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Affective Arousal as Information: How Affective Arousal Influences Judgments, Learning, and Memory

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Abstract

The affect-as-information framework posits that affect is embodied information about value and importance. The valence dimension of affect provides evaluative information about stimulus objects, which plays a role in judgment and decision-making. Affect can also provide evaluative information about one's own cognitions and response inclinations, information that guides thinking and reasoning. In particular, positive affect often promotes, and negative affect inhibits, accessible responses or dominant modes of thinking. Affect thus moderates many of the textbook phenomena in cognitive psychology. In the current review, we suggest additionally that the arousal dimension of affect amplifies reactions, leading to intensified evaluations, increased reliance on particular styles of learning, and enhanced long-term memory for events. We conclude that whereas valenced affective cues serve as information about value, the arousal dimension provides information about urgency or importance.

All living creatures have in common the necessity of continually evaluating aspects of their environment. Even animals as primitive as snails are apparently guided by a hedonic decision mechanism that weighs the need for nutrients against the potential risk from predators (Gillette, Huang, Hatcher, & Moroz, 2000). In humans, such evaluative processes are examined in a variety of models, including the affect-as-information model (Clore & Storbeck, 2006; Schwarz & Clore, 2007). That model proposes that pleasant, unpleasant, and arousing reactions provide bodily and experiential information about the positive value, the negative value, and the importance of whatever is encountered. This information serves as a basis for judgments and decisions, as a guide for cognitive processing, and as a signal for the regulation of long term memory.

In this view, making judgments and decisions often involves asking oneself, 'How do I feel about it?' (Schwarz & Clore, 1988). To the extent that a particular judgment object or decision alternative is experienced as the source of an affective reaction, it should take on the positive or negative value of the affect. Similarly, in task situations, to the extent that affect is

experienced as feedback about current thoughts and inclinations, such thoughts and inclinations should take on the positive or negative value of the affect. Cognitive tasks generally elicit relational processing (relating incoming information to what one already knows). Positive affect should maintain and promote such processing, whereas negative affect, which implies a problem with one's approach, should result in the use of the alternative possibility, item-specific processing (see Clore & Storbeck, 2006 for a review). Thus, affective cues attributed to judgment objects and decision alternatives can govern judgments and decisions, whereas affect experienced as feedback about task-relevant thoughts and inclinations can regulate styles of thinking.

Two studies, in particular, illustrate the roles of affect in judgments on the one hand and learning styles on the other. One of these studies (Schwarz & Clore, 1983) found affective influences on judgments of life satisfaction. Individuals were asked how satisfied they were with their lives on either rainy or sunny days in early Spring. People experiencing a sunny day were found to be in happier moods and to be more satisfied with their lives than people experiencing a rainy day. Another group was first asked about the weather and only then about life satisfaction. They too were happier on sunny than on rainy days, but their life satisfaction ratings were unaffected by their moods. The results indicated that it was not mood per se that influenced people's judgments, but the information that participants' feelings seemed to convey about their underlying life satisfaction. This kind of result has been found commonly in the social psychological literature, leading to the conclusion that judgments, decisions, preferences, and attitudes may all reflect current or anticipated affect (e.g., Baumeister, Vohs, & Tice, 2006; Cabanac, Guillaume, Balasko, & Fleury, 2002).

The second illustrative study (Storbeck & Clore, 2005) found affective influences on styles of learning rather than on evaluative judgments. When people are confronted with cognitive tasks, their affect can confer value on particular thoughts and styles of processing. Specifically, the affect-as-information approach suggests that positive affect should promote the use of relational processing (the dominant style of processing in such tasks), whereas negative affect should inhibit that dominant style of processing, making the non-dominant style of item-specific processing more likely. Storbeck and Clore (2005, forthcoming) tested this assumption using a paradigm in which relational processing produces false memories (Brainerd & Reyna, 1998; Hege & Dodson, 2004). Word lists were presented after the mood manipulation. Each word within a given list was related to a single, non-presented word referred to as a critical lure. For example, a list including such words as bed, pillow, wake, rest, and dream should prime the critical lure 'sleep'. As predicted, happy individuals did produce more false memories (i.e., recalled more critical lures) than sad individuals. Follow-up studies found that differences in retrieval strategies or motivation cannot account for these false memory effects (Storbeck & Clore, 2008). The results thus

suggest that affective cues can guide cognitive processing by imparting value to accessible learning styles.

