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Memory enhancement by a semantically unrelated emotional arousal source induced after learning

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Abstract

It has been well established that moderate physiological or emotional arousal modulates memory. However, there is some controversy about whether the source of arousal must be semantically related to the information to be remembered. To test this idea, 35 healthy young adult participants learned a list of common nouns and afterward viewed a semantically unrelated, neutral or emotionally arousing videotape. The tape was shown after learning to prevent arousal effects on encoding or attention, instead influencing memory consolidation. Heart rate increase was significantly greater in the arousal group, and negative affect was significantly less reported in the non-arousal group after the video. The arousal group remembered significantly more words than the non-arousal group at both 30 min and 24 h delays, despite comparable group memory performance prior to the arousal manipulation. These results demonstrate that emotional arousal, even from an unrelated source, is capable of modulating memory consolidation. Potential reasons for contradictory findings in some previous studies, such as the timing of "delayed" memory tests, are discussed.

Keywords: Memory consolidation; Heart rate; Galvanic skin response; Electrodermal activity; Skin conductance; Long-term memory; Emotion; Memory modulation; Arousal

1. Introduction

It has long been known that some events or facts are remembered better than are others and that emotionally arousing events are recollected with greater frequency than similar but emotionally neutral events. From a number of perspectives enhanced memory for emotional events is adaptive, effectively making important stimuli stand apart from those that are less significant (McGaugh, 1990), and thus protecting and preparing an organism for similar occasions in the future. Many psychological studies have investigated factors that might explain the memory advantage for emotional events, such as enhanced attention and elaboration (e.g., Revelle & Loftus, 1992; Walker, 1958). Although these factors play a role in the memory advantage of emotionally charged information, they are likely insufficient to explain it (e.g., Bohannon, 1988; Conway et al., 1994; Guy & Cahill, 1999). Less often discussed are the neural and endogenous hormonal mechanisms that are preferentially engaged in response to arousing or emotive stimuli that can enhance memory (cf. Gold & McGaugh, 1975; McGaugh, 1990, 2000).

Memory consolidation, the means of storing a memory, is the outcome of a complex set of neurobiological processes occurring over a period of time (cf. Deutsch & Deutsch, 1966; McGaugh, 2000; Müller & Pilzecker, 1900; Torras-Garcia, Portell-Cortes, Costa-Miserachs, & Morgado-Bernal, 1997). As such, events occurring during, or even shortly after learning can alter, or modulate,

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the consolidation of memory. Although emotional events naturally involve arousal onset during the event itself, it typically persists also for some time afterward. Therefore, like other arousal sources, emotion can have physiological effects on memory consolidation, rather than just on encoding and attention. Indeed, although arousal can facilitate detection and encoding for long-term retention, it can also hinder retrieval for as much as 30 min (Revelle & Loftus, 1992; Walker, 1958).

A variety of substances, including glucose and the adrenal hormones epinephrine, norepinephrine, and cortisol are released into the bloodstream during times of arousal, stress and emotion (Gold & McCarty, 1981) and have been closely linked to memory enhancement (e.g., Czech, Nielson, & Laubmeier, 2000; McGaugh, 2000; Nielson, Czech, & Laubmeier, 1999; Nielson & Jensen, 1994; van Stegeren, Everaerd, Cahill, McGaugh, & Gooren, 1998). Many animal studies have consistently shown that these substances alter memory and that they generally follow the classic inverted-U dose–response effect (Yerkes & Dodson, 1908) on memory performance (McGaugh, 1990, 2000). These effects are also time-dependent, such that doses administered during or shortly after learning are effective, but those administered 30 min or 2 h after learning are ineffective (Gold & van Buskirk, 1975; but see also Powless et al., 2003).

