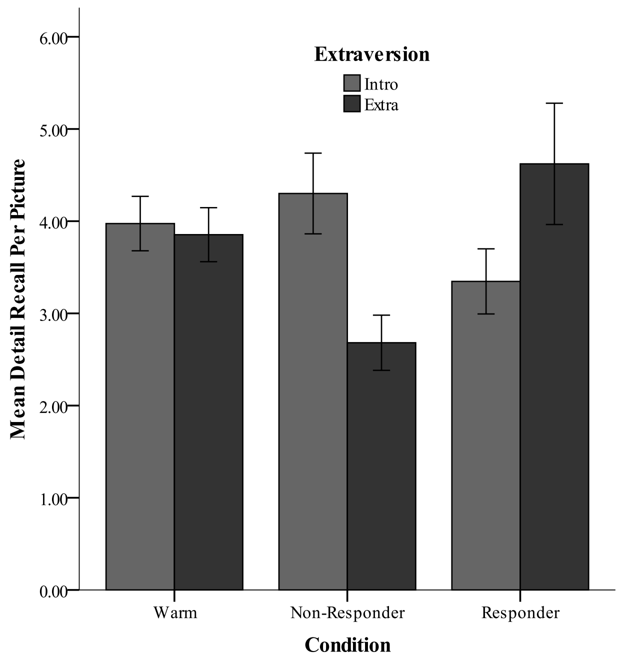


Figure 10. Detail recall as a function of arousal and overall extraversion.

Discussion

Study 3 revealed intriguing results that replicate and extend studies 1 and 2. Study 3 included cortisol collection and the use of pictorial stimuli rather than words as in studies 1 and 2. Main effects consistent with previous studies emerged for condition, where warm water participants recalled more than ice water participants; gender, where women recalled more than men; and affect, where arousing stimuli were recalled more than neutral.. Three way interactions between arousal, gender, and extraversion revealed that the way extraversion is measured may be important—activity level showed interactions similar to studies 1 and 2, wherein warm female introverts recalled the most words. Friendliness and gregariousness, however, showed different effects---that warm female extraverts recalled the most.

While there were fewer effects for detail recall, arousing pictures did result in higher detail recall than neutral pictures. Extraversion interacted similarly for all subscales and overall, such that extravert responders recalled more than introvert responders, but introvert non-responders recalled more than extrovert non-responders.

Cortisol results also proved interesting, and showed that the ice water did indeed arouse participants. Cortisol results also revealed that the recall advantage of the warm water condition over ice water is due to the poor recall of participants in the ice water condition who did not respond with elevated cortisol. Cortisol also revealed that stress affected women in different stages of the menstrual cycle and those taking oral contraceptives differently, findings that are consistent with the literature. It is interesting to note that women in the luteal phase showed a decrease in cortisol in response to stress, yet recalled the most words. A somewhat different pattern emerged for contraceptives, in that those with the least cortisol response to stress (those taking oral contraceptives) recalled the fewest words in the non-responder condition.

Thus, these results continue to suggest that women and men, as well as introverts and extraverts, respond differently to stress. As cortisol was not, however, generally related to memory performance, this suggests that some other factor besides cortisol reactivity may explain arousal, gender, and extraversion effects and interactions.

2.4 Study 4: Ice Water does not Interfere with Post-Encoding Processing

Studies 1, 2, and 3 provided evidence that extraversion and gender modulate the relationship between arousal and memory. Furthermore, those in the non-arousing condition (warm water) continued to recall more stimuli than those in the arousing (ice) condition. It is possible, however, that these findings are due to the ice water condition serving as a source of interference. It is easy to imagine that one could continue to think about the stimuli that were just seen in the warm water condition—the water is a warm, not distracting temperature, and holding one's hand in it does not demand any attention. The cold water, however, is quite uncomfortable, and requires effort and attention to keep one's arm immersed. Therefore, it is possible that those in the warm water condition continue to think about the stimuli, whereas those in the ice water condition are prevented from doing so. Study 4 addressed this possibility by having all participants count the seconds out loud while their arm was in water; this task was chosen to be demanding enough to prevent either group from simultaneously thinking about the previously seen stimuli, but not so demanding as to serve as a distracter from the physical sensation of the water. In addition, both groups were given one minute after seeing the stimuli to rest and think about the stimuli before the CPS task begins.

While study 3 was a close replication of Cahill et al. (2003), there were a few differences. Study 4 was designed to even more closely replicate Cahill et al. by having negative and neutral pictures only (no positive pictures), and by increasing the amount of time participants kept their arm in water to three minutes. Study 4 also involved the collection of salivary samples to measure cortisol at three time points—before stress and 15 minutes after stress, as in study 3, but also 25 minutes after stress, because cortisol responses are typically higher between 20-30 minutes post-arousal (Dickerson & Kemeny, 2004).

If interference with further processing of stimuli in the ice water condition is not the reason for the superior performance of the warm water condition, then the results from study 4 should replicate those from study 3. If, however, holding one's hand in the ice water does interfere with attention to the experimental stimuli, then arousal effects should disappear or even reverse, with the ice water group no longer showing memory impairment compared to the warm water group.

2.4.1 Method

Participants

One hundred and twenty-seven undergraduates volunteered to participate for partial course credit. Table 4 shows the breakdown of men, women, extraverts and introverts in the arousal and control conditions for 126 participants (a woman in the ice condition did not complete personality questionnaires).

Table 4.	**Ice: Aroused**	**Warm: Not Aroused**	Totals
Women Introvert	**13**	**16**	29
Women Extravert	**21**	**18**	39
Women Total	34	34	68
Men Introvert	**18**	**14**	32
Men Extravert	**11**	**15**	26
Men Total	29	29	58
Introvert Total	31	30	61
Extravert Total	32	33	65
Total	63	63	126

Stimuli

Stimuli consisted of 21 pictures (11 neutral, 10 negative; see Appendix A) taken from IAPS (International Affective Picture System; Lang et al., 2005). The pictures were the same as in Study 3.

Procedure

The procedure is the same as in Study 3, except: 1) participants rested for one minute before undergoing the CPS task; 2) the CPS task lasted for 3 minutes; 3) participants were given a stopwatch and instructed to count the seconds out loud while their arm was in water, and 4) cortisol was additionally collected at a third time point, 25 minutes after the CPS task.

2.4.2 Results and Discussion

Results

Cortisol

The saliva samples were sent to the Gierens lab in Germany for analysis, where they were stored at -20 °C until analysis. After thawing, saliva samples were centrifuged at 2000 g for 10 minutes, which resulted in a clear supernatant of low viscosity. 100ul of saliva were used for duplicate analysis. Cortisol levels were determined employing a competitive solid phase time-resolved fluorescence immunoassay with flouromeric end point detection (DELFIA). 96-well-Maxisorb microtiterplates were coated with polyclonal swine anti-rabbit immunoglobulin. After an incubation period of 48h at 4°C plates were washed three times with wash buffer (pH=7.4). In the next step the plates were coated with a rabbit anti-cortisol antibody and incubated for 48h at 4°C. Synthetic saliva mixed with cortisol in a range from 0-100nmol/l served as standards. Standards, controls (saliva pools) and samples were given in duplicate wells. 50µl of biotin-conjugated cortisol was added and after 30min of incubation the non-binding cortisol / biotin-conjugated cortisol was removed by washing (3x). 200µl europium-streptavidin (Perkin Elmerc, Liefe science Turku, Finland) was added to each well and after 30 minutes and 6 times of washing 200µl enhancement solution was added (Pharmacia, Freiburg, Germany). Within 15 minutes on a shaker the enhancement solution induced the fluorescence which can be detected with a DELFIA-Fluorometer (Wallac, Turku, Finland). With a computer-controlled program a standard curve was generated and the cortisol concentration of the samples was calculated. The intra-assay coefficient of variation was between 4.0% and 6.7%, and the corresponding inter-assay coefficients of variation were between 7.1% -9.0%.

The samples of seven participants were not able to be assayed due to insufficient saliva. There was no difference between the ice water (*M* = 4.34 nmol/L) and warm water (*M* = 4.73) groups in baseline cortisol, but the increase in cortisol 15 minutes after the CPS task was significantly higher in the ice water group (*M* = 2.95) compared to the warm water group (*M* = -.37) 15 minutes after the CPS task, $t\ (117) = 4.86$, $p < .001$. The ice (*M* = 4.21) and warm (*M* = -.66) water groups also showed large differences in cortisol change 25 minutes after the CPS task, $t\ (118) = 4.48$, $p < .001$. As cortisol differences were most pronounced at 25 minutes, the difference between baseline and 15 minutes after stress will not be further discussed. As in study 3, about half of the ice water participants did not show a cortisol response to stress. Dividing the ice water group by a median split into non-responders (ice water participants with little or no cortisol response to stress) and responders (ice water participants with a cortisol response to stress) also resulted in a significant effect of condition, $F\ (2, 117) = 46.56$, $p <.001$, such that the non-responders actually showed a decrease in cortisol in response to stress (*M* = -.64) and did not differ significantly from the warm (*M* = -.66) group; the responders, however (*M* = 9.06) showed a change in cortisol significantly greater than both warm and non-responders (*p*'s < .001, see Figure 11).