The goal of the affect-as-information and related approaches is to understand the transformative power of affect on cognition. These approaches generally assume that there is adaptive value in having ready access to one's attitudes (Fazio & Powell, 1997) and in being able to read one's own and others' affective reactions (Mayer, Salovey, & Caruso, 2004). This assumption is also consistent with research on the difficulties faced by individuals with damage to the pre-frontal cortex, damage that limits access to affective information (Damasio, 1994). In everyday life, affective reactions transform events, actions, and objects into *desirable or undesirable* events, *praiseworthy or blameworthy* actions, and *appealing or unappealing* objects (Ortony, Clore, & Collins, 1988).

Arousal as Information

Affective experience is often treated as having two dimensions – valence and arousal (e.g., Russell, 1980; Wundt, 1886). Research on affect has focused mainly on the valence or good–bad dimension. The arousal dimension has been examined less often, at least in recent years. In this review, we extend the affect-as-information approach to consider how arousal also serves as information by signaling *importance* or *urgency*. Specifically, arousal can play a role in judgments, processing, and memory, by indicating the personal relevance of an issue, the urgency of a potential response, or the importance of an event.

A number of questions surround the concept of arousal. To what does the term arousal refer? There appears to be no convincing evidence that arousal is a single, unitary entity (Neiss, 1988). It is sometimes thought of as activation (Russell & Barrett, 1999), motivation, or tension (Thayer, 1989). Within a given emotion, is arousal the same thing as emotional intensity? That might be the case if emotional intensity is thought of as variations in the amplitude of an emotional response. But emotional intensity is itself multidimensional, involving a duration as well as an amplitude dimension (see, Frijda, Ortony, Sonnemans, & Clore, 1992).

Consistent with Russell and Barrett (1999), we treat arousal as a psychological concept associated with emotional states that is variously indexed by activation of the sympathetic nervous system, the autonomic nervous system, or the endocrine system. For example, the modulation of memory by arousal can occur with the activation of the peripheral or the central nervous systems or the various endocrine systems (see McGaugh, 2004, for extensive review). A critical feature of our model is that any source of arousal can modulate judgment, thoughts, and memory, as long as it is implicitly attributed to or associated with an emotional reaction toward the object of that judgment, thought, or memory. For instance, the enhancement of memory can reflect either arousal that is actually elicited by the to-be-remembered

object (Cahill et al., 1996) or that comes from an irrelevant source, such as a cold presser task (Cahill, Gorski, & Le, 2003) or an upsetting film (Nielson & Powless, 2007), as discussed in the final section.

In this review, we conclude that arousal can be both beneficial and detrimental to cognitive performance. The Yerkes-Dodson law (1908) specified an inverted U-shaped curve with low levels of arousal having little impact on performance, medium levels enhancing performance, and high levels being detrimental. However, many investigators have failed to find support for such a curvilinear relation (Matthews, 1985; Neiss, 1988; Revelle & Loftus, 1992). More recent models propose that the influence of arousal on performance is determined by an interaction of personality style (e.g., extraversion, trait anxiety) and task requirements (e.g., Matthews, 1985, 2006; Revelle & Loftus, 1992). In a similar vein, we suggest that the interaction of affective arousal and processing style determines task performance. If the cognitive style invoked by affective arousal is appropriate for the task, performance will be benefited, but if inappropriate, performance should be impaired. This suggestion is compatible with much earlier work that focused on the interaction of arousal and task difficulty in performance (e.g., Bargh & Cohen, 1978). In the next section, we examine how arousal influences judgment, processing, and memory by conveying information about *urgency* or *importance.*