Most of the research on the processes of memory modulation has been done in animal models. The animal research demonstrating a locus of the effect of memory modulators on the consolidation process is important for evaluating the results of human studies, which have instead primarily manipulated arousal during encoding. In seeming conflict to what would be expected based on the findings in the animal literature, a number of authors of human studies have concluded that arousal only affects memory if it is *semantically related* to the material being remembered, purportedly because high attentional selectivity induced by arousal is assumed to interfere with memory (i.e., Easterbrook, 1959). For example, Christianson and Mjörndal (1985) found that epinephrine injections, an unrelated arousal source, produced physiological and subjective arousal but did not enhance memory performance for faces over saline injections. Christianson, Nilsson, Mjörndal, Perris, and Tjelldén (1984) also found that saline injected participants shown traumatic pictures remembered significantly less than epinephrine injected participants shown neutral materials (i.e., unrelated arousal source). Buchanan and Lovallo (2001) found that pre-learning injections of cortisol selectively enhanced delayed memory for arousing pictures but not neutral pictures. Varner and Ellis (1998) did two experiments manipulating mood and arousal state either before or after learning. They found mood- and theme-congruence effects, but physiological arousal via exercise did not affect word retrieval. Finally, Libkuman, Nichols-Whitehead, Griffith, and Thomas (1999) examined source of arousal on memory for details in a series of experiments finding that emotional arousal enhanced memory but physiological arousal by exercise had no effect. They concluded "…in order for arousal to have any impact on memory, it must be relevant to the to-be-remembered event; merely arousing someone will not suffice (p. 180)."

At best the relationship amongst emotion or arousal and memory is as yet incompletely understood. Although the human studies described have significantly contributed to our understanding of the effects of emotion on memory, each also had significant limitations precluding strong conclusions about the role of arousal per se in memory. In some studies, the degree of arousal achieved in the experiment was potentially too high to enhance memory (e.g., Christianson et al., 1984), and in some studies, memory for different materials was compared across groups (e.g., Christianson et al., 1984; Libkuman et al., 1999), or sources of arousal were combined from external and stimulus sources, which clouds the issue of the effect of arousal source on memory. Importantly, in most of these studies, arousal was manipulated during the encoding phase of the tasks employed, which confounded the effects of arousal on attention and encoding with its effects on consolidation (Buchanan & Lovallo, 2001; Christianson & Mjörndal, 1985; Christianson et al., 1984; Libkuman et al., 1999). Finally, previous animal and human research makes clear that memory consolidation takes time (e.g., McGaugh, 2000; Revelle & Loftus, 1992; Walker, 1958), but each of these previous studies used very short-term retention tests (10–15 min delay), potentially missing the effects of the arousal manipulation (Buchanan & Lovallo, 2001; Christianson & Mjörndal, 1985; Christianson et al., 1984; Libkuman et al., 1999; Varner & Ellis, 1998). Indeed, a recent study showed that an emotional version of a story produced better 1-week delayed retrieval of the story than did a neutral version, but there was no difference in retrieval when only a short 1 h delay was used (Quevedo et al., 2003).

Studies specifically examining the effects of arousal on the memory *consolidation* process in humans are limited. Nicotine (Colrain, Mangan, Pellett, & Bates, 1992), glucose (Manning, Parsons, & Gold, 1992), and muscle tension (Nielson & Jensen, 1994; Nielson, Radtke, & Jensen, 1996) have been shown to enhance delayed retrieval of non-arousing memory materials when given after learning. For example, Nielson and Jensen (1994) showed that induction of muscle tension shortly after exposure to target words embedded in paragraphs increased heart rate and enhanced delayed recall and recognition of the words, except in participants who were taking β-blockers to control hypertension. Importantly, immediate retrieval was not affected by arousal. Similarly, a list-learning study showed that hypermnesia, improvement in memory over time, was inhibited by showing a violent

videotape (high arousal), only when shown after initial list-learning compared with presentation before learning or with use of a neutral stimulus (Shaw, Bekerian, & McCubbin, 1995).

One potential limitation of the studies by Nielson and colleagues (Nielson & Jensen, 1994; Nielson et al., 1996) is that the arousal source used was physiological, but designed to be relatively non-emotive (i.e., muscle tension). As such, it could be argued that an emotional arousal source could produce different effects. Therefore, the present study was designed to determine if moderate emotional arousal from a source semantically unrelated to the to-be-remembered material, induced after learning, would enhance delayed memory performance. It was hypothesized that exposure to an emotionally arousing stimulus after learning a list of words would produce acute physiological arousal. In addition, the arousal stimulus was expected to enhance delayed retention performance (30 min and 24 h) for the word list.

