Remembering emotional experiences: The contribution of valence and arousal

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Synopsis: Emotional experiences can be described by two factors: valence (how negative or positive) and arousal (how calming or exciting). Although both dimensions appear to influence memory, they may do so via distinct mechanisms. The amygdala likely plays a specific role in modulating memory for arousing experiences, whereas non-amygdalar networks may be instrumental in enhancing memory for nonarousing positive or negative events.

Introduction

We remember only a fraction of life's experiences. While a multitude of factors can influence the likelihood that an event is remembered, one important contributor is the emotional salience of the event: Events that contain emotional relevance are often more likely to be remembered than events devoid of emotional import. This memory-enhancing effect of emotion has been demonstrated in a large number of laboratory studies, using stimuli ranging from words to pictures to narrated slide shows (reviewed by Hamann, 2001 [#37]; Bradley et al., 1992 [#10]; Buchanan & Adolphs, 2002 [#12]; Christianson, 1992 [#20]). Data from studies of autobiographical memory converge with the findings from the laboratory: Individuals are more likely to remember personal experiences that contain some emotional salience (Conway et al., 1994 [#22]). Neuroimaging research and studies of brain lesioned patients have begun to clarify the neural processes contributing to memory for neutral and emotional experiences. In this review, I outline how these studies have begun to elucidate the effects that emotion has on the neural processes that allow us to remember information, focusing on the distinct effects exerted by valence and arousal (defined below) on declarative memory formation.
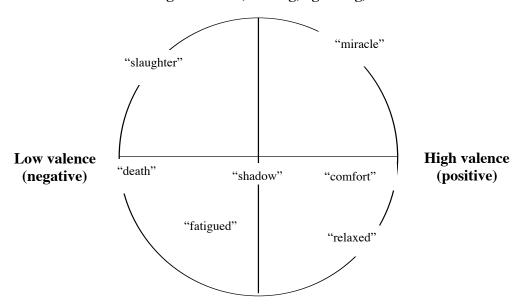
Dimensions of Emotion: Arousal and Valence

To fully understand the ways in which emotion effects memory, it is important to recognize that emotional and neutral stimuli likely differ from one another in more than one dimension. A widely-accepted framework proposes that affective experiences are best characterized in a two-dimensional space (Figure 1). The dimension of valence ranges from highly positive to highly negative, whereas the dimension of arousal ranges from calming or soothing to exciting or agitating (Russell, 1980 [#72]; Lang et al., 1992 [#50]). Thus, there can be events that are negative and agitating; positive and soothing; positive and exciting; etcetera.

The majority of studies investigating declarative memory for emotional experiences have compared memory for neutral events (i.e., events that are neither highly positive nor highly negative; and that are not exciting or agitating) with events that are both arousing (i.e., exciting or agitating) and at an extreme on the valence dimension (either highly positive or highly negative). These studies leave unanswered the relative contributions of the valence dimension and the arousal dimension to the memory enhancement effect.
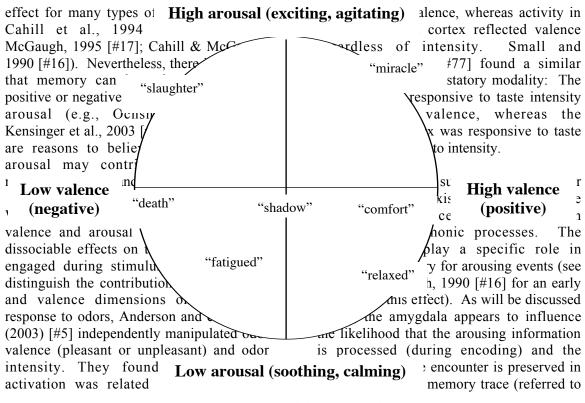
Emotional arousal clearly is a critical factor contributing to the emotional enhancement

Figure 1. Affective experiences may be best described in two dimensions: Valence refers to how positive or negative an event is, and arousal reflects whether an event is exciting/agitating or calming/soothing. Words have been placed at locations within this space, indicating their approximate valence and arousal ratings (ratings from Bradley & Lang, 1999 [#11]).