Judgments

According to the affect-as-information approach, people often make judgments essentially by asking themselves, 'How do I feel about it?' (Schwarz & Clore, 1988). Positive feelings then generally lead to positive judgments and negative feelings to negative judgments. But in addition to the information provided by affective valence, affective arousal or excitement should also provide information about the importance or personal relevance of objects and events. Therefore, part of asking, 'How do I feel about it?' may involve asking, 'How *strongly* do I feel about it?' If so, then we might expect that feeling strongly about something should intensify whatever value is signaled by affective valence. Thus, arousal may make an object seem more important or may intensify its apparent affective value so that positive objects seem more positive and negative objects more negative.

Marketing schemes often seek to exploit such effects to make products seem more desirable. Television advertisements for new cars, for example, may include arousing imagery, such as high-speed driving along dangerous roads or attractive and exciting models. If the resulting arousal is experienced as a reaction to the car itself, then any implicit positive evaluation and desire for the car might be expected to increase. A series of well-known studies by Zillmann and colleagues (e.g., Zillmann, 1971) show clearly that cues of emotional arousal are easily transferred from irrelevant target sources to relevant ones, but only when the arousal manipulation occurs in close

temporal proximity of the target judgment. We assume, then, that when asking oneself, 'How *strongly* do I feel about the car?' feelings of positive value may be intensified by both relevant and irrelevant sources of arousal.

According to the affect-as-information approach (Clore et al., 2001; Schwarz & Clore, 1983, 2007), the influence of affect on judgment requires that the affect be associated with, attributed to, or experienced as a reaction to the object of judgment. A classic experiment showing the role of such causal attributions for arousal was conducted by Dutton and Aron (1974). Participants crossed a high suspension bridge over a deep ravine, which induced an emotionally arousing state. On the other side of the bridge, the male participants met an attractive female experimenter, who debriefed them about the experiment, a process that included giving them her telephone number. The investigators found that a couple of days later, in comparison with a control group that crossed a low, non-arousing bridge, the aroused males were more likely to telephone her. Consistent with predictions, the young men tended to misattribute the feelings of arousal caused by the height of the bridge as a reaction to the woman, thus amplifying feelings of attraction to her.

Related processes have been found for evaluative judgments of famous individuals, cartoons, and advertisements. Specifically, when students made evaluations of famous faces while they were aroused by apprehension about upcoming exams, their evaluations were intensified compared to those of non-aroused students (Paulhus & Lim, 1994). In other research involving physical exercise, aroused individuals rated themselves as more amused by cartoons than did non-aroused individuals (Martin, Harlow, & Strack, 1992). Finally, judgments of advertisements have also been shown to be subject to the influence of arousal. Positive ads tended to be judged as more positive and negative ads as more negative when raters were aroused (Gorn, Pham, & Sin, 2001).

These and other studies suggest that arousal intensifies evaluative judgments. However, the effect is observed primarily when individuals assess their own feelings toward an evaluated object, not necessarily when asked to evaluate the target directly (Gorn et al., 2001; Martin et al., 1992). Affective feelings thus appear to serve primarily as explicit information about people's implicit reaction to objects, which are not necessarily taken to be indications of the quality of the objects themselves.

Brain activation patterns are also more intense when evaluating arousing targets. In research in which brain activation patterns were recorded as participants evaluated emotionally arousing words, the words judged as arousing increased brain activation, particularly in the amygdala, which is known to be involved in stimulus evaluation (Atchley, Stringer, Mathias, Ilardi, & Minatrea, 2007; Keil et al., 2003). In addition, when particular task goals increase the evaluative importance of stimuli, the amygdala becomes more active for both positive and negative stimuli (Cunningham, Van Bavel, & Johnsen, 2008). These results suggest that arousal may signal

the importance of stimuli by intensifying activation in areas of the brain involved in evaluation.