2. Method

2.1. Participants

Thirty-five undergraduate students (13 male, 22 female) aged 18–23 years were included in this study and some received course credit for their participation. All subjects were randomly assigned to the arousal or non-arousal condition and tested individually with procedures approved by the Institutional Review Board.

2.2. Materials and apparatus

Thirty high-imagery nouns were selected to equilibrate memorability (>6.0 on a scale of 1–7, Paivio, Yuille, & Madigan, 1968, e.g., "butterfly," "queen," "house") and recorded onto a videotape using white letters on a dark blue background and presented at 3 s intervals with no interstimulus interval as an intentional memory test. None of the words selected were from dental, oral, medical, or tool categories. Of the 30, 19 have also been standardized for subjective arousal response (Bradley & Lang, 1999), showing they fall in the low-moderate range with little variability ($M = 4.65$, $SD = 0.81$; range = 3.17–6.27 on a 9-point scale); imageable nouns are not typically found in the lower ratings range (cf. Bradley & Lang, 1999).

The arousal condition was manipulated using videotaped live-action demonstrations (3 min) of either oral surgery (arousal) or tooth-brushing (non-arousal). Immediate, 30 min and 24 h delayed recall tests and a 24 h recognition test were used to assess memory for the word list. Participants were given up to 3 min to recall, in writing, as many of the words from the list as possible. The recognition test consisted of 140 words (the 30 list items and 110 distracter words, using the same criteria used for the target list), presented in five columns of 28 words each. Participants were instructed to mark all words that they believed were from the original word list.

Several questionnaires were administered, including the Wechsler Adult Intelligence Scale-Revised Vocabulary Subtest (WAISR-V) (Wechsler, 1981), the 14-item Perceived Stress Scale (PSS, Cohen, Kamarck, & Mermelstein, 1983), the 21-item Beck Depression Inventory (BDI, Beck, Ward, Mendelson, Mock, & Erbaugh, 1968), the 21-item Beck Anxiety Inventory (BAI, Beck, Brown, Epstein, & Steer, 1988), and a 14-item negative affect adjective rating scale designed to measure current affective state based on the Emotional Intensity Scale (EIS, Bachorowski & Braaten, 1994). Items included sad, sick, angry, surprised, disgust, etc. Only negative adjectives were used due to the negative orientation of the arousal stimulus.

Heart rate and galvanic skin response (skin conductance) were measured continuously throughout the first session. Heart rate (beats per minute) was measured using a photoplethysmograph placed on the thumb pad of the non-dominant hand, and galvanic skin response (micro mho) was measured using electrodes on the 2nd and 3rd fingers of the same hand. These data were collected at a rate of 16 Hz using *Virtual Instruments MasterLab* (Expanded Technologies, Shreveport, LA).

2.3. Procedure

After a brief study explanation was given and informed consent was obtained, the electrodes were placed on the non-dominant hand (fingers 2, 3; photoplethysmograph on the thumb). The word list was then presented via videotape with instruction to repeat the words aloud as they were presented and to intentionally try to remember them. Immediate recall performance was then tested. A 5 min rest period, without activity was then given to establish baseline heart rate and galvanic skin response; minutes 2–5 constituted the computed baseline. The EIS was then administered, followed by the arousal manipulation, given by videotape with the instruction to watch it carefully and in its entirety. Physiological measures were recorded until 5 min had elapsed, including the 3 min video period and the 2 min directly following it. A second EIS assessment were then made, followed by administration of the PSS, BDI, and BAI, as well as a variety of other personality measures used as filler. After 30 min had elapsed, an unannounced delayed recall test was given. When participants returned 24 h later, expecting a session similar to the first, unannounced delayed recall and recognition tests were given, followed by the WAISR-V.