effect for many types of [...] alence, whereas activity in Cahill et al., 1994 [...] cortex reflected valence McGaugh, 1995 [#17]; Cahill & McG[...] [...]rdless of intensity. Small and 1990 [#16]). Nevertheless, there[...] [...]#77] found a similar that memory can [...] statory modality: The positive or negative [...] responsive to taste intensity arousal (e.g., Ochsn[...] [...] valence, whereas the Kensinger et al., 2003 [...] [...]x was responsive to taste are reasons to belie[...] [...]to intensity. arousal may contr[...]

valence and arousal [...] [...]honic processes. The dissociable effects on [...] [...]play a specific role in engaged during stimul[...] [...]y for arousing events (see distinguish the contribution [...] [...]h, 1990 [#16] for an early and valence dimensions o[...] [...]his effect). As will be discussed response to odors, Anderson and [...] [...]he amygdala appears to influence (2003) [#5] independently manipulated o[...] [...]he likelihood that the arousing information valence (pleasant or unpleasant) and odor is processed (during encoding) and the intensity. They found [...] [...]e encounter is preserved in activation was related memory trace (referred to

as storage or consolidation). In contrast, although nonarousing events that are highly positive or highly negative can also be better remembered than neutral events, this enhancement may occur independently of amygdala activation.

Emotional Arousal and Encoding
We are often confronted with a panoply of sensory information, more than can be processed simultaneously. Attentional networks are therefore required to select the relevant sensory information to which we should attend. Critical effects of emotional arousal relate to modulation of attention. First, attention appears to be focused on emotionally arousing stimuli, increasing the likelihood that emotional aspects of experiences are perceived. Second, emotionally arousing items appear privy to prioritized or facilitated processing, such that emotional items can be processed even when attention is limited (reviewed by Dolan & Vuilleumier, 2003 [#30]). Because the ability to attend to and to perceive stimuli is a necessary requirement for remembering information, these effects of emotional arousal on attention influence the frequency with which emotional information is remembered.

Arousal and Selective Attention
The capture of attention by emotional stimuli has been demonstrated in a variety of tasks. For example, when asked to perform a visual search task, participants are faster and more accurate at detecting emotional stimuli, such as snakes or spiders embedded within a display of stimuli, than at detecting neutral stimuli such as flowers or mushrooms (Ohman et al., 2001 [#64]). Spatial orienting tasks show similar effects. On these tasks, participants are instructed to respond to a target stimulus that can appear in one of two locations on a screen (e.g., on the left or the right). Preceding the target's presentation is a cue item, presented either on the left or the right. With regard to emotion, the critical finding is that participants are faster to identify target stimuli when they occur in the same location

as an emotional cue compared to when they occur in the opposite location as the emotional cue (Armony & Dolan, 2002 [#8]; Mogg et al., 1997 [#58]). In other words, attention appears to be directed toward the emotional cue, facilitating the processing of information presented in that spatial location.

Arousal and Selective Attention: Implications for Memory
These effects of emotional arousal on attention lead to specific predictions with regard to memory performance. Since attention seems to be directed selectively toward emotional stimuli, individuals should be more likely to attend to emotional elements in a scene and less likely to attend to other neutral elements (Figure 2). Thus, memory for the emotional element of the scene should be enhanced, while memory for the neutral elements should be reduced. Easterbrook (1959) [#31] originally proposed this effect of emotional arousal on memory in his "cue-utilization" theory. He predicted that emotional arousal would decrease the attentional resources available for information processing, thus restricting the focus of attention to the arousal-eliciting stimulus. As a consequence, information central to the source of the emotional arousal would be encoded while peripheral details would be reduced. His prediction has been upheld in investigations of eyewitness testimony as well as in the laboratory (reviewed by Buchanan & Adolphs, 2002 [#12]).

This effect of emotional arousal on eyewitness testimony has been termed the "weapon-focus" effect (Loftus, 1979 [#52]): Witnesses to a crime often will remember the weapon from the crime but not other details such as the perpetrator's clothing or vehicle. This effect has been replicated in the laboratory. Participants spend a disproportionate amount of time looking at a weapon in a scene. Further, this looking time is inversely related to the likelihood that individuals will subsequently identify the perpetrator of the crime (Loftus, Loftus,

Figure 2. When encountering an arousing stimulus (A), attention is often focused on the emotional element of the scene and diverted from nonemotional details in the periphery (B).