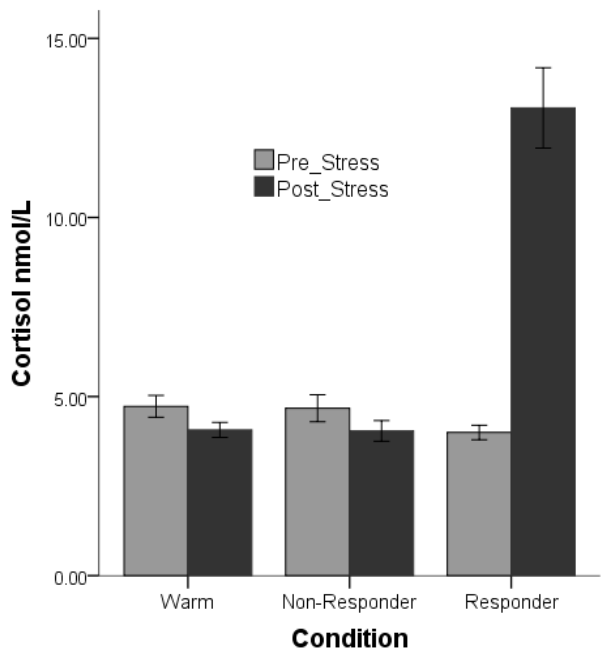
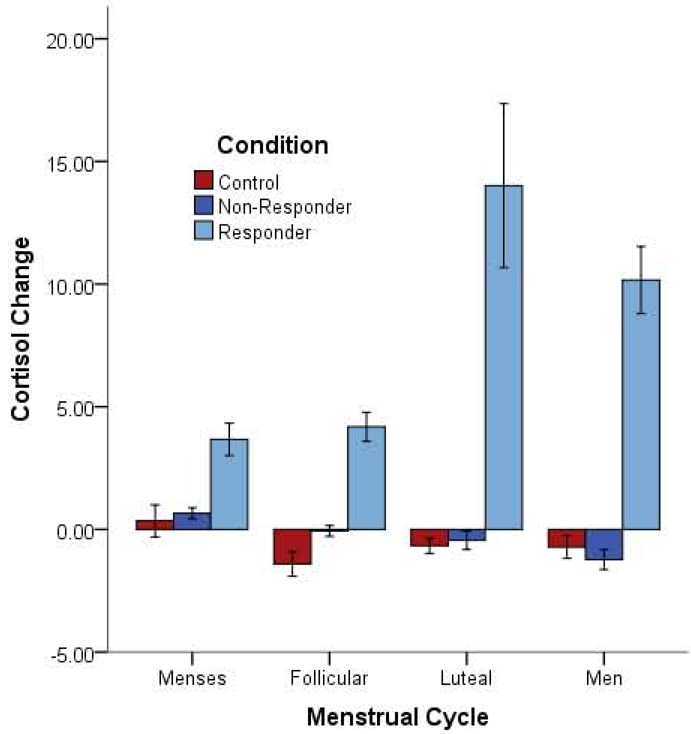


Figure 11. Cortisol as a function of arousal and time.

As in study 3, cortisol did not differ at baseline or after stress as a function of gender or extraversion. However, menstrual cycle stage was again a marginal predictor of the change in cortisol from baseline to post-stress, F (3, 117) = 2.12, p = .1; post-hoc tests revealed that women in the luteal phase increased more in cortisol (M = .43) than women in the follicular stage (M = .90, p = .02), whereas men (M = 2.74) and women in menses (M = 1.56) did not differ (see Figure 12a). Oral contraceptive use interacted marginally with condition, F (4, 119) = 1.76, p = .14; post-hoc tests revealed that while warm and non-responders did not differ, for responders, those who were taking oral contraceptives had the lowest cortisol response (M = 3.93; taking = 9.92, men = 10.16) to ice water (see Figure 12b).



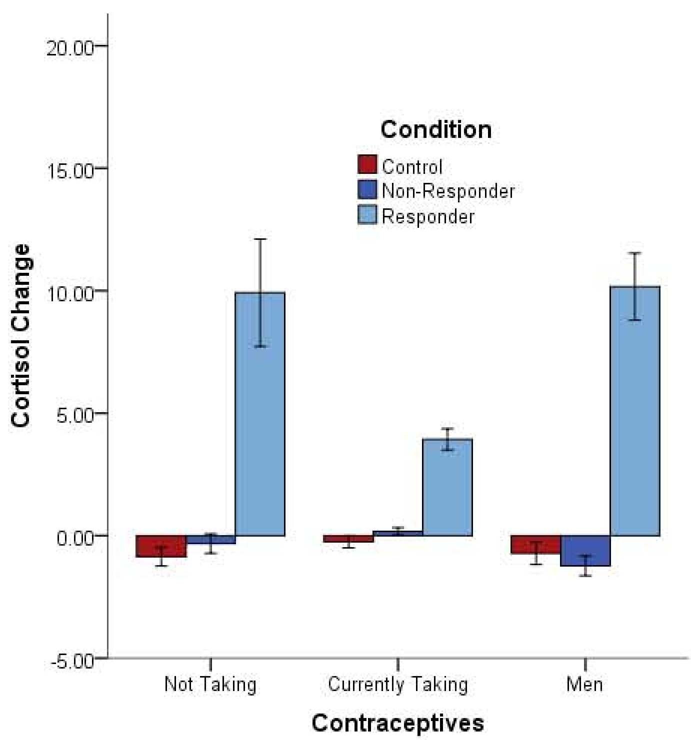


Figure 12. Cortisol as a function of menstrual cycle and oral contraceptive use.

Picture Recall

Recall was analyzed with the factors of picture type (affect), gender, arousal, and extraversion in a normal identity generalized estimating equation. As in Study 3, the extraversion was measured in one of seven ways—overall extraversion (a combination of the six subscales), and six subscales (activity level, assertiveness, excitement seeking, cheerfulness, friendliness, gregariousness), and gender was also measured in 3 different ways—men vs. women, menstrual cycle stage, and use of oral contraceptives. Lastly, arousal was conceptualized in two different ways—by condition (ice vs. warm) and by response to stress—warm vs. nonresponders (ice water participants with little or no cortisol response to stress) vs. responders (ice water participants with a cortisol response to stress).

Condition: Those who were not aroused (M = 4.06) recalled more pictures than those who had been aroused (M = 3.64), Wald $\chi 2$ (1, N = 254) = 4.04, p = .068, QICC = 618.67. When divided into responders vs. nonresponders vs. warm, there was also a significant effect (Wald $\chi 2$ (2, N = 254) = 5.12, p = .077, QICC = 610.20). Estimated marginal means revealed that those in the warm water condition (M = 4.06) recalled more pictures than those who did not respond to ice water (M =3.45, p = .02), but did not differ from those who responded to arousal (M = 3.85). Responders did not differ from non-responders (see Figure 13a).

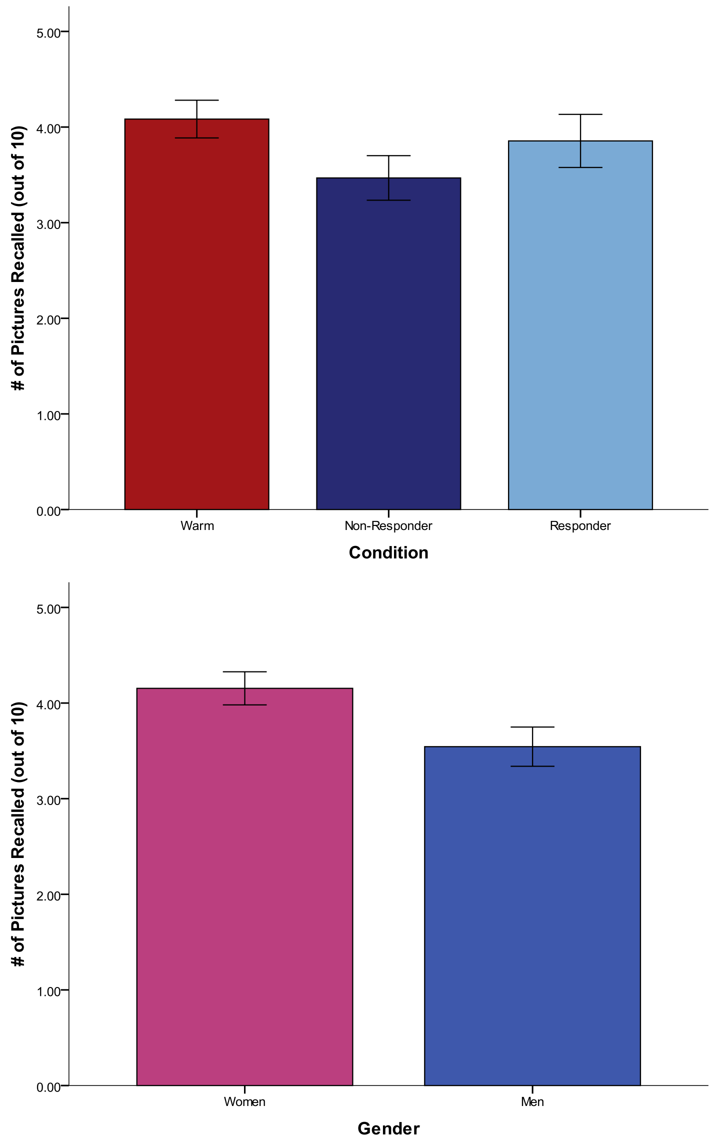


Figure 13. Picture recall as a function of condition and as a function of gender.

Gender: As in study 2 and 3, women (*M* = 4.16) recalled more pictures than men (*M* = 3.55). Wald $\chi 2$ (1, *N* = 254) = 7.01, *p* < .01, QICC = 618.67 (see Figure 13b). Menstrual phase did not affect picture recall. There was a significant oral contraceptives by condition interaction, Wald $\chi 2$ (8, *N* = 254) = 25.70, *p* =.001, QICC = 605.30. Those not taking oral contraceptives (4.7) recalled more than both men (3.75, *p <.01*) and those taking oral contraceptives (3.88, *p* = .09) in the warm condition; no difference was found for responders, and women not taking oral contraceptives (*M* = 4.06) recalled more than men (*M* = 3.0, *p* = .03) for non-responders.

Extraversion: Those low in cheerfulness (*M* = 4.14) recalled more pictures than those high in cheerfulness (*M* = 3.60); Wald $\chi 2$ (1, *N* = 254) = 5.22, *p* =.02, QICC = 609.26.

Affect: Negative (*M* = 5.18) pictures were recalled more than neutral (*M* = 2.53), Wald $\chi 2$ (1, *N* = 254) = 247.12, *p* <.001, QICC = 618.67.

Interactions: Depending on the measure of extraversion used, condition and gender interact in different ways. Assertiveness showed a notable but nonsignificant tendency (Wald $\chi 2$ (7, *N* = 254) = 142.99, *p* =.11, QICC = 609.84) for warm introvert (low in assertiveness) women to recall the most words. This tendency was also seen in studies 1 and 2. However, while many interactions between arousal, gender, and the seven different measures of extraversion were significant, these interactions were not consistent and did not show any particular pattern (see Figure 14a and 14b for assertiveness and gregariousness).