Statistical analyses. Recognition scores were corrected for guessing using: corrected recognition =

(1 − ER) ∗ (%Hits), where %Hits = Hits/30 Targets and Error Rate (ER) = proportion of false alarms (FA/110 Distracters). The physiological data were reduced to one measure per 5 s interval for each index. Three indices were then computed by averaging the 5 s intervals over the measurement epoch: 3 min baseline epoch, 3 min stimulus epoch (i.e., videotape viewing), and 2 min post-stimulus epoch. Difference or change scores, subtracting stimulus and post-stimulus periods from baseline, as well as post-arousal EIS to baseline EIS, were computed and compared between groups using one-way analysis of variance (ANOVA). Analysis of covariance (ANCOVA) was used to control for possible non-experimental group differences in the memory analyses. Additional comparisons were made by *t* test, as indicated. All analyses were performed using Statistical Package for the Social Science (SPSS, Chicago, IL), ver. 11.0 for Windows.

3. Results

3.1. Demographics

Characteristics of subjects in the arousal and non-arousal groups are provided in Table 1. Comparison by *t* test indicated that no statistically significant differences ($p > .05$) were observed between the groups for WAIS-R Vocabulary, PSS, BDI, or BAI.

3.2. Memory performance

An immediate recall test was given, after list-learning but prior to the arousal manipulation, to verify that participants paid attention to the task and that the groups had generally comparable memory ability. The groups did not significantly differ (arousal group: $M = 41.2\%$, $SD = 11.9$; non-arousal group: $M = 36.5\%$, $SD = 8.9$; $F(1,33) = 1.8$, $p = .19$). However, immediate recall performance was used as a covariate in the delayed memory analyses to remove any effects of the initial performance differences among participants.

Fig. 1 shows the mean percentage of words recalled and recognized at each of the delayed retention tests by participants in both arousal conditions. A 2 (Group; between) × 3 (Memory Tests; within) repeated measures ANCOVA (immediate recall = covariate) revealed a significant effect for Memory Tests ($F(2,64) = 21.3$, $p = .001$), which can be attributed to the difference in performance level of recall vs. recognition, as expected. There was also a significant effect of Group ($F(1,32) = 9.2$, $p = .005$), such that the arousal group outperformed the non-arousal group overall (see Fig. 1). There was no significant interaction effect ($F(1,32) = 2.0$, $p = .14$). As a follow-up, a 2 Group × 2 Memory Tests (30 min and 24 h recall) ANCOVA showed a marginal effect of Memory Tests ($F(1,32) = 3.72$, $p = .06$), a significant Group difference (Group $F(1,32) = 3.9$, $p = .05$), and a non-significant Interaction ($F(1,32) = 0.11$, $p = .74$). Confirmatory one-way ANOVAs showed significantly better performance by the arousal group for each retention test: 30 min delayed recall ($F(1,33) = 5.0$, $p = .03$), 24 h delayed recall ($F(1,33) = 4.8$, $p = .04$), and 24 h recognition ($F(1,33) = 10.6$, $p = .003$).

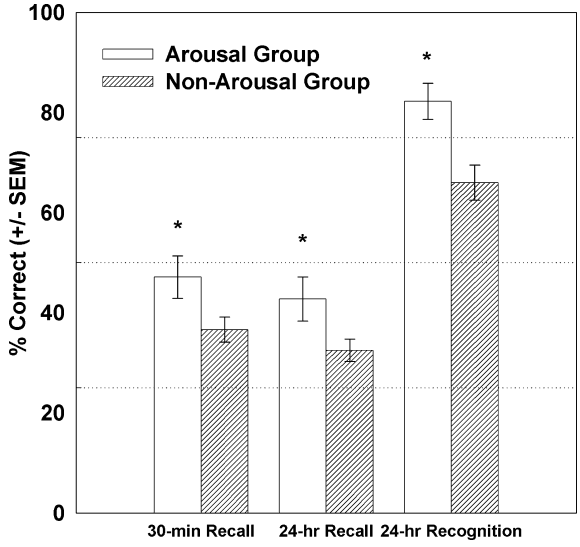

Fig. 1. The mean percentages of words recalled and recognized by participants in the arousal and non-arousal groups are presented for each index. Immediate recall, which occurred prior to the arousal manipulation and did not differ significantly between the groups ($p > .05$), was used to control for covariance in the analysis of the remaining memory tests. The arousal group outperformed the non-arousal group at each delayed retention test (*; $p < .05$).