& Messo, 1987 [#53]). More broadly, the presence of any emotionally arousing component in a scene has often been found to reduce the likelihood that the details of other, nonemotional elements of the scene are remembered (reviewed by Buchanan & Adolphs, 2002 [#12]).

Arousal and Prioritized Processing

The capture of attention is not the only means through which emotional arousal can affect encoding. Emotional items also appear more likely to be processed when attention is limited, suggesting a facilitated or prioritized processing of emotional information. One study demonstrated this effect of emotion using a phenomenon known as "attentional blink" (Raymond et al., 1992 [#69]; Chun & Potter,1995 [#21]). To elicit this effect, participants are asked to attend to a couple of target items. When the target items are presented in close temporal proximity within a stream of rapidly presented stimuli, participants often miss the second target item. It is as if there were a "blink" of attention following the first target's presentation, reducing the likelihood that the second target stimulus is attended.

The intriguing finding with regard to emotional arousal is that, if the second target stimulus elicits arousal (e.g., is a "taboo" word), participants are less likely to miss the target's presentation (Anderson & Phelps, 2001 [#6]). This finding suggests that arousing items are more likely to be processed under conditions of limited attention than neutral items.

Other evidence of facilitated processing of emotional information comes from studies of patients with visual extinction. Extinction is relatively common following right parietal lobe damage, and describes a deficit in directing attention toward contralesional space when competing stimuli are presented in the ipsilesional space. Emotion appears to modulate the magnitude of the deficit. Thus, items that signal emotional relevance (e.g., spiders) are more likely to be processed in the presence of competing distractors than nonemotional items (e.g., flowers; Vuilleumier et al., 2001 [#82]; Vuilleumier & Schwartz, 2001 [#83]; Vuilleumier et al., 2002 [#81]; see deGelder et al., 1999 [#29] for similar finding in patients with blindsight).

Arousal and Prioritized Processing: Implications for Memory

The fact that emotionally arousing items are more likely to be processed with limited attention than neutral items has important implications for memory performance. Empirical and anecdotal evidence indicates that we typically are less able to learn information when our attention is divided between two tasks. In the laboratory, this effect is often demonstrated by asking participants to learn a series of items while simultaneously performing a secondary task (e.g., auditory discrimination). The critical behavioral finding is that memory is poorer following encoding with the secondary task than with no task, and performance often tracks the difficulty of the secondary task. In other words, encoding is less successful when simultaneously performing a harder version of the discrimination task than when simultaneously performing an easier version of the task (Baddeley, 1984 [#9]; Craik et al., 1996 [#25]; Naveh-Benjamin et al., 2000 [#60] [#61]).

If processing of arousing items is less likely to suffer from demands on attention, then memory for arousing items should be less affected by the performance of the secondary task than memory for neutral items. Indeed, this is exactly the result that has been obtained in a couple of behavioral experiments. Kensinger and Corkin (2004) [#45] asked participants to encode words either as the sole task, or while concurrently performing an auditory discrimination task. Results showed that participants' memory for the neutral items was markedly affected by the performance of the secondary task, whereas their memory for the arousing items was not (see also Bush & Geer, 2001 [#13]). In other words, the emotionally arousing items were more likely than the neutral to be processed, and thus remembered, even when the amount of attention devoted toward learning was limited by performance of the distracting task.
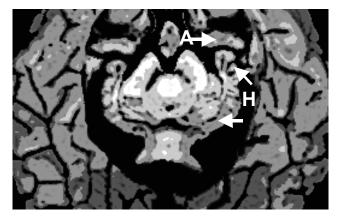
Attention and the Amygdala

These findings suggest that arousing items can be selectively attended and can benefit from prioritized or facilitated processing. What neural processes may support these attentional effects? Patient and neuroimaging studies have implicated the amygdala (Figure 3).

Patients with amygdalar damage do not show modulation of attention by emotional arousal. They are no more likely to notice arousing targets presented during the attentional blink than they are to notice neutral targets (Anderson & Phelps, 1998 [#6]). Further, patients with bilateral amygdala damage do not show the trade-off between memory for the central, emotional detail of scenes and the nonemotional details (Adolphs et al., 2001 [#2]). These patient data provide evidence that the amygdala plays a critical role in mediating selective attention toward emotional stimuli and the "weapon-focus" effect on memory.