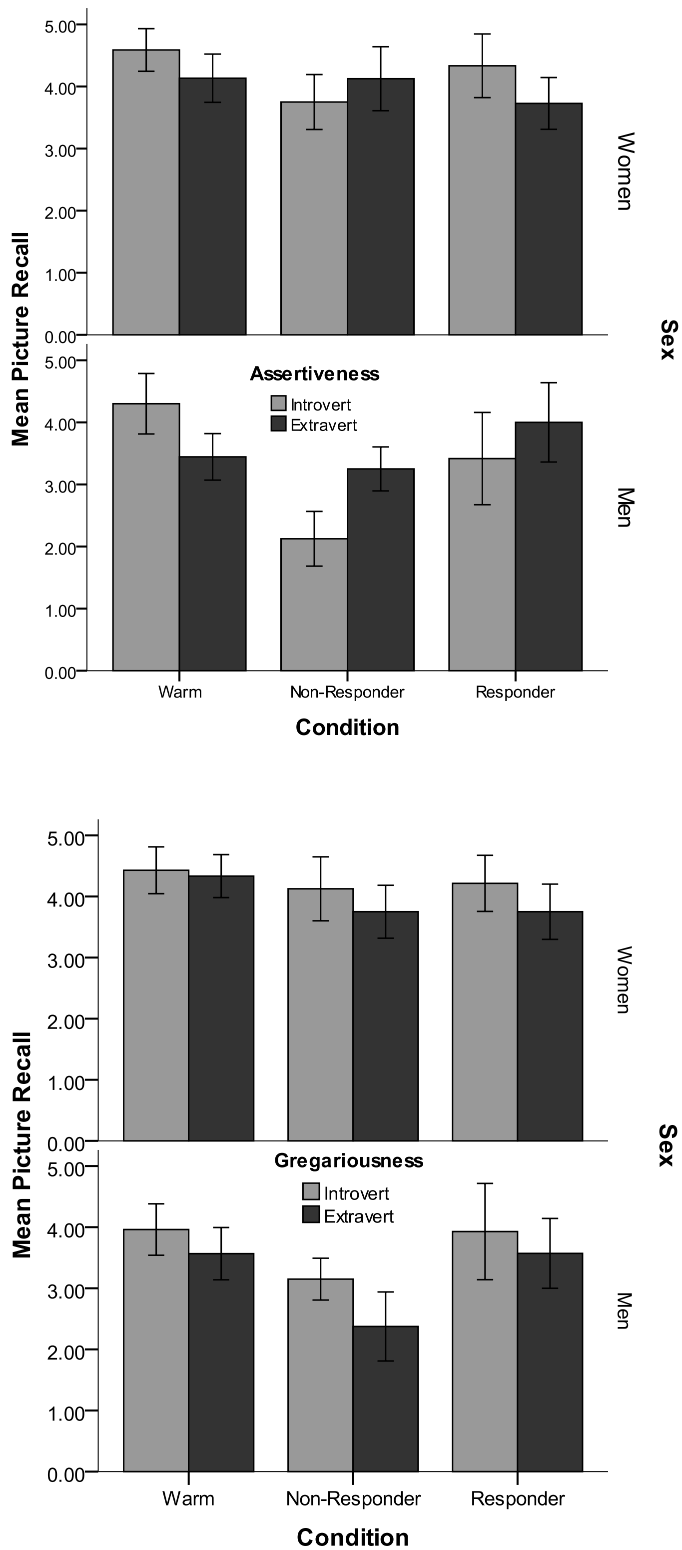


Figure 14. Picture recall as a function of arousal, gender, and extraversion (assertiveness and gregariousness).

Detail Recall

Detail recall was calculated as in study 3. Condition was a significant predictor of detail recall, Wald $\chi 2$ (2, *N* = 254) = 8.99, *p* =.01, QICC = 473.7, such that warm (*M* = 2.76) and responders (*M* = 3.15) recalled more details than non-responders (*M* = 2.33, *p* = .04 and .006, respectively) but did not differ from each other. Women (*M* = 2.98) also recalled more details than men (*M* = 2.51), Wald $\chi 2$ (1, *N* = 254) = 4.35, *p* =.04, QICC = 473.7. An analysis with condition, menstrual cycle, and affect revealed that menstrual cycle was also a significant predictor of detail recall, Wald $\chi 2$ (3, *N* = 254) = 10.83, *p* =.01, QICC = 401.6, such that women in the follicular stage (*M* = 3.5) recalled more than women in menses (*M = 2.5*, p = .002), marginally more than women in the luteal phase (*M* = 3.03, *p* = .12), and more than men (*p* = .02). Oral contraceptive use was not a predictor of detail recall. There was a main effect for affect, such that negative details (*M* = 3.19) were recalled more than neutral details (*M* = 2.3), Wald $\chi 2$ (1, *N* = 254) = 44.33, *p* <.001, QICC = 473.7.

There were numerous interactions between arousal, extraversion, and gender. Arousal and gender interacted, Wald $\chi 2$ (2, *N* = 254) = 9.12, *p* =.01, QICC = 473.7, such that women non-responders (*M* = 2.93) recalled more than men non-responders (*M* = 1.72, *p* < .001), but there was no difference between women and men in either the warm (*M* = 2.75, 2.77) or responder (*M* = 3.25, 3.05) conditions.

Arousal and extraversion interacted in the same way for assertiveness, friendliness, gregariousness, and overall. As many measures were similar, only overall extraversion is reported here; in a model with condition (warm vs. responders vs.

nonresponders) and gender, estimated marginal means revealed that extraversion and condition interacted, Wald $\chi2$ (5, N = 254) = 19.59, p =.001, QICC = 472.98, such that non-responding extraverts (M = 1.99) recalled less than any other group (all p's < .07).

Similarly, the three way interaction between extraversion, arousal, and gender was similar for all measures of extraversion, and was significant for all except assertiveness. Therefore, overall extraversion is reported, Wald $\chi2$ (11, *N* = 254) = 38.69, *p* < 0.001, QICC = 473.7 (see Figure 15). Estimated marginal means showed that women did not differ significantly from each other, except for a tendency for responder extraverts to recall more. For men, however, the warm and responder conditions recalled more than non-responders, and this effect was stronger for extraverts than introverts.

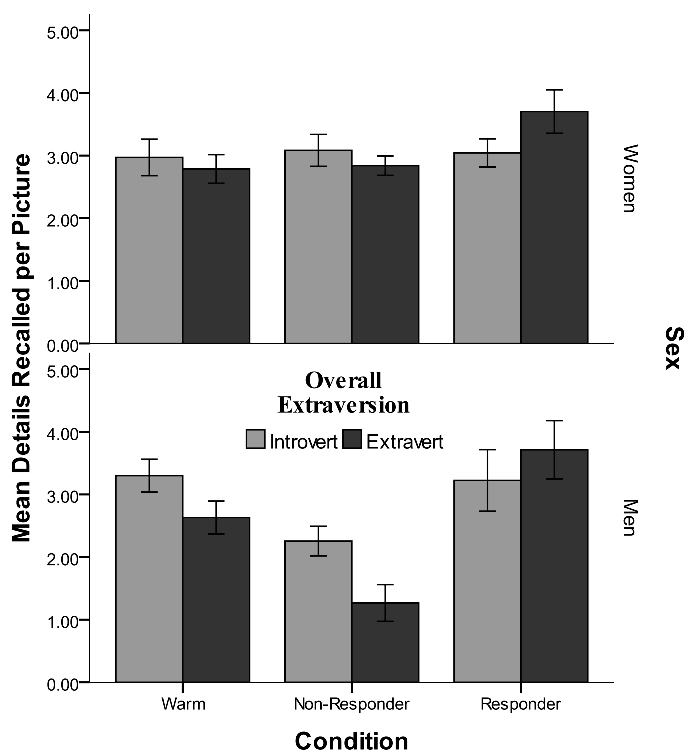


Figure 15. Detail recall as a function of arousal, gender, and overall extraversion.

Discussion

Study 4 suggested that the consistent finding of the non-aroused group performing better than the aroused group is not due to interference. Despite both groups being prevented from thinking about the pictures while immersed in water, the warm group continued to recall more stimuli than the ice water group. As in study 3, this difference between ice and warm was due to poor recall among those in the ice water group for whom the arousal manipulation did not produce an increase in cortisol. As in previous studies, women recalled more than men. Cortisol analyses revealed that, consistent with the literature, those in the luteal phase of the menstrual cycle and those taking oral contraceptives showed the least reactivity to arousal. Menstrual cycle and oral contraceptive use, however, had only minimal effects on memory. Also as in study 3, interactions with arousal, gender, and extraversion revealed that extraversion effects differ depending on which measure is used.

Detail recall showed similar main effects of condition, gender, and affect. Interactions between arousal, gender, and extraversion were similar for all measures of extraversion.

2.5 Additional Analyses from Studies 3 and 4

Despite near methodological replication of Cahill et al. (2003), I continued to find opposite effects—that the non-aroused condition recalled more than the aroused condition. An important clue to this difference may lie in baseline cortisol scores. In

Cahill et al. (2003), participants entered the study with cortisol around 9.6 nmol/l[2], and the arousal group increased to around 11.73, whereas the control dropped to around 7.7. In the current study 3, however, participants entered the study with an average cortisol of 5.71, and the ice group increased to 7.55 and the warm did not change (5.89). In study 4, participants entered with an average cortisol of 4.52, and increased to 8.55 in the ice group and decreased to 4.04 in the warm group (see Table 5). It is apparent that, while cortisol did increase significantly in response to arousal, baseline scores were very low compared to Cahill; in fact, cortisol scores in response to stress (7.55 and 8.55) did not even reach the baseline cortisol scores of Cahill et al. (9.6). It is possible, therefore, that opposite findings in regards to arousal are due to very different baseline (and thus also post-stress) cortisol.

Table 5.	**Pre Stress**	**Post Stress Warm**	**Post Stress Ice**
Cahill et al	9.6	7.7	11.73
Study 3	5.71	5.89	7.55
Study 4	4.52	4.04	8.55

To examine this possibility, I analyzed the top 30% of baseline cortisol scores in experiment 3 to get baseline cortisol scores (M = 10.1) similar to those (9.6) of Cahill et al (2003). With those who had comparable baseline scores, I then ran a new analysis on picture recall with the factors of condition, gender, and picture type. There were 41

[2] Exact cortisol means from Cahill et al. (2003) are not published and are presented as ng/ml; the means given in this table are approximated from Figure 2 in Cahill et al. (2003) and converted to nmol/l.

participants, 24 of whom were in the warm condition, and 17 of whom were in the ice (10 non-responders, and 7 responders). With only 41 participants, there were no significant differences between conditions. However, the trend for the warm group to recall more words still existed—the mean for warm (*M* = 3.25) was higher than for ice (2.95). Similarly, in experiment 4, to get a baseline cortisol group comparable to Cahill, I analyzed the top 18%, with an average baseline cortisol of 9.38. There were 23 participants, 12 of whom were in the warm condition, and 11 of whom were in the ice (8 non-responders, and 3 responders). Despite only 23 participants, there was a marginal effect of condition (Wald $\chi 2$ (1, N = 46) = 3.54, p = .06, QICC = 100.29, such that the warm group (*M* = 4.13) recalled more than the ice group (*M* = 3.4).