Judgments concerning memory, such as whether or not one has previously seen an item, are also influenced by arousal. For example, participants might study both emotional and non-emotional pictures and later, when shown several pictures, indicate whether they recognize them or not. In the recognition memory literature, investigators distinguish between a memory of actually seeing something (*remember*) and a memory based on a sense of something being familiar (*known*). A common finding is that emotional stimuli are more often recognized than non-emotional stimuli, and that people claim to remember them (I saw that picture and I remember the details) rather then merely knowing them (that picture looks familiar, but I do not remember any of the details) (Kensinger & Corkin, 2003; Ochsner, 2000). However, *remembering* the emotional stimuli better does not correlate with accuracy. Presumably, the brain sometimes treats the arousal from a stimulus as a cue of familiarity, and as a result, participants can misattribute feelings of perceptual fluency as *remembering* the event, even though their memory may not be any more accurate compared to a *known*, non-emotional event (Dougal & Rotello, 2007; Sharot, Delgado, & Phelps, 2004). Thus, arousal cues may lead to erroneous judgments of events as *remembered* when they are more likely *known* but not actually remembered.

The effects of arousal on judgment that we have reviewed appear to result from misattributions of arousal. As mentioned above, Zillmann's (1971) theory of excitation transfer maintained that arousal cues can be misattributed or transferred from one source to another. In that view, attribution of the arousal to the object of judgment is critical for finding such effects. A test of this hypothesis involved first priming positive, negative, or neutral ideas and then having participants engage in physical exercise (Sinclair, Hoffman, Mark, Martin, & Pickering, 1994). The participants then made self-evaluative judgments either immediately after stepping down from a treadmill or after a delay. The arousal from physical exercise had no impact in the immediate self-evaluation condition, but when sufficient time had passed and the source of the feelings had become unclear, then feelings of arousal intensified whatever self-evaluative judgments were consistent with the earlier priming manipulation.

These effects of arousal on judgment have been extended to evaluations of social groups. Studies examining high arousal emotions, including anger, anxiety, and frustration, have found increases in stereotypic judgments toward out-group members when compared to judgments in low arousal states (Bodenhausen, 1993; Dollard, Doob, Miller, Mowrer, & Sears, 1939; Stephan & Stephan, 1985). In addition, research shows that white individuals who show increased amygdala activation when viewing unfamiliar black faces are also more likely to evaluate African-Americans negatively (Phelps et al., 2000). The results indicate that, as measured by amygdala activation, arousal intensified implicit biases among Whites against African

Americans. More generally, the amygdala responds to arousal more than valence, becoming more active in high arousal situations and therefore intensifying evaluations (Adolphs, Russell, & Tranel, 1999; Storbeck, Robinson, & McCourt, 2006). Again, high arousal appears to amplify accessible judgments, including stereotyped judgments of individuals seen by raters as members of an out-group.

Can arousal carry affective value?

In the usual characterization of affect, arousal and valence are seen as independent dimensions. However, Michael Robinson (1998) proposes that, in fact, valence is not independent of arousal (see also Jennings, McGinnis, Lovejoy, & Stirling, 2000). Specifically, high arousal triggers a defensive reaction, which is initially negative, whereas low arousal triggers an appetitive reaction, which is initially positive (Atchley et al., 2007; Mehrabian & Russell, 1974; Robinson, 1998; Robinson, Storbeck, Meier, & Kirkeby, 2004). In demonstrating this principle, Robinson et al. asked participants to evaluate emotional pictures that varied orthogonally in arousal and valence. They found that high arousing negative and low arousing positive pictures were evaluated faster and more accurately compared to high arousing positive and low arousing negative pictures. Thus, high arousal appears to carry a negative value, and low arousal a positive value. Another demonstration of this implicit valence-arousal relationship found that advertisements were rated more negatively after writing about exciting events than after writing about less exciting events (Faseur & Geuens, 2006). The authors conclude that high arousal can lead to negative evaluations, although it was not clear that the valence of the induced affective states was adequately assessed.