Neuroimaging studies have helped to clarify the ways in which the amygdala may modulate attention. These studies have provided evidence that the amygdala is

Figure 3. In this image, the ventral portions of the brain have been dissected to allow viewing of the amygdala (A) and hippocampus (H). The amygdala plays a critical role in influencing memory for emotional experiences. Many of these effects likely emerge from interactions between the amygdala and hippocampus.

activated by at least some emotional stimuli, such as fearful faces, under conditions of limited attention (but see Pessoa et al., 2002 [#66] for evidence that some attention may be required for processing of emotional information). Thus, the amygdala shows increased activity in the presence of an emotional stimulus compared to a neutral stimulus even when attention is not directed to the emotional stimulus (Vuilleumier et al., 2001 [#82]; Morris et al., 1998 [#59]; Whalen et al., 1998 [#84]; Glascher & Adolphs, 2003 [#35]). When the amygdala is activated, it then appears to bias sensory processing, likely due to its robust connections with lower-level sensory regions (Amaral et al., 1992 [#3]; Amaral et al., 2003 [#4]). Thus, during presentation of an emotional stimulus, activity in visual regions is increased (Morris et al., 1998 [#59]; Vuilleumier et al., 2001 [#82]), and the amount of activity in the amygdala and in visual cortex is correlated (Tabert et al., 2001 [#79]). Ultimately, this biasing of sensory processing increases the likelihood that the emotional stimulus will become the focus of attention (LeDoux, 1995 [#51]; Davis & Whalen, 2001 [#28]).
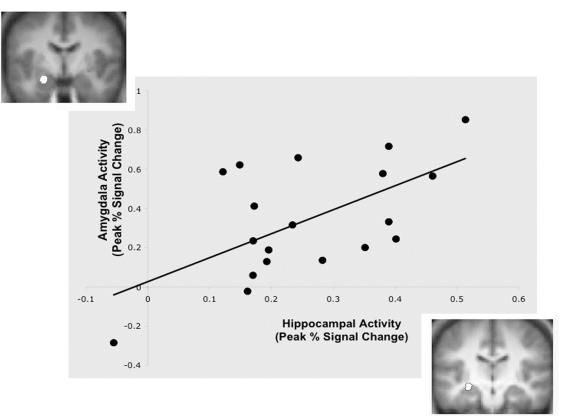
Emotional Arousal and Storage
In addition to its effects during the encoding phase, emotional arousal also appears to increase the likelihood of memory consolidation. For example, memory enhancements for emotional information tend to be greater after longer delays than after relatively short ones (Eysenck, 1976 [#32]; Heuer & Reisberg, 1990 [#39]; Kleinsmith & Kaplan, 1963 [#47]; LaBar & Phelps, 1998 [#49]). This effect of delay is consistent with the proposal that emotionally arousing memories are more likely to be converted into a relatively permanent trace, whereas memories for nonarousing events are more prone to disruption.

<u>Interactions Between Amygdala and Hippocampus</u>
Stronger evidence for an effect of emotional arousal on storage comes from animal studies demonstrating interactions between the amygdala and the hippocampus. These studies have provided convincing demonstrations that the amygdala is able to influence hippocampal consolidation via the action of stress hormones (McGaugh, 2000 [#56]; McGaugh & Roozendaal, 2002 [#57]).

Though this consolidation theory was derived through animal research, human studies have confirmed a role of the amygdala in emotional memory. Patients with amygdalar lesions show a blunted memory enhancement for emotional information (e.g., Adolphs et al., 1997 [#1]; Cahill et al., 1995 [#14]; Hamann et al., 1999 [#38]; Markowitsch et al., 1994 [#55]; Phelps et al., 1998 [#67]), and they do not show resiliency of memory for emotionally arousing information over increasing delays (LaBar & Phelps, 1998 [#49]). Neuroimaging studies have revealed a link between the amount of amygdalar activation at encoding and the likelihood of remembering emotional information (Cahill et al., 1996 [#15]; Canli et al., 2000 [#19]; Hamann et al., 1999 [#38]). Thus, evidence converges on the amygdala's role in enhancing memory for emotionally arousing information.