Lastly, it is interesting to note that the differences between these results and Cahill et al. (2003) is not due entirely to the poor performance of the ice water group, but was also due to the good performance of the warm water group (see table 6 for percent recall for each condition across studies). As recall in study 3 is generally lower, due to the fact that there were more pictures to recall (30 pictures total: 10 negative, 10 neutral, 10 positive) compared to Cahill et al. and Study 4 (20 pictures), it is not included in the table. It is apparent that the differences in recall between these studies and Cahill are not due to poor performance of the responders—responders in study 4 are comparable to Cahill et al.'s ice group. Rather, it seems that performance of the warm water group is much higher in study 4 than in Cahill et al.

Table 6.	**Cahill**[3]		**Study 4**	
	Negative	*Neutral*	*Negative*	*Neutral*
Warm	42	35	54	28
Ice	57	35	50	23
Responder			54	24
Non-Responder			46	23

Chapter 3

3.1 Summary of Studies

Those in the warm condition consistently recalled more stimuli than those in the ice water condition across multiple experiments. Both self report (experiments 1 and 2) and cortisol (experiments 3 and 4) indicated that the ice water manipulation was successful in inducing arousal. When cortisol was collected, those results revealed that the memory deficit in the ice water condition is mostly driven by those who were in the ice water condition but did not respond with a cortisol increase to stress. Those who were in the ice water condition but did have a cortisol response to stress did not differ from the warm water condition. In study 4, memory for details also showed that the non-responder group recalled the least. Thus, ice water is detrimental to memory only when it does not result in cortisol increases. These findings are different than typical findings in the literature, as described in the introduction. Study 4 revealed that these differences are

[3] Exact recall means from Cahill et al. (2003) are not published; the means given in this table are approximated from Figure 2 in Cahill et al. (2003).

not due to the ice water interfering with opportunity to think about or rehearse the stimuli.

In addition, women consistently recalled more stimuli than men, and also recalled more details than men in study 4. Menstrual cycle and oral contraceptives may play a role in memory. Those taking oral contraceptives have decreased response to stress compared to men and compared to those not taking oral contraceptives; this decreased response to stress was accompanied by a decreased recall in the warm condition in study 4 and responder condition in study 3. As for menstrual cycle, those in the luteal phase had the largest decrease in response to stress and also recalled more stimuli in study 3; in study 4, those in the luteal phase had an increase in response to stress, but memory was not significantly different. Thus, it appears that decreased cortisol response to stress due to the luteal menstrual phase may be linked to better memory, and decreased response to stress for those taking oral contraceptives is linked to worse memory.

Another consistent finding is that arousing words and pictures and the details of arousing pictures were recalled more than neutral words and pictures and picture details. Extraversion results, however, are a little less clear. In study 1 and 2, women who were non-aroused introverts demonstrated enhanced memory (as did the other group expected to have moderate levels of arousal, aroused extraverts, in study 1). Men demonstrate the opposite pattern as women in study 2 (there were no men in study 1). In studies 3 and 4, however, some measures of extraversion—activity level in study 3, assertiveness in study 4—followed the same pattern for women in studies 1 and 2 (female non-aroused introverts performed the best). Other extraversion measures in studies 3 and 4 (gregariousness, friendliness, cheerfulness), however, demonstrated that female non-aroused extraverts performed the best. With regard to memory for details, non-responding extraverts consistently demonstrated poor recall in study 3 and 4; however, responder extraverts recalled more details than responder introverts in study 3. Thus, extraversion likely does modulate the effect of arousal on memory, particularly when gender is taken into account, but the direction of this effect depends on the measure of extraversion.

3.2 Why Women Recall more than Men

Women consistently recalled more than men in these studies. There were no arousal by gender interactions (i.e., arousal was not more beneficial for women or men overall). While some studies have shown that arousal is more beneficial for women (i.e., Canli et al., 2002), others have shown it to be more beneficial for men (Andreano & Cahill, 2006; Jackson Payne, Nadel, & Jacobs, 2006; see Andreano & Cahill, 2009, for a review). Still others have found no interaction between arousal and gender (Liu et al., 2008; Elzinga & Roelofs, 2005). There were, however, interesting interactions between condition and menstrual cycle and condition and use of oral contraceptives.

3.2.1 Oral Contraceptives, Cortisol, and Memory

In both study 3 and study 4, women who were taking oral contraceptives showed a decreased cortisol response to the ice water. This finding is supported by research in this area, which shows that oral contraceptives cause low levels of estradiol and progesterone (Likis, 2002). High levels of these hormones have been linked to reduced feedback sensitivity in the HPA axis, meaning that more cortisol must be released and bind to receptors in the hypothalamus before HPA axis activity stops (Kirschbaum et al., 1999). The low levels of estradiol and progesterone found with use of oral contraceptives, then, result in higher feedback sensitivity and thus lower cortisol response, as less cortisol must be released and bind to receptors to stop HPA axis activity (Kuhlmann & Wolf, 2005).

In addition to reducing cortisol reactivity, oral contraceptive use also influenced memory. In study 3, women who were not taking oral contraceptives recalled more than those who were taking oral contraceptives in the responder condition; in study 4, the same effect was found, but for the warm condition. Although studies of contraceptive use and memory are rare, Kuhlman & Wolf (2005) found a similar marginally significant effect for those taking oral contraceptives who did not receive cortisol (non-aroused) to show lower memory. Wright & Badia (1999), however, found no effects of oral contraceptive use on memory. Thus, there may be a memory impairing effect for those taking oral contraceptives, but this possibility needs further research. There may be other differences among college women who are or are not taking contraceptives that could account for these effects. For example, non-sexually active women may be more conscientious or more studious.

3.2.2 Menstrual Cycle, Cortisol, and Memory

The results from cortisol reactivity and menstrual cycle are a little less clear. In menses, estradiol and progesterone are high, whereas levels of these hormones are low in the luteal phase (Kirschbaum et al., 1999). This typically results in reduced cortisol reactivity for menses (and often the follicular phase), but enhanced reactivity in the luteal phase. In addition, while cortisol reactivity does not differ between men and women in physical stress (exercise), most studies of psychological stress find either that men and women do not differ or that men have more significant cortisol responses than women (Kudielka & Kirschbaum, 2005). In one study, ACTH and free cortisol increases in men were twice as high in response to stress as in women (Kirschbaum, Wust, & Hellhammer, 1992). Thus, women in the luteal phase often have comparable responses to men, but women in other stages have lower cortisol responses.

While I did find the cortisol reactivity of women in the luteal stage to be comparable to that of men, and for both to have more reactivity than women in menses or the follicular stage, I did not find this effect in study 3. In fact, in study 3, I found women in the follicular stage to be the most reactive and comparable to men, and non-responding women in the luteal phase actually showed a cortisol decrease in response to stress. One possible explanation for this surprising finding in study 3 is the way in which menstrual cycle was calculated. Women were asked to report the date of their last period, and also how long their cycle typically lasts. Many women, however, either did not answer the question about cycle length, or responded with numbers (e.g., “4-5”) that seemed to indicate they misinterpreted the question to be about length of menstruation rather than overall cycle length. Thus, menstrual cycle was computed using a chart for unknown cycle length provided by Sally Dickerson, an expert in the field (2009, personal communication; see Appendix D). When cycle length is unknown, women who have been 12-21 days from the start of their last menstruation are considered to be in a follicular/luteal phase. Thus, the assignment of women to various stages of the menstrual cycle was not as precise in study 3. In study 4, however, the question about average cycle length was reworded and explained in more detail to participants, and most participants gave answers (e.g., “28”, “33”) that indicated they understood the question. Thus, menstrual cycle stage was able to be more accurately computed in study 4, which may explain why results are more in line with the literature.

As far as memory is concerned, menstrual cycle predicted memory only in study 3, where women in the luteal phase recalled the most pictures. Others (Schoofs & Wolf, 2009) have hypothesized but not found stronger effects of arousal in the luteal phase, while most (e.g., Kuhlmann & Wolf, 2005) find no effect of menstrual stage on memory. Given that menstrual stage was more difficult to define in study 3, the data do not allow definitive conclusions about the role of menstrual cycle in memory.

3.2.3 Verbal vs. Spatial Memory

That men tend to perform better than women in tests of spatial memory is a well-established finding in the literature (Macoby and Jacklin, 1974; Dabbs Jr. et al., 1998; Epting & Overman, 1998; Driscoll, Hamilton, Yeo, Brooks & Sutherland, 2005; see Linn & Petersen, 1985 and Voyer, Voyer, & Bryden, 1995 for metaanalyses), but women tend to perform better than men in tests of verbal memory (Macoby & Jacklin, 1974; Kimura, 1996; Mann, Sasanuma, Sakuma, & Masaki, 1990; Capitani, Laicona, & Basso, 1998; Thilers, MacDonald, & Hurlitz, 2007; Hyde and Linn, 1988; Bolla, Gray, Resnick, Galante, & Kawas, 1998; Capitani, Laicona, & Barbarotto, 1999), and particularly word list recall (Kail Jr. & Siegel 1978; Kimura and Seal, 2003). Thus, it is not surprising that women recalled more words then men in study 2, given the robust findings of superior verbal memory. In study 3 and 4, however, the stimuli were not words, but pictures. Again, however, women may have had an advantage, as the procedure asked participants to generate a name or short phrase for each picture, and then to recall that name.

3.3 Why Arousing Stimuli are Recalled more than Neutral

A memory benefit for arousing or valenced material over neutral material is a well-established, robust finding across many different types of stimuli (see Buchanan & Adolphs, 2002, and Hamann, 2001, for reviews). Many studies have shown that the memory benefit for emotional material is likely due to increased distinctiveness of or increased attention to emotional material. Thus, the findings in studies 2-4 that arousing material was recalled more than neutral material is consistent with a vast body of prior research. Superior recall for neutral material in immediate recall in study 1, while it may at first seem surprising, directly replicates other findings using DRM word lists (Palmer & Dodson, 2009), and has been attributed to a focus on more item-specific instead of relational processing for emotional items.

There was not, however, an interaction of arousal with arousing stimuli, which was surprising given that most studies find that arousal has more of an effect for arousing items. However, if arousal was not actually associated with or attributed to the stimuli, but instead associated only with the arousal task (a possibility discussed below), then there would be no reason to expect that arousal would influence arousing items more than neutral.