Summary

We suggested that people make everyday evaluative judgments by asking themselves, implicitly, 'How do I feel about it?' or 'How *strongly* do I feel about it?' In this process, the valence and arousal aspects of affect can be thought of as providing value and importance information, respectively. Arousal can intensify evaluative reactions, leading to more polarized judgments. A tendency for high arousal to be treated as negative may account for arousal-produced increases in stereotypic judgments toward out-group members. And judgments of memory can be influenced when arousal is experienced as fluency or familiarity. As with affective valence, the impact of affective arousal depends on it being experienced as a reaction to the object of judgment. Like other affective cues, irrelevant arousal can sometimes misattributed as judgment relevant. Indeed, a common goal of marketing campaigns is to enhance consumer excitement about products by associating them with irrelevant sources of arousal.

Styles of Learning (Processing and Attention)

A common model of arousal assumes that high arousal narrows attentional focus (Easterbrook, 1959). The 'weapon focus' phenomenon in which witnesses to an armed robbery failed to remember the robber, but did remember the gun, illustrates this idea (Christianson & Loftus, 1987; Loftus, 1979). It suggests that highly arousing events promote attention to important objects with the result that peripheral information remains unattended (Heuer & Reisberg, 1990). Some evidence for this narrowing of attention under arousal comes from research showing that individuals prone to anxiety disorders or depression are more likely to attend to central, threat-related details (Matthews, 2006).

In task situations, arousal cues can be experienced as task-relevant feedback concerning the urgency or importance of current thoughts and inclinations. High arousal cues intensify tendencies to act in line with current thoughts and inclinations, whereas low arousal cues do not. Thus, high arousal may intensify reliance on one's currently active processing strategies (e.g., item-specific or relational). Evidence that arousal cues might enhance item-specific processing comes from research comparing exposure to fear vs. neutral faces (Phelps, Ling, & Carrasco, 2006). Participants engaged in a perceptual discrimination task requiring them to detect the orientation of fuzzy vertical or horizontal lines (Gabor patches). Just prior to presentation of the Gabor patches, participants were exposed unconsciously to fearful or neutral faces. The arousing fear faces led to superior detection of the orientation of the Gabor patches when compared with the low arousal, neutral faces, indicating that the fear faces actually increased the visual sensitivity to perceptual contrasts. This study did not assess the role of arousal separately from the role of other aspects of fear, but arousal seems likely to have been critical.

We hypothesize that arousal can increase dedication to whatever processing strategy may have been cued by positive or negative affect. When people are in happy moods, they tend to relate information together using relational processing strategies. In doing so, there can be associated costs in that happy individuals are more prone to false memories when recalling information from highly related or structured events (Bless, Clore, Golisano, Rabel, & Schwarz, 1996; Storbeck & Clore, 2005). The role of arousal in such false memory production has been examined by comparing the effects of high and low arousal, positive states (Corson & Verrier, 2007). Arousal was found to amplify the tendency for positive mood to foster relational processing, since aroused individuals in positive moods produced more false memories than individuals in positive but low arousal states.

Physiological studies also provide support for the hypothesis that arousal intensifies dedication to currently active processing strategies. Particular processing strategies can be elicited in numerous ways, including through

task instructions (Phelps et al., 2006) and through the induction of affect (e.g., Storbeck & Clore, 2005). Evidence comes from studies in which presented images varied in arousal and valence and physiological responses, including heart rate, respiration, and skin conductance, were recorded (Gomez, Stahel, & Danuser, 2004). The physiological measures revealed that negative affect promoted item-specific processing, but in addition, arousal also intensified reliance on the accessible processing strategy by increasing the readiness to act on current thoughts and inclinations (see also, Hamm, Schupp, & Weike, 2003). In terms of the formulation we propose, affect can be seen as promoting whatever processing strategy is activated, and arousal can be seen as enhancing this tendency by signaling the urgency of the situation.