Table 1
Group demographic data (mean ± SEM)

Group	Gender	WAIS-R Vocabulary	PSS	BDI	BAI
Arousal	6 Male 10 Female	48.5 (2.5)	45.9 (0.97)	6.8 (1.6)	6.4 (1.46)
Non-arousal	7 Male 12 Female	48.4 (1.7)	48.2 (1.1)	6.2 (1.4)	7.6 (0.82)
$t(33) =$		.03	−1.5	.31	−.66

All independent samples *t* tests were non-significant ($p > .05$). WAIS-R, Wechsler Adult Intelligence Scale-Revised; PSS, Perceived Stress Scale; BDI, Beck Depression Inventory; BAI, Beck Anxiety Inventory.

3.3. Arousal response measures

Baseline measures were within normal ranges and not significantly different between groups for either heart rate (HR; arousal mean = 72.2, $SD = 2.6$; non-arousal mean = 72.8, $SD = 2.9$; $F(1,33) = .02$, $p = .90$) or galvanic skin response (GSR; arousal mean = 11.6, $SD = 1.3$; non-arousal mean = 10.8, $SD = 1.2$; $F(1,33) = .19$, $p = .70$). Because change from baseline is the common form of analysis for these types of data to control for variability

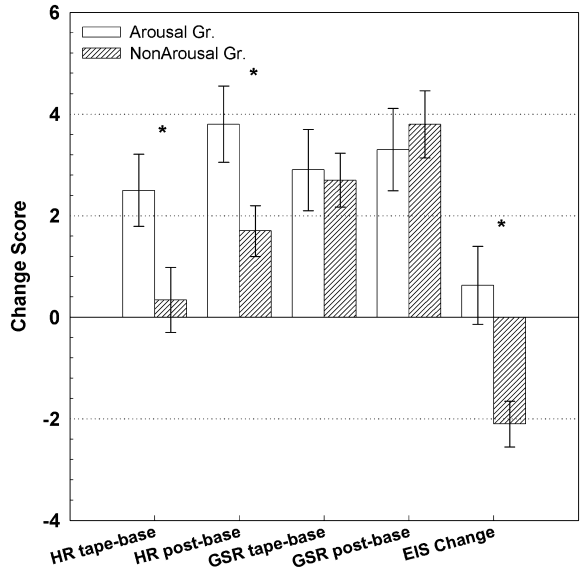

Fig. 2. Shown separately for the arousal and non-arousal groups is change from baseline in heart rate (HR; beats per minute) and galvanic skin response (GSR; micro-mho), during both the video stimulus (tape) and post-video intervals (post). Heart rate significantly increased in the arousal group relative to the non-arousal group (*; $p < .05$). Subjective arousal change scores (pre to post video) are also shown (emotional intensity scores; EIS; negative adjective sum). The arousal group reported more negative feelings while the non-arousal group reported less negative feelings after their respective videos (*; $p < .05$).

in absolute scores within and between groups (and was planned for this reason), a one-way ANOVA comparing the HR difference or change scores (tape—baseline, post-tape—baseline) between groups showed that the arousal group had significantly higher heart rate than the non-arousal group during the stimulus ($F(1,33) = 5.2$, $p = .03$) and post-stimulus intervals ($F(1,33) = 5.6$, $p = .02$). The comparison of change scores (tape—baseline, post-tape—baseline) between groups for GSR showed no difference between the groups (tape: $F(1,33) = 0.5$, $p = .83$; post-tape: $F(1,33) = .19$, $p = .66$). Subjective response to the arousal manipulation, measured using the self-report adjective rating scale, were compared using a difference score analysis between post- and pre-video sums. One-way ANOVA showed a significant difference between the groups ($F(1,33) = 9.7$, $p = .004$), where the non-arousal group had lower negative affective ratings than the arousal group. These results are shown in Fig. 2.