3.4 Why Non-Aroused Participants Recall more than Aroused

Non-aroused participants consistently recalled more than aroused participants, a difference that was especially robust for non-responders in studies 3 and 4. The effect appears to be driven by especially good performance in the control (warm water) condition, and poor performance in the non-responders. These results are different than the established finding in the literature (see Chapter 1 above), but the consistent findings in these studies only further support the point that arousal does not have the same effect on memory for all—individual differences or situational differences between laboratories may result in vastly different findings. These results, consistent as they are, do not necessarily indicate that all of the published literature is wrong. However, as the literature is dominated by findings of arousal enhancing memory, there may be a significant "file-drawer" problem wherein findings similar to these, of an arousal detriment to consolidation, are not published. A few possible reasons for these effects are discussed below.

3.4.1 Low Baseline Cortisol

One possible explanation for conflicting findings is that, while those in the ice water condition did show an increase in cortisol in response to stress comparable to other studies, baseline measures of cortisol were considerably lower. For instance, participants in studies 3 and 4 came in to the lab (pre-stress) with cortisol levels considerably lower than in others studies. As the proportional increase in cortisol in response to stress is equivalent to other studies, however, it can be concluded that the arousal manipulation was effective. Analyses addressing this possibility are given at the end of Chapter 2. In both study 3 and 4, analyzing memory by condition for the top 30% (study 3) and 18%

(study 4) of baseline cortisol scores comparable to Cahill et al. (2003) revealed the same pattern as the entire sample—the non-aroused condition recalled more than the aroused. Despite the low power, this effect was marginally significant in study 4. This finding indicates that low baseline cortisol does not account for the superior performance of the non-aroused condition.

3.4.2 Relaxation Improves Memory

Some researchers have found that mental relaxation improves memory (Nava et al., 2004). It is conceivable that the warm water condition used in these studies, which involves placing an arm in bath water-like temperature, also produced relaxation, leading to a memory benefit for those in the warm condition. However, two sources of evidence make this conclusion unlikely. First, cortisol did not decrease in response to the warm water condition for studies 3 and 4 nearly as much as it did in Cahill et al. (2003); thus, there is no evidence to conclude that participants in these studies were any more relaxed than in other studies. Second, studies in which cortisol did decrease in warm water—a sign of possible relaxation—do not find a memory benefit for those in the warm water.

3.4.3 Distribution of Extraversion and Gender

Given that these studies have demonstrated the importance of individual differences in considering the effect of arousal and memory, and the fact that the warm female introverts consistently demonstrate superior memory, it is possible that differing distributions of men, women, introverts, and extraverts in various conditions may drive the effect. However, as Tables 2, 3, and 4 show, the distributions are roughly similar across conditions, and across experiments. It is also the case that no particular group was more likely to be a responder or a nonresponder (see Table 7).

Table 7		**Introverts**	**Extraverts**
Non-Responders (Study 3)	**Women**	9	7
	Men	9	7
Responders (Study 3)	**Women**	9	6
	Men	9	6
Non-Responders (Study 4)	**Women**	6	10
	Men	9	5
Responders (Study 4)	**Women**	6	11
	Men	8	6

3.4.4 Interference from Arousal

Study 4 was designed to get at the possibility that the ice water, by nature of being distracting, prevents further processing of stimuli while the warm water allows further processing. Results showed no evidence to support this possibility. Despite the fact that both groups were prevented from thinking about the stimuli during the arm immersion task, the warm water group continued to recall more than the ice water group.

3.4.5 Pleasant Arousal in Warm Condition

As mentioned previously, the warm water was at a very pleasant temperature. It is possible that the sensation of placing an arm in bath-water-like temperature is actually pleasurably arousing—it feels good. If this is the case, then we would not expect the warm water group to increase in cortisol in response to the water, but they would still be experiencing arousal. Thus, the experimental groups would actually be a positive arousal versus a negative arousal group. If the warm water participants were indeed aroused, it might explain their superior performance in comparison with the non-responders (whose cortisol responses show no evidence of arousal), and the lack of difference from responders (who are negatively aroused).

To examine this possibility, 15 participants were asked to place their arm in warm water for 3 minutes, and then to rate their happiness, how pleasant the water was, how positive the water was, how stimulating/exciting, and how arousing the water was. For ratings of happiness, participants gave an average answer of 4.1 on a 1 to 7 scale, which equated to “neither happy nor unhappy”. For ratings of pleasantness, participants also had an average of 4.1, which equated to “neither pleasant nor unpleasant”. For ratings of positivity, participants gave an average of 4.4, which was between “neither positive nor negative” and “a little positive”. Stimulating/exciting ratings averaged 2.8, which was equivalent to “a little calm/relaxed”, and arousal ratings averaged 3.5, which was between “a little unaroused” and “neither aroused nor unaroused”.

Thus, the warm water appears to be an ideal control condition, as it induces neither strong positive nor negative mood/affect, and is not arousing. As the warm water is not pleasurably arousing, arousal cannot account for better memory in the control condition.

3.4.6 Warm Female Introverts

In all experiments, female introverts in the warm water condition consistently recalled more stimuli. Thus, there may be something about female introverts that leads to superior performance in an non-aroused condition. As mentioned previously, the data fits an inverted-U-shaped curve, wherein introverts (who are more reactive to stress) should perform better at a medium level of arousal. Thus, warm introverts would be expected to perform well. Why warm male introverts do not show this pattern in addition to female introverts is unknown. Thus, the combination of extraversion and gender is shown to be an important moderator of memory, but the reasons that only women show this effect are unclear.

3.4.7 Attribution

Studies of mood and cognition have shown that when people are made aware of the source of their mood, typical effects disappear or often reverse. For instance, Schwarz & Clore (1983) called participants on either a warm and sunny or a cold and rainy spring day. They asked participants to indicate their life satisfaction; first, however, half of the participants were asked about the weather. Those who had first been asked about the weather (i.e., been made aware of the source of their mood) showed no effects of mood on life satisfaction. In contrast, judgments of life satisfaction were affected by the weather for those who had not been asked about the weather (for whom the source of their mood was not made salient).

Such reversal of effects have been shown to occur in judgments about culpability for bankruptcy (Kadous, 2001); while juror distress related to the bankruptcy positively predicted judgments of liability, those jurors who had first been asked to rate anxiety about being a juror were less likely to deliver a guilty verdict, presumably because their distress was attributed to anxiety from being a juror rather than to distress about the bankruptcy. Attribution effects also occur in processing; Gasper (2004) showed that when participants are made aware of the true cause of their mood, the mood no longer results in typical local (for sad mood) and global (happy mood) processing. Hence, induced moods affect judgment and processing when the true source of the mood is not salient. Asking participants how the mood manipulation made them feel or otherwise calling attention to the true source of their feelings, so that participants attribute them accurately to the mood manipulation, generally eliminates mood effects. Similarly, anything that psychologically separates the mood induction experience from the presentation of the experimental materials is likely to eliminate any effects of mood.

This attribution account appears to be a plausible explanation for the surprising results of these studies. The most well known studies demonstrating such attribution effects on arousal come from Zillman and colleagues (Cantor, Bryant, & Zillman, 1974; 1975). These early studies of arousal attribution predate the later work on affect attribution and show that attribution of arousal to a source works in the same way as attribution of mood to a source. In the current studies, while the arousal manipulation and the learning procedure occurred very close in time, it is possible that participants attributed the arousal they felt to the arousal manipulation. The reason is that space limitations (i.e., very small testing rooms) made it so that participants had to exit the room after viewing the stimuli and enter a different room to immerse their arm in water. In Cahill et al. (2003), participants were able to stay in the same room. Standing up and moving to a different room seems likely to have made the arousal manipulation stand out as a distinct and separate procedure from the stimulus viewing. Thus, it seems quite possible that participants may have experienced their arousal as associated with the ice water rather than with the stimuli they had just seen. If this is the case, then as in the mood literature, we could expect to see exactly what occurred—a reversal of typical arousal findings.

Future studies will examine this possibility by creating an attribution and a misattribution condition. In an attribution condition, participants will be asked about the source of their arousal and how the arousal manipulation made them feel, and will receive instructions that make the arousal manipulation appear to be a different task than the stimuli. In the misattribution condition, however, participants will not be asked about the arousal or how it made them feel, and will experience the arousal manipulation immediately after viewing stimuli with instructions that make the arousal manipulation seem connected with rather than separate from the stimuli they would later be asked to recall. If attributing the arousal to the manipulation does reverse effects, then we would expect this attribution group to show similar results to studies 1-4: poor performance for those who were aroused compared to those who were not aroused. Those in the misattribution condition, where the arousal is not attributed to the manipulation but is rather more general, should show the typical findings in which arousal enhances memory consolidation.

3.4.8 Self-Regulation in Non-Responders

The poor recall of non-responders is intriguing. Non-responders both did not show a cortisol response to arousal, and also showed poor memory. This could be because the non-responders are using their available resources to deal with and suppress or change arousal, rather than experiencing it as arousing. In other words, non-responders may be viewing the task in a different way (perhaps as a challenge rather than a physical pain to be endured), or they could be suppressing their arousal. Devoting resources to suppressing arousal may then negatively affect memory. There is experimental support for this idea, as researchers have found (Richards & Gross, 2000, 2006; Bonanno et al., 2004) that suppressing emotion leads to poor memory performance. Thus, if non-responders are truly suppressing their arousal, then one could expect to find poor memory. While there have been no experimental tests of suppression with this type of arousal and memory paradigm, Elzinga & Roelofs (2005) in a test of working memory also found that a non-responder group failed to show expected effects of arousal on memory.

Future studies will examine this possibility by asking some participants in the arousal condition to try to suppress their felt arousal, and to view the task in a non-arousing way. Other participants, however, will be asked to dwell upon their arousal and focus on the feelings of discomfort. If arousal suppression is the reason for poor performance among non-responders, then similar poor performance should be observed for the suppression condition compared to the no suppression condition.

3.5 Interactions between Extraversion, Gender, and Arousal

In each of the four studies, there were interactions between arousal, gender, and extraversion. In studies 1 and 2, non-aroused female introverts performed the best. Intriguingly, in study 2, men showed the opposite pattern. In studies 3 and 4, however, while there were significant interactions between arousal, extraversion, and gender, the nature and pattern of these interactions changed depending on which measure of extraversion was examined. Overall, there was evidence for warm female introverts to perform well, but this was not always the case, and men and women did not always show opposite patterns. Rather than allowing insight into what particular facet of extraversion may be driving these effects, it seems that using the expanded extraversion questionnaire yielded results that were less easily interpretable. Thus, while there is considerable evidence that extraversion may be an important moderator of arousal effects, more work needs to be done to tease out exactly how extraversion works to modulate memory.