Perception

Recent discoveries point to a role for affect even in perceptions of physical reality. Most investigators of visual perception would contend that perceptions of the basic geometry of the world should be impervious to emotional and motivational factors. Indeed, the only suggestion by serious scientists that affect might influence perception, a movement referred to as the 'New Look' in perception (Bruner & Postman, 1947), has long been discredited. Nevertheless, the standard view of perception has recently been challenged by robust findings that perceptions of physical layout are resource dependent (Proffitt, 2006). Perceptions of physical slant, distance, and height have been found to reflect available physical, social, and emotional resources (e.g., Schnall, Harber, Stefanucci, & Proffitt, 2008). For example, Proffitt et al. find that hills appear steeper when resources are limited or threatened, as when individuals are physically exhausted, elderly, or carrying a heavy backpack. Consistent with this view, the apparent incline of hills is increased by sad affect when standing at the bottom of a hill (Reiner, Stefanucci, Proffitt, & Clore, 2008) and by fear when standing at the top (Stefanucci, Proffitt, Clore, & Parekh, forthcoming). In addition, studies assessing perceptions of the distance from a balcony to the ground below find that the distance is increased by mild fear (Stefanucci & Proffitt, 2008). To examine the role of arousal in this process, in one experiment, participants viewed emotionally arousing pictures just before estimating the height of the balcony, which increased overestimation of the distance to the ground (Stefanucci & Storbeck, 2008). In a follow-up study, when viewing the arousing pictures, some individuals were asked to try to regulate their reaction by viewing the pictures in a way that would make them more or less arousing. The results showed that the up-regulation group provided significantly higher estimates of the balcony height than the control or down-regulation group. Whether arousal acts by increasing the level of fear or by potentiating the fear–perception relationship in some other way is not yet clear. Nevertheless, the results indicate that fear can influence

height perception and that increases in the magnitude of arousal can magnify this phenomenon.

Time perception

In addition to perceptions of physical reality, perceptions of time may also be altered by emotional states. In one experiment, participants viewed a series of pictures varying in both arousal and valence and then estimated how long the pictures were shown (Angrilli, Cherubini, Pavese, & Manfredini, 1997). The results indicate that highly arousing images were perceived as having been shown for a longer period of time than less arousing images. The authors argued that arousal influenced attention by speeding up the internal clock within the brain (Angrilli et al., 1997; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007).

Attentional capture

In addition to polarizing judgments, intensifying processing styles, and altering perception, arousal also activates attention. In the service of detecting and evaluating potentially dangerous objects quickly, attention appears to be drawn to arousing stimuli. Facial expressions are effective conveyers of arousal cues, and expressions that convey arousing information (e.g., fear, surprise, anger) tend to capture attention. For example, measures of cortical brain activity (electroencephalograph or EEG measures) indicate that threatening faces garner more attention (Schupp et al., 2004) and hold attention longer than non-threatening faces (Lipp, 2006). Threatening faces are also detected especially quickly among non-threatening faces (Fox, Russo, Bowles, & Dutton, 2001; Ohman, Lundqvist, & Esteves, 2001; Tipples, Atkinson, & Young, 2002). For example, angry faces are detected more quickly than happy faces (Schubo, Gendolla, Meinecke, & Abele, 2006). Since fear is generally considered a high arousal negative state, such findings are consistent with the current view that the negative component promotes item-specific processing and that arousal, by signaling urgency, intensifies such processing. Together, they appear to promote the detection of arousing or potentially important stimuli.

Summary

We have proposed that arousal can be viewed as task-related feedback about the urgency or importance of current thoughts and inclinations. When high arousal cues are present, therefore, dedication to currently activated thoughts, inclinations, and processing strategies may be intensified. This effect included some data suggesting that fearful arousal can influence even visual acuity (Phelps et al., 2006). In addition, we presented evidence from studies of the role of fear in the perception of heights showing that

arousal also intensifies the effects of emotion on perception. Additionally, evidence was reviewed showing how arousal slows the perception of time. Finally, we briefly reviewed evidence of the role of arousal in activating and guiding attention. We proposed that the cognitive consequences of specific emotions can often be predicted by considering how the valence aspect influences processing style and arousal aspect governs the degree of dedication to that style. In the case of fear, negative valence elicits item-specific processing and high arousal increases use of that strategy, resulting in heightened attentional vigilance and ability to detect threat. The research on attention leads us to a final set of findings concerning arousal as information about the importance of events to be remembered.