While these studies cannot confirm that the amygdala's role stems from its modulation of consolidation processes rather than from effects at encoding, a couple of neuroimaging studies have provided data to support the consolidation interpretation. In one study, participants underwent an fMRI scan as they studied a series of words; some words were neutral, some were negative and nonarousing, and others were arousing. Activity in the hippocampus related to successful memory formation for all of the word types (i.e., the amount of hippocampal activity during study predicted whether the words would later be remembered or forgotten). Amygdala activity also related to successful memory formation, but only for the arousing words. Critically, the amount of activity in the amygdala and the hippocampus was correlated during the

Figure 4. During the encoding of arousing words that would later be remembered, the magnitude of activation in the left, anterior hippocampus (x-axis) correlated with the magnitude of activation in the left amygdala (y-axis). Adapted from Kensinger & Corkin, 2004 [#45].

encoding of arousing words (Kensinger & Corkin, 2004 [#45]; see Figure 4). These results provide evidence of a link between hippocampal activity, amygdala activity, and subsequent memory for arousing items (see also Hamann et al., 1999 [#38]).

These correlations between amygdala and hippocampal activity cannot speak to the direction of modulation (i.e., amygdalar influence of hippocampal function or vice-versa; and see Richardson et al., 2004 [#70] for evidence of bi-directional influences). To address the question of directionality, structural equation modeling was conducted on data acquired using positron emission tomography. The model supported the conclusion that during encoding of emotionally arousing information, the amygdala exerts a greater influence on the parahippocampal gyrus (a region of the hippocampal formation) than during encoding of neutral information

(Kirkpatrick & Cahill, 2003 [#46]). These lines of research provide converging evidence that amygdalar influences on hippocampal function play a critical role in modulating memory for emotionally arousing experiences.

Emotional Valence and Encoding
In comparison to the large number of studies investigating memory for arousing items, relatively few studies have examined memory for nonarousing positively or negatively valenced information. Nevertheless, the studies that have examined memory for these stimuli have suggested that the valence dimension is sufficient to boost memory performance: Thus, there are instances in which nonarousing items with positive or negative valence are better remembered than neutral ones (Kensinger & Corkin, 2003 [#44]; Kensinger et al., 2002 [#42]; Ochsner, 2000 [#63]; LaBar & Phelps, 1998 [#49]).

The processes contributing to this enhancement, however, likely are distinct from those mediating the enhanced memory for arousing items. In contrast to the relatively automatic, attentional modulation discussed with regard to memory for arousing information, memory for nonarousing positive or negative stimuli may benefit instead from conscious encoding strategies, such as elaboration.

Valence and Elaboration
Elaboration refers to the process of establishing links between newly encountered information and previously stored information. It has long been known that when individuals process items in an elaborative fashion, such that meaning is extracted from items and inter-item associations are formed, memory is enhanced (Craik & Lockhart, 1972 [#26]; Craik & Tulving, 1975 [#27]; Craik, 2002 [#24]). A viable proposal is that, for positive and negative nonarousing stimuli, this ability to elaborate on the items is what leads to the enhanced memory. This elaborative processing could take at least two forms: Autobiographical and semantic.

Autobiographical elaboration is known to benefit memory. For example, when individuals are asked to process stimuli in regard to themselves (e.g., deciding whether words would describe them), memory is enhanced as compared to when the items are processed for meaning, but not in relation to the self (Rogers et al., 1977 [#71]; Macrae et al., 2004 [#54]). Thus, it is plausible that autobiographical elaboration may explain the memory benefit for nonarousing positive or negative items. It is reasonable that words such as "sorrow" or "comfort" may be more likely to be associated with autobiographical experiences or self-introspection than neutral words such as "shadow".

Another possibility is that individuals are more likely to semantically elaborate on the valenced items – to think about the items' meanings, and their relations to other items.

Although this semantic elaboration could occur for a number of reasons, one possibility is that valenced items contain a semantic cohesiveness typically not present with neutral items. Consistent with this proposal, in at least some instances, the memory advantage for emotionally valenced items is reduced or eliminated when memory is compared for valenced words and neutral words with similar inter-item associations (LaBar & Phelps, 1998 [#49]; Talmi & Moscovitch, in press [#80]).