3.6 Theoretical Explanations

While theories of arousal and performance are not as developed as theories about other kinds of emotion (e.g., mood), there are a few theories that may explain the present results. As mentioned in the introduction, hormonal theories of consolidation predict that cortisol should predict memory, such that those who show an increase in cortisol should also show an increase in memory. Furthermore, different memory patterns for men, women, introverts and extraverts should be reflected by changes in reactivity to arousal. These studies, however, found no relationship between cortisol and memory, except that non-responders, who did not show a cortisol increase, performed poorly. Those responders who did have an increase in cortisol in response to stress did not recall more than those who were not aroused and who had lower cortisol. While these findings do not concur with what is known about cortisol and memory consolidation, this does not mean that cortisol does not potentiate consolidation. Rather, the findings in these studies may indicate that cortisol is not solely responsible for arousal effects on consolidation; other behavioral factors, such as attribution and suppression of arousal, may also influence the effect of arousal.

This research provides some support for the idea that arousal follows an inverted-U-shaped curve. Studies 1 and 2 (and partial evidence from studies 3 and 4) found that female non-aroused introverts, who are presumably at a medium, optimal level of arousal, performed well, whereas aroused introverts and non-aroused extraverts (at too high and too low levels of arousal, respectively) performed poorly. However, men did not show the same pattern in study 2, which may indicate that the relationship of arousal and performance is different for men and women. Furthermore, examining different measures of extraversion yielded different effects. There was no support for the idea that arousal is linearly related to performance.

The data also yielded support for the arousal-as-information hypothesis (Clore & Schnall, 2005), but further research is needed. If indeed the arousal was attributed to the ice water and not to the stimuli, then the results are in line with predictions from the arousal-as-information hypothesis that arousal should potentiate memory only when the arousal experience is linked to the stimuli to be remembered. More studies of arousal and attribution are needed to substantiate this prediction. The fact that memory but not cortisol differed by gender and extraversion (except in response to the use of oral contraceptives and the luteal stage of the menstrual cycle) may reflect the fact that introverts and extraverts and men and women have equivalent physiological response to stress, but have differing evaluations of importance or urgency.

3.7 Conclusion: The Importance of Individual Differences

Overall, the studies described illustrate the importance of taking individual differences such as gender (accounting for menstrual stage and oral contraceptives use) and personality into account when examining the effect that arousal has on memory. Considering the wealth of published studies that claim that arousal uniformly enhances memory consolidation, these studies show that arousal does not work the same for everyone. In these data, I found that long term memory for events depends in part on individual differences in gender and extraversion. I hypothesize that a critical role may also be played by differences in people's tendencies to try to suppress arousal and differences in the attributions that they make for their arousal.

References

Abercrombie, H. C., Speck, N. S., & Monticelli, R. M. (2006). Endogenous cortisol elevations are related to memory facilitation only in individuals who are emotionally aroused. *Psychoneuroendocrinology, 31*(2), 187-196.

Anderson, A. K., Wais, P. E., & Gabrieli, J. D. E. (2006). Emotion enhances remembrance of neutral events past. *Proceedings of the National Academy of Sciences, 103*(5), 1599-1604.

Andreano, J.M., & Cahill, L. (2006). Glucocorticoid release and memory consolidation in men and women. *Psychological Science, 17,* 466-470.

Andreano, J.M., & Cahill, L. (2009). Sex influences on the neurobiology of learning and memory. *Learning & Memory, 16*, 248-266.

Bem, Sandra L. (1974). The measurement of psychological androgyny. *Journal of Consulting and Clinical Psychology, 42,* 155-162.

Bolla, K.I., Gray, S., Resnick, S.M., Galante, R., & Kawas, C. (1998). Category and letter fluency in highly educated older adults. *Clinical Neuropsychology, 12,* 330–338.

Bonanno, G. A., Papa, A., O'Neill, K. O., Westphal, M., & Coifman, K. (2004). The importance of being flexible: The ability to enhance and suppress emotional expression predicts long-term adjustment. *Psychological Science, 15,* 482–487.

Bradley, M.M., & Lang, P.J. (1999). *Affective norms for English words (ANEW): Stimuli, instruction manual and affective ratings*. Technical report C-1, Gainesville, FL. The Center for Research in Psychophysiology, University of Florida.

Brainerd, C. J., Wright, R., Reyna, V. F., & Payne, D. G. (2002). Dual retrieval processes in free and associate recall. *Journal of Memory and Language, 46,* 120-152.

Brignell, C.M., Rosenthal, J., & Curran, H. V. (2007). Pharmacological manipulations of arousal and memory for emotional material: Effects of a single dose of methylphenidate or lorazepam. *Journal of Psychopharmacology, 21,* 673-683.

Buchanan, T., & Adolphs, R. (2002). The role of the human amygdala in emotional modulation of long-term declarative memory. In S. Moore & M. Oaksford (Eds.), *Emotional cognition: From brain to behavior* (pp. 9 –34). London: John Benjamins.

Buchanan, T. W., & Lovallo, W. R. (2001). Enhanced memory for emotional material following stress-level cortisol treatment in humans. *Psychoneuroendocrinology, 26,* 307-317.

Buchanan, T. W., Tranel, D., & Adolphs, R. (2006). Impaired memory retrieval correlates with individual differences in cortisol response but not autonomic response. *Learning and Memory, 13,* 382-387.

Buss, C., Wolf, O.T., Witt, J., & Hellhammer, D.H. (2004). Autobiographic memory impairment following acute cortisol administration. *Psychoneuroendocrinology, 29,* 1093-1096.

Cacioppo, J. T., & Petty, R. E. (1983). Foundations of social psychophysiology. In *Social psychophysiology: A sourcebook* (pp. 666-690). New York: Guilford Press.

Cahill, L. (2004). His brain, her brain. *Scientific American, 292*, 40-47.

Cahill, L. (2006). Why sex matters for neuroscience. *Nature Reviews Neuroscience, 7,* 1-7.

Cahill, L., et al., (2001). Sex-related difference in amygdala activity during emotionally influenced memory storage. *Neurobiology of Learning and Memory, 75*, 1-9.

Cahill, L., & Alkire, M.T. (2003). Epinephrine enhancement of human memory consolidation: Interaction with arousal at encoding. *Neurobiology of Learning and Memory, 79*, 194-198.

Cahill, L., Gorski, L., Belcher, A., & Huynh, Q. (2004a). The influence of sex versus sex-related traits on long-term memory for gist and detail from an emotional story. *Consciousness and Cognition, 13*, 391-400.

Cahill, L., Gorski, L., & Le, K. (2003). Enhanced human memory consolidation with post-learning stress: Interaction with the degree of arousal at encoding. *Learning and Memory, 10*, 270-274.

Cahill, L., & McGaugh, J. L. (1995). A novel demonstration of enhanced memory associated with emotional arousal. *Consciousness and Cognition, 4*, 410-421.

Cahill, L., & McGaugh, J. L. (1998). Mechanisms of emotional arousal and lasting declarative memory. *Trends in Neurosciences, 21*, 294-299.

Cahill, L., Prins, B., Weber, M., & McGaugh, J. L. (1994). B-Adrenergic activation and memory for emotional events. *Nature, 371*, 702-704.

Cahill, L., Uncapher, M., Kilpatrick, L., Alkire, M.T., & Turner, J. (2004b). Sex-related hemispheric lateralization of amygdala function in emotionally influenced memory: An fMRI investigation. *Learning and Memory, 11*, 261-266.

Cahill, L., & Van Stegeran, A. (2003). Sex-related impairment of memory for emotional events with β-adrenergic blockade. *Neurobiology of Learning and Memory, 79,* 81-88.

Campbell, L.A., & Bryant, R.A. (2007). How time flies: A study of novice skydivers. *Behaviour Research and Therapy, 45*, 1389-1392.

Canli, T., Desmond, J.E., Zhao, Z., & Gabrieli, J.D.E. (2002). Sex differences in the neural basis of emotional memories. *PNAS*, *99*, 10789-10794.

Cantor, J. R., Bryant, J., & Zillmann, D. (1974). Enhancement of humor appreciation by transferred excitation. *Journal of Personality and Social Psychology, 15,* 470-480.

Cantor, J. R., Bryant, J., & Zillmann, D. (1975). Enhancement of experienced sexual arousal in response to erotic stimuli through misattribution of unrelated residual excitation. *Journal of Personality and Social Psychology*, *32*, 69-75.

Capitani, E., Laicona, M., & Barbarotto, R. (1999). Gender affects word retrieval of certain categories in semantic fluency tasks. *Cortex*, *35*, 273–278.

Capitani, E., Laicona, M., & Basso, A. (1998). Phonetically cued word-fluency, gender differences and aging: A reappraisal. *Cortex*, *34*, 779–783.

Clore, G.L., & Schnall, S. (2005). The influence of affect on attitude. In A. Dolores, B.T. Johnson, & M.P. Zanna (Eds.), *The handbook of attitudes* (pp. 437-489). Mahwah, NJ: Erlbaum.

Corcoran, D. W. J. (1965). Personality and the inverted-U relation. *British Journal of Psychology, 56*, 267-273.

Dabbs, J.M., Jr., Chang, E.L., Strong, R.A., & Milun, R. (1998) Spatial ability, navigation strategy, and geographic knowledge among men and women. *Evolution & Human Behavior, 19*, 89–98.

De Pascalis, V. (2004). On the psychophysiology of extraversion. In R. M. Stelmack (Ed.), *On the psychobiology of personality: Essays in honor of Marvin Zuckerman* (pp. 295-337).

Dickerson, S.S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130*, 355-391.

Domes, G., Heinrichs, M., Rimmele, U., Reichwald, U., & Hautzinger, M. (2004). Acute stress impairs recognition for positive words—Association with stress-induced cortisol secretion. *Stress*, *7,* 173-181.

Driscoll, I., Hamilton, D.A., Yeo, R.A., Brooks, W.M., & Sutherland, R.J. (2005). Virtual navigation in humans: The impact of age, sex, and hormones on place learning. *Hormones & Behavior, 47*, 326–335.