4. Discussion

The purpose of the present study was to investigate the ability of emotional arousal induced after learning to affect memory consolidation, and whether it is necessary for the source of arousal to be semantically associated with the learned material for modulation to occur. The results of this study support the hypothesis that emotionally induced arousal enhances delayed memory performance. Significantly better recall and recognition scores were obtained for the arousal group than for the non-arousal group on the 30 min test and on both 24 h delayed retention tests. The difference averaged more than 8% for recall (approximately 2.5 items), and 13% for recognition (approximately 3.9 items). Although galvanic skin response did not show a significant effect of arousal, moderate physiological arousal was documented by a significant increase in heart rate. Therefore, the present findings are consistent with those of previous studies in both the animal and human literatures demonstrating that memories are consolidated over time and that the events occurring shortly after learning can modulate memory (McGaugh, 2000; Nielson & Jensen, 1994; Nielson et al., 1996; Shaw et al., 1995).

In the present study, memory was significantly enhanced in the arousal group by a semantically unrelated emotional stimulus. These results contrast with other studies whose authors concluded that the arousal source must be related to the to-be-remembered material (e.g., Christianson & Mjörndal, 1985; Christianson, Nilsson, Mjörndal, Perris, & Tjelldén, 1986; Libkuman et al., 1999). Importantly, the memory stimuli were both temporally and semantically distinct from the source of arousal. The contradictory findings could be due to the isolation of the effect in the present study to the memory consolidation interval, which prevented confounding with encoding or attention effects, or material differences across conditions. In addition or alternatively, the contrasting findings could be due to the use of short-term retention tests in past studies, which is not ideal to measure retention because arousal inhibits retrieval in the short-term (e.g., Nielson & Jensen, 1994; Nielson et al., 1996; Revelle & Loftus, 1992) and consolidation effects appear later in time (McGaugh, 2000; Revelle & Loftus, 1992; Torras-Garcia et al., 1997; Walker, 1958). Indeed, Quevedo et al. (2003) demonstrated that an emotional version of a story produced better long-term (1 week) retrieval but not short-term (1 h) than did a matched neutral version. The authors concluded that the amygdala plays a role in long-term but not short-term memory mechanisms. An alternative interpretation is that the effects of arousal, via the amygdala, had not yet consolidated enough to show the effect. These results are consistent with the current study.

A variety of substances, including glucose and the adrenal stress hormones epinephrine and cortisol are released into the bloodstream during times of arousal; stress and emotion and have been closely linked to memory consolidation via peripheral or central receptors and brain stem actions (e.g., nucleus of the solitary tract) (cf. McGaugh, 2000). These in turn affect amygdala activation via norepinephrine, and its basolateral β-adrenergic receptors play a central role in both adrenergic and

glucocorticoid effects on memory by modulating hippocampal and striatal activity (cf. McGaugh, 2000). The current study indirectly supports this biological model. The learned material was not inherently arousing, but an arousing stimulus presented after learning enhanced later retrieval. The arousal response was validated by both subjective response and heart rate, suggesting an adrenal hormone response. Very compatible heart rate and memory modulation results were reported in a previous study that also verified that the mechanism of action of the effect involves β-adrenergic receptors (Nielson & Jensen, 1994).

The present findings suggest that arousal induced after learning could potentially enhance retention for any type of material. Livingston (1967) proposed such an idea, that hormone response to stress that occurs after learning can modulate memory for any recently acquired information. Our findings are consistent with this proposition, as were a number of other studies using an arousing treatment after learning of non-emotive stimuli (Colrain et al., 1992; Manning et al., 1992; Nielson & Jensen, 1994; Nielson et al., 1996). However, the present findings contrast with a recent few recent studies that suggest that post-learning arousal may only be effective to modulate inherently arousing stimuli (Cahill, Gorski, & Le, 2003) or that some amount of arousal or novelty at encoding is necessary for post-learning arousal treatments to modulate memory (Cahill & Alkire, 2003; Okuda, Roozendaal, & McGaugh, 2004). The present study cannot directly address these issues because arousal was not measured during encoding. However, because post-training arousal enhanced overall retention for a 30-item word list, it is unlikely that situational arousal at the beginning of the session was responsible. Alternatively, novelty of the task and situation could have interacted with arousal induced after learning. Yet, college students frequently experience very similar learning situations and tasks and do not have elevated subjective or physiological baseline arousal, prior to task commencement, relative to later in the session (Nielson & Jensen, 1994; Stone & Nielson, 2001). Moreover, memory modulation systems might preferentially affect memory for arousing information when such information occurs, but be less preferential when information is more neutral. Furthermore, both epinephrine and norepinephrine given after learning can enhance memory for emotional materials (Cahill & Alkire, 2003; Southwick et al., 2002), but epinephrine's effects may be only for emotional materials (Cahill & Alkire, 2003), suggesting that the two mechanisms may have differential roles depending on task or stimulus conditions.