Numerous studies have shown that divided attention at encoding decreases a person's ability to carry out controlled encoding processes, such as autobiographical or semantic elaboration. Therefore, if these types of elaborative processes underlie the memory enhancement for nonarousing positive and negative items, then dividing people's attention as they encode these items should disrupt the memory advantage. This prediction has been upheld in a couple of studies showing that participants' memory for negative nonarousing words suffers with divided attention (Bush & Geer, 2000 [#13]) and that the memory advantage for negative, nonarousing words can be eliminated when participants encode items while simultaneously performing a secondary task (Kensinger & Corkin, 2004 [#45]). These findings lend credence to the hypothesis that additional elaborative processing may underlie the memory enhancement at least for negative nonarousing words. Further research will need to be conducted to examine whether the same is true for positive nonarousing words.

Valence and Prefrontal Cortex
What neural processes could underlie the boost in elaboration for valenced items? Numerous lines of research have pointed to a role of the prefrontal cortex in mediating elaborative processing. First, individuals with prefrontal damage tend not to engage in controlled, self-initiated encoding strategies to help them integrate information (e.g., Hildebrandt et al., 1998 [#40]; Pillon et al., 1993 [#68]; Gershberg & Shimamura,1995

[#34]; Shallice & Burgess, 1991 [#74]). Second, a number of neuroimaging studies have demonstrated correlations between depth-of-processing and prefrontal activity. That is, tasks that require more elaboration result in greater prefrontal activation (Sharp, Scott & Wise, 2004 [#76]; Savage et al., 2001 [#73]). Further, the amount of activity in the prefrontal cortex during encoding relates to the likelihood that information is later remembered (reviewed by Paller & Wagner, 2001 [#65]), consistent with the long-term memory advantage conferred by elaborative encoding. Third, dividing a person's attention during encoding modulates prefrontal activity (Fletcher et al., 1995 [#33]; Shallice et al., 1994 [#75]; Anderson et al., 2000 [#7]; Iidaka et al., 2000 [#41]) and alters the relation between activity in some prefrontal regions and subsequent memory performance (Kensinger et al., 2003 [#43]).

Based on this research, it would be plausible to propose that memory for the nonarousing positive and negative items is boosted due to differential engagement of prefrontal networks implicated in controlled, elaborative encoding. Suggestive evidence to support this hypothesis comes from a study in which young and older adults' memory was compared for neutral, negative nonarousing, and arousing words. While young and older adults both showed memory enhancement for the arousing as compared to the neutral words, only the young adults showed memory enhancement for the negative nonarousing words as compared to the neutral words (Krendl et al., 2003 [#48]). This result is consistent with data showing that older adults are impaired in using prefrontally-mediated self-initiated encoding strategies (Craik, 1977 [#23]; Glisky et al., 2001 [#36]; Naveh-Benjamin et al., 2003 [#62]; Spencer & Raz, 1995 [#78]).

To more directly test the role of the prefrontal cortex in the enhancement for negative nonarousing items, Kensinger and Corkin (2004) [#45] compared memory for neutral words, nonarousing negative words, and negative arousing words. As discussed earlier, amygdala-hippocampal interactions appeared critical for the enhancement for the arousing words. Amygdala activity, however, was not related to the likelihood of remembering the negative nonarousing words. Rather, activity in the prefrontal cortex and the hippocampus related to successful memory formation for the negative nonarousing items, and also for the neutral items. Further, the activity in these regions related more strongly to subsequent memory for the negative nonarousing items than for the neutral items. This result is consistent with the hypothesis that the memory benefit for the nonarousing negative items results from additional engagement of controlled cognitive processes (e.g., elaboration) that also underlie memory for neutral information.

If memory for nonarousing positive and negative items is enhanced due to engagement of regions aside from the amygdala (e.g., prefrontal-hippocampal interactions), then amygdalar damage should not disrupt the enhancement for these items with emotional valence but not arousal. While few data speak to this hypothesis, the one study to examine memory for nonarousing positive and negative stimuli in a patient with amygdalar damage found that the patient showed enhancement for these words (LaBar & Phelps, 1998 [#49]).

Summary
The dimensions of valence and arousal appear to influence declarative memory via modulation of distinct processes. For arousing items, the amygdala plays a critical role in the memory enhancement by modulating encoding as well as consolidation processes. Nonarousing positive or negative items, in contrast, appear to be remembered due to recruitment of processes independent of the amygdala. At least for nonarousing negative stimuli, it is likely that enhanced engagement of controlled encoding processes (e.g., elaboration) underlies the memory benefit.

Further investigation is needed to examine whether the role of elaboration is as central for positive nonarousing information.

Acknowledgements

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