Elzinga, B. M., Bakker, A., & Bremner, J.D. (2005). Stress-induced cortisol elevations are associated with impaired delayed, but not immediate recall. *Psychiatry Research, 134*, 211-223.

Elzinga, B. M., & Roelofs, K. (2005). Cortisol-induced impairments of working memory require acute sympathetic activation. *Behavioral Neuroscience, 119*, 98-103.

Epting, L.K., & Overman, W.H. (1998). Sex sensitive tasks in men and women: A search for performance fluctuations across the menstrual cycle. *Behavioural Neuroscience, 112*, 1304–1317.

Eysenck, H. J. (1967). *The biological basis of personality.* Springfield, IL: Charles C. Thomas.

Gasper, K. (2004). Do you see what I see? Affect and visual information processing. *Cognition and Emotion, 18*, 405-421.

Goldberg, L.R. (1992). The development of markers for the big-five factor structure. *Psychological Assessment, 4*¸ 26-42.

Goldberg, L. R. (1999). A broad-bandwidth, public domain, personality inventory measuring the lower-level facets of several five-factor models. In I. Mervielde, I. Deary, F. De Fruyt, & F. Ostendorf (Eds.), *Personality Psychology in Europe*, Vol. 7 (pp. 7-28). Tilburg, The Netherlands: Tilburg University Press.

Gore, J.B., Krebs, D.L., & Parent, M.B. (2006). Changes in blood glucose and salivary cortisol are not necessary for arousal to enhance memory in young or older adults. *Psychoneuorendocrinology, 31*, 589-600.

Gorn, G., Pham, M., & Sin, L. (2001). When arousal influences ad evaluation and valence does not (and vice versa). *Journal of Consumer Psychology, 11*, 43-55.

Hadley, C.B., & MacKay, D.G. (2006). Does emotion help or hinder immediate memory? Arousal versus priority-binding mechanisms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 79-88.

Hamann, S. (2001). Cognitive and neural mechanisms of emotional memory. *Trends in Cognitive Science, 5,* 394 – 400.

Hyde, J.S., & Linn, M.C. (1988). Gender differences in verbal ability: A meta-analysis. *Psychological Bulletin, 104,* 53–69.

Jackson, E.D., Payne, J.D., Nadel, L., and Jacobs, W.J. 2006. Stress differentially modulates fear conditioning in healthy men and women. *Biological Psychiatry, 59,* 516–522.

Jacobs, W. J., & Nadel, L. (1988) Neurobiology of reconstructed memory. *Psychology, Public Policy, and Law, 4,* 1110-1134.

James, W. (1890). *Principles of Psychology*. New York, NY: Holt.

Joels, M., Pu, Z., Weigert, O., Oitzl, M.S., & Krugers, H.J. (2006). Learning under stress: How does it work? *Trends in Cognitive Sciences, 10,* 152-158.

Kadous, K. (2001). Improving jurors' evaluations of auditors in negligence cases. *Contemporary Accounting Research, 18,* 425-444.

Kail, R.V., Jr., & Siegel, A.W. (1978). Sex and hemispheric differences in the recall of verbal and spatial information. *Cortex, 14,* 557–563.

Kimura, D. (1996). Sex, sexual orientation and sex hormones influence human cognitive function. *Current Opinion in Neurobiology, 6,* 259–263.

Kimura, D., & Seal, B.N. (2003). Sex differences in recall of real or nonsense words. *Psychological Report, 93,* 263–264.

Kirschbaum, C., Kudielka, B. M., Gaab, J., Schommer, N. C., & Hellhammer, D.H. (1999). Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus–pituitary–adrenal axis. *Psychosomatic Medicine, 61*, 154–162.

Kirschbaum, C., Wust, S., & Hellhammer, D. (1992). Consistent sex differences in cortisol responses to psychological stress. *Psychosom Med., 54*, 648–57.

Kudielka, B. M., & Kirschbaum, C. (2005). Sex differences in HPA axis responses to stress: A review. *Biological Psychology, 69, 113-132.*

Kuhlmann, S., Kirschbaum, C., & Wolf, O.T. (2005a). Effects of oral cortisol treatment in healthy young women on memory retrieval of negative and neutral words. *Neurobiology of Learning and Memory, 83,* 158-162.

Kuhlmann, S., Piel, M., & Wolf, O.T. (2005b). Impaired memory retrieval after psychosocial stress in healthy young men. *The Journal of Neuroscience, 25*, 2977-2982.

Kuhlmann, S., & Wolf, O.T. (2005). Cortisol and memory retrieval in women: Influence of menstrual cycle and oral contraceptives. *Psychopharmacology, 183,* 65-71.

Kuhlmann, S., & Wolf, O.T. (2006). Arousal and cortisol interact in modulating memory consolidation in healthy young men. *Behavioral Neuroscience, 120*, 217-223.

LaBar, K.S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews, 7,* 54-64.

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (2005). International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-6. University of Florida, Gainesville, FL.

Likis, F. E. (2002). Contraceptive applications of estrogen. *The Journal of Midwifery &*

Women's Health, 47, 139–156.

Linn, M.C., & Petersen, A.C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*, 1479–1498.

Lipnicki, D.M., & Byrne, D.G. (2005). Thinking on your back: Solving anagrams faster when supine than when standing. *Cognitive Brain Research, 24*, 719-722.

Liu, D.L. J., Graham, S., & Zorawski, M. (2008). Enhanced selective memory consolidation following post-learning pleasant and aversive arousal. *Neurobiology of Learning and Memory, 89,* 36-46.

Loftus, E. F., Loftus, G. R., & Messo, J. (1987). Some facts about 'weapon focus'. *Law and Human Behavior, 11*, 55-62.

Lovallo, W. R. (1975). The cold pressor test and autonomic function: A review and integration. *Psychophysiology, 12*(3), 268-282.

Lupien, S.J., Gillin, C.J., & Hauger, R.L. (1999). Working memory is more sensitive than declarative memory to the acute effects of corticosteroids: A dose-response study in humans. *Behavioral Neuroscience, 113,* 420-430.

MacKay, D. G., & Ahmetzanov, M. V. (2005). Emotion, memory, and attention in the taboo Stroop paradigm: An experimental analogue of flashbulb memories. *Psychological Science, 16*, 25-32.

MacKay, D. G., Hadley, C. B., & Schwartz, J. H. (2005). Relations between emotion, illusory word perception, and orthographic repetition blindness: Tests of binding theory. *Quarterly Journal of Experimental Psychology, 58*, 1514-1533.

MacKay, D. G., Shafto, M., Taylor, J. K., Marian, D. E., Abrams, L., & Dyer, J.R. (2004). Relations between emotion, memory, and attention: Evidence from taboo Stroop, lexical decision, and immediate memory tasks. *Memory and Cognition, 32*, 474-488.

Mackiewicz, K. L., Sarinopoulos, I., Cleven, K. L., & Nitschke, J. B. (2006). The effect of anticipation and the specificity of sex differences for amygdala and hippocampus function in emotional memory. *PNAS, 103* (38), 14200-14205.

Macoby, E.E., & Jacklin, C.N. (1974). *The psychology of sex differences.* Stanford, CA: Stanford University Press.

Mann, V.A., Sasanuma, S., Sakuma, N., & Masaki, S. (1990). Sex differences in cognitive abilities: A cross-cultural perspective. *Neuropsychologia, 28*, 1063–1077.

Martin, L., Harlow, T.F., & Strack, F. (1992). The role of bodily sensations in the evaluation of social events. *Personality and Social Psychology Bulletin, 18*, 412-419.

Mather, M. (2007). Emotional arousal and memory binding: An object-based framework. *Perspectives on Psychological Science, 2*, 33-52.

Mather, M., Mitchell, K. J., Raye, C. L., Novak, D. L., Greene, E. J., & Johnson, M. K. (2006). Emotional arousal can impair feature binding in working memory. *Journal of Cognitive Neuroscience, 18,* 614-625.

McGaugh, J. L. (2004). The amygdala modulates the consolidation of memories of emotionally arousing experiences. *Annual Review of Neuroscience, 27,* 1-28.

McGaugh, J.L., & Gold, P.E. (1989). Hormonal modulation of memory. In F. R. Brush & S. Levine (Eds.), *Psychoendocrinology* (pp. 305-340). San Diego, CA: Academic Press.

McGaugh, J.L., & Roozendaal, B. (2002). Role of adrenal stress hormones in forming lasting memories in the brain. *Current Opinion in Neurobiology, 12*, 205-210.

McMorris, T., et al. (1999). Exercise, plasma catecholamine concentrations and decision-making performance of soccer players on a soccer-specific test. *Journal of Sports Sciences, 17*, 667-676.

Metcalfe, J., & Jacobs, W. J. (1998). Emotional memory: The effects of stress on "cool" and "hot" memory systems. *Psychology of Learning and Motivation, 38,* 187-222.

Miller, G. E., Cohen, S., Rabin, B. S., Skoner, D. P., & Doyl, W. J. (1999). Personality and tonic cardiovascular, neuroendocrine, and immune parameters. *Brain, Behavior, and Immunity, 13*, 109-123.

Nadel, L., & Jacobs, W. J. (1998). Traumatic memory is special. *Current Directions in Psychological Science, 7*, 154-157.

Nava, E., Landau, D., Brody, S., Linder, L., & Schächinger, H. (2004). Mental relaxation improves long-term incidental visual memory. *Neurobiology of Learning and Memory, 81*(3), 167-171.

Neiss, R. (1988). Reconceptualizing arousal: Psychobiological states in motor performance. *Psychological Bulletin*, *103*(3), 345-366.

Netter, P. (2004). Personality and hormones. In R. M. Stelmack (Ed.), *On the psychobiology of personality: Essays in honor of Marvin Zuckerman* (pp. 353-

377).

Nielson, K. A., & Powless, M. (2007). Positive and negative sources of emotional arousal enhance long-term word-list retention when induced as long as 30min after learning. *Neurobiology of Learning and Memory, 88*(1), 40-47.

Nielson, K. A., Yee, D., & Erickson, K. I. (2005). Memory enhancement by a semantically unrelated emotional arousal source induced after learning. *Neurobiology of Learning and Memory, 84*, 49-56.

Palmer, J. E., & Dodson, C. S. (2009). Investigating the mechanisms fuelling reduced false recall of emotional material. *Cognition and Emotion, 23*(2), 238-259.

Pan, W. (2001). Akaike's information criterion in generalized estimating equations. *Biometrics, 57*, 120-125.

Paulhus, D. L., & Lim, D. T. K. (1994). Arousal and evaluative extremity in social judgments: A dynamic complexity model. *European Journal of Social Psychology, 24*, 89-99.