Cortisol release associated with the arousal could also be responsible for the current effects. Although several studies have shown that cortisol given before learning or just before retrieval impairs memory retrieval, cortisol levels likely remained elevated at retrieval during these studies (de Quervain et al., 2003; de Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2000; Kuhlmann, Kirschbaum, & Wolf, 2005; Wolf et al., 2001). When given shortly after learning and when levels return to baseline prior to testing, a number of studies show that glucocorticoids alter memory consolidation in an inverted-U fashion, similar to epinephrine (Abercrombie, Kalin, Thurow, Rosenkranz, & Davidson, 2003; de Quervain et al., 2000). Indeed recent research suggests that adrenergic and glucocorticoid hormones may interact (Maheu, Joober, Beaulieu, & Lupien, 2004), indicating that further studies are needed to evaluate their specific roles in arousal and memory modulation studies.

The arousal stimulus induced heart rate changes but not GSR changes. Heart rate has complex physiological control, innervated by both the sympathetic and parasympathetic nervous systems. The Intake-Rejection hypothesis (Lacey & Lacey, 1970) states that stimulus intake (externally oriented processing) typically causes heart-rate deceleration, while stimulus rejection (internally oriented processing) typically causes heart-rate acceleration. Indeed, when stimuli vary on valence, and particularly when they are unpleasant, deceleration often occurs (Gomez, Zimmermann, & Guttormsen-Schar, 2005; Kemp & Nathan, 2004), while stimuli associated more with stronger arousal responses, fear, imagery or social induction tasks often show acceleration (Ekman, Levenson, & Friesen, 1983; Witvliet & Vrana, 1995). Based on this literature, heart rate deceleration might have been expected in the current study. However, the 3 min video of live-action oral surgery produced significant heart rate acceleration. It was negatively valenced, but also with uncomfortable sights of blood and sounds of drilling and suctioning. Dental procedures have strong negative imagery and often provoke fear reactions. Furthermore, heart rate was significantly elevated by this same stimulus in another study (Stone & Nielson, 2001). Thus, this stimulus likely produces rejection processing. Nevertheless, emotional or arousing stimuli of both positive and negative valence produce adrenal activity and stress hormone release, which can influence memory consolidation (e.g., McGaugh, 2000; Nielson & Bryant, 2005; Nielson & Jensen, 1994; van Stegeren et al., 1998). It remains to be evaluated whether heart rate acceleration or deceleration associated with emotional or arousing stimuli produce differential effects on memory consolidation.

Several recent studies have indicated gender differences in the processing of emotional memories (Cahill et al., 2001; Canli, Desmond, Zhao, & Gabrieli, 2002) and responsiveness to memory modulation techniques (Cahill & van Stegeren, 2003). Indeed, one recent study found gender-role identity differences, rather than actual gender differences in emotional memory scores (Cahill, Gorski, Belcher, & Huynh, 2004). The present study was not designed to evaluate gender differences, having a nearly

2:1 ratio of females to males, which would yield small cell sizes if further analyzed by gender. The ever-increasing ratio of female to male students in psychology programs, who constitute the participants for many such studies, frequently results in this discrepancy. Although this is difficult to address, gender and gender-related effects should be more specifically evaluated in future studies.

In summary, participants who viewed an emotionally arousing videotape after learning a list of words exhibited a significantly greater acute arousal response and significantly better delayed memory performance (30 min and 24 h) than subjects who viewed a non-arousing tape after learning. These findings are consistent with both animal and human studies, demonstrating that emotion and arousal affect the consolidation of memory after the learning event and, contrary to some reports, that the source of arousal need not be associated with the material to be remembered. These findings further suggest that such a technique could be applied as a memory intervention strategy and that it could be effective for a wide variety of learning situations.

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