Payne, J. D., Nadel, L., Britton, W.B., & Jacobs, W. J. (2004). The biopsychology of trauma and memory. In D. Reisberg and P. Hertel (Eds.), *Memory and Emotion* (pp. 76-128). London: Oxford University Press.

Revelle, W., & Loftus, D. (1992). The implications of arousal effects for the study of affect and memory. In S. A. Christianson (Ed.), *Handbook of emotion and memory* (pp. 113-150). Hillsdale, NJ: Erlebaum.

Richards, J. M., & Gross, J. J. (2000). Emotion regulation and memory: The cognitive costs of keeping one's cool. *Journal of Personality and Social Psychology, 79,* 410–424.

Richards, J.M., & Gross, J.J. (2006). Personality and emotional memory: How regulating emotion impairs memory for emotional events. *Journal of Research in Personality, 40*(5), 631-651.

Roediger, H. L. III, & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 803-814.

Rogers, R.D., Lancaster, M., Wakely, J., & Bhagwagar, Z. (2004). Effects of beta-adrenoceptor blockade on components of human decision-making. *Psychopharmacology*, *172*, 157-164.

Roozendaal, B. (2002). Stress and memory: Opposing effects of glucocorticoids on memory consolidation and memory retrieval. *Neurobiology of Learning and Memory*, *78*(3), 578-595.

Salimetrics, LLC. (2009). Saliva collection and handling advice. http://www.salimetrics.com /assets/documents/collection-supplies/Saliva-Collection-and-Handling-Advice-large-format-4-7-09.pdf

Schoofs, D., & Wolf, O. T. (2009). Stress and memory retrieval in women: No strong impairing effect during the luteal phase. *Behavioral Neuroscience, 123,* 547-554.

Schwarz, N., & Clore, G.L. (2007). Feelings and phenomenal experiences. In A. W. Kruglanski & E. T. Higgins (Eds.), *Social psychology: Handbook of basic principles* (2nd ed.) (pp 385-407). NY, NY: Guilford.

Schwarz, N., & Clore, G.L. (1983). Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. *Journal of Personality and Social Psychology, 45*, 513-523.

Stelmack, R. M. (2004). On personality and arousal: A historical perspective on Eysenck and Zuckerman. In R. M. Stelmack (Ed.), *On the psychobiology of personality: Essays in honor of Marvin Zuckerman* (pp. 17-28).

Stelmack, R. M. (1990). The biological basis of extraversion: Psychophysiological evidence. *Journal of Personality, 58*, 293-311.

Storbeck, J., & Clore, G. L. (2008). Affective arousal as information: How affective arousal influences judgments, learning, and memory. *Social and Personality Psychology Compass*, *2*, 1824-1843.

Thilers, P.P., MacDonald, S.W., & Herlitz, A. (2007) . Sex differences in cognition: The role of handedness. *Physiology & Behavior, 92*, 105–109.

Tollenaar, M. S., Elzinga, B. M., Spinhoven, P., & Everaerd, W. A. M. (2008). The effects of cortisol increase on long-term memory retrieval during and after acute psychosocial stress. *Acta Psychologica, 127*, 542-552.

Touryan, S. R., Marian, D. E., & Shimamura, A. P. (2007). Effect of negative emotional pictures on associative memory for peripheral information. *Memory, 15*, 154-166.

Voyer, D., Voyer, S., & Bryden, M.P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, *117*, 250– 270.

Whissell, C., Fournier, M., Pelland, R., Weir, D. & Makarec, K. (1986). A dictionary of affect in language: IV. Reliability, validity, and applications. *Perceptual and Motor Skills, 62*, 875-888.

Wright, K. P., Jr., & Badia, P. (1999). Effects of menstrual cycle phase and oral contraceptives on alertness, cognitive performance, and circadian rhythms during sleep deprivation. *Behavioural Brain Research*, *103*, 185-194.

Yerkes, R. M., & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative Neurology and Psychology, 18*, 459-482.

Appendix A. Word Lists used in Study 1 (critical lures in bold type).

KILL	**SAD**	**PAIN**
Assassinate	Depressed	Suffer
Slay	Melancholy	Hurt
Slaughter	Cheerless	Ouch
Murder	Somber	Anguish
Execute	Miserable	Pleasure
Massacre	Lonely	Harm
Stab	Upset	Distress
Behead	Gloomy	Back
Homicide	Hopeless	Death
Shoot	Desolate	Blood

HAPPY	**LOVE**	**BEAUTIFUL**
Glad	Adore	Gorgeous
Elated	Affection	Stunning
Content	Passion	Picturesque
Joyful	Heart	Breathtaking
Pleased	Kiss	Pretty
Ecstatic	Like	Lovely
Laugh	Attraction	Exquisite
Enjoyment	Care	Striking
Satisfied	Devoted	Attractive
Enjoyable	Admire	Elegant

SLEEP	**CHAIR**	**NEEDLE**
Doze	Table	Thread
Bed	Rocking	Haystack
Snooze	Recliner	Injection
Tired	Stool	Sewing
Snore	Desk	Knitting
Pillow	Sit	Prick
Dream	Sofa	Sharp
Relax	Sitting	Thorn
Quiet	Bench	Point
Blanket	Legs	Eye

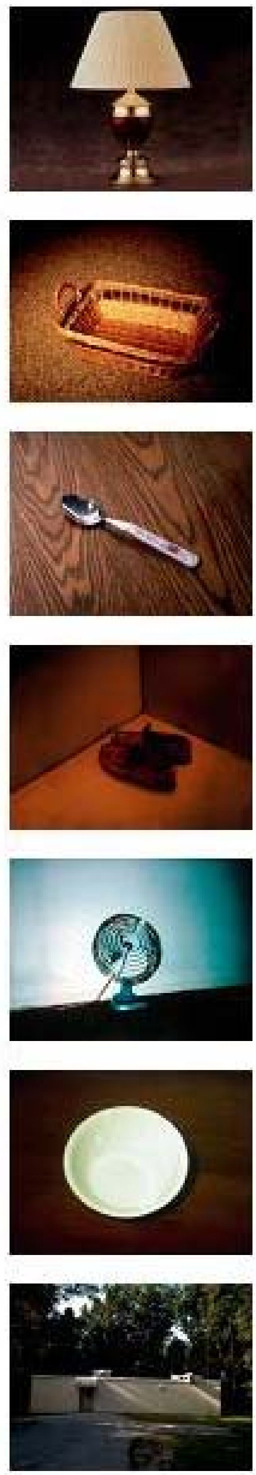
Appendix B. Word Lists used in Study 2.

NEGATIVE	NEUTRAL	POSITIVE
Rage	Foot	Exercise
Anger	Kettle	Miracle
Nightmare	Square	Romantic
Stress	Indifferent	Ecstasy
Danger	Butter	Kiss
Terrorist	Pencil	Passion
Horror	Nonchalant	Joy
Panic	Seat	Adventure
Abuse	Subdued	Triumphant
Demon	Quiet	Engaged

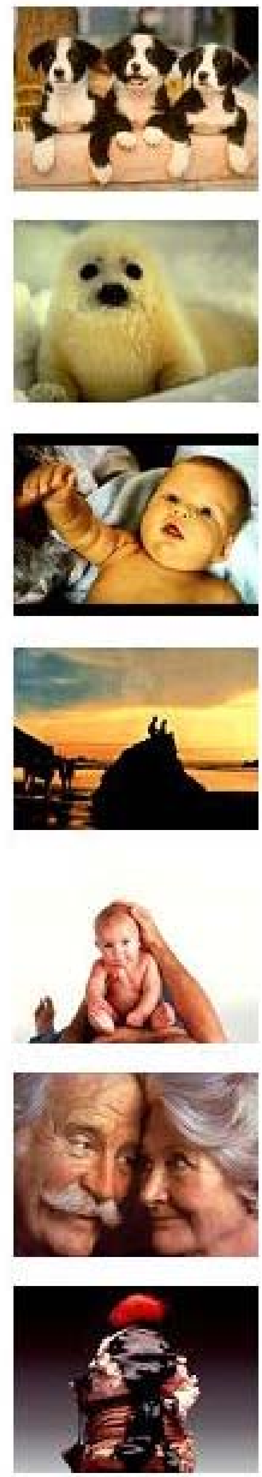
Appendix C. Pictures used in Studies 3 and 4.

Negative

Neutral



Positive







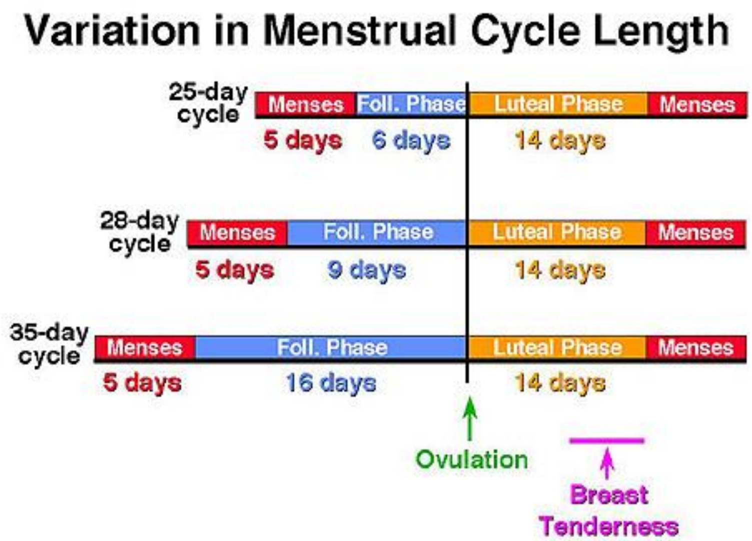




Appendix D Menstrual Cycle Calculations.

28 Day Cycle
Day 0 – 5: Menses
Day 6 – 14: Follicular
Day 15 – 28: Luteal

Unknown Cycle Length
Day 0 – 5: Menses
Day 6 – 11: Follicular
Day 12 – 21: Follicular/Luteal
Day 22+: Luteal



	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Menses	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
Follicular	6-7	6-8	6-9	6-10	6-11	6-12	6-13	6-14	6-15	6-16	6-17	6-18	6-19	6-20	6-21	6-22	6-23	6-24	6-25
Luteal	8-21	9-22	10-23	11-24	12-25	13-26	14-27	15-28	16-29	17-30	18-31	19-32	20-33	21-34	22-35	23-36	24-37	25-38	26-39