Memory

What would life be like if we remembered everything? We might never to be late to meetings, professors would remember all their students' names, and grocery lists would no longer be needed. However, one mnemonist, who reportedly was able to remember almost everything, found this skill a burden (Luria, 1968). He lacked the ability to observe patterns in the environment, extrapolate from facts, ignore irrelevant details, and construct complex thoughts. It seems that remembering everything is not as beneficial as one might imagine. Hence, some mechanism is needed to inform us about what is important to remember and what we can safely forget.

As seen in the previous section, arousal draws attention to salient environmental stimuli, but in addition, it marks information as important for memory. It signals importance both implicitly, through adrenergic hormones, and explicitly, through subjective experience. That is, adrenergic hormones are typically released in stressful or emotionally arousing situations, a process that is believed to result in enhanced long term memory for associated events. For example, most people remember where they were on September 11, 2001, but few recall much about September 10th or 12th of that year.

This kind of memory consolidation relies on both the peripheral and central nervous systems. The adrenal gland releases epinephrine into the peripheral nervous system, which triggers changes in the central nervous system (Packard, Williams, Cahill, & McGaugh, 1995). Within the brain, the effects of norepinephrine on the amygdala appear to be the critical process in the modulation of long-term memory. Norepinephrine can be activated by multiple neuromodulators, such as gamma-aminobutyric acid, opioid petides, and glucocorticoids (McGaugh, 1989; 2004). Activation of the amygdala can then influence memory consolidation processes in other areas of the brain as well (Packard, Cahill, & McGaugh, 2001), suggesting that the process is not limited to fear conditioning (for a more extensive treatment of the memory consolidation process, see McGaugh, 2004).

Arousal apparently has its greatest influence on memory for events about 2 days after encoding (Christianson, 1984; McGaugh, 2004). The process is believed to be the basis of traumatic stress disorder (e.g. Cahill, 1997). Traumatic stress problems are common among police, emergency workers, disaster teams, rape or assault victims, and the military. The high arousal associated with intense incidents can create intrusive memories and emotions long after the event. As a side note, we should mention that intense arousal is also sometimes associated with amnesia and forgetting (see Cahill, 1997). For example, evidence in the anxiety and phobia literatures shows reduced memory for relevant, anxiety-arousing material (e.g., Christianson, 1984). However, we assume that this pattern reflects attentional disengagement during learning, rather than arousal effects on forgetting.

The basic effect of enhanced memory after a delay occurs even when arousal is induced after learning has already been completed. The effect is thus not due to heightened attention during learning, but rather to hormonal modulation of processes that take place afterward. The process is perhaps not completely different than that of engaging in practice, in that it presumably involves sustaining the activation of appropriate neural connections. However, the fact that the process occurs after learning and can involve even irrelevant arousal raises questions about how the arousal gets linked to relevant rather than irrelevant stimuli. One possibility is that the object or event to be remembered must carry its own arousal (see Cahill & Alkire, 2003; Cahill et al., 2003). That is, perhaps the object itself must be at least minimally arousing to signal its importance in order for a secondary source of arousal to enhance memory for it.

An excellent example of research demonstrating both how affect governs processing and how arousal governs remembering involves a straightforward word learning task (Hurlemann et al., 2005). Individuals were asked to remember interrelated words, which were presented in a serial manner. However, on occasion, an unrelated, emotional word (referred to as an 'oddball') was presented. Negative oddballs produced retrograde amnesia for the preceding word, whereas positive oddballs produced especially good memory for it (retrograde hypermnesia). These results appear to involve the same affect-mediated processing effects discussed earlier. That is, negative words led to item-specific processing, which prevented the previous word from being encoded, whereas positive words fostered relational processing so that memory was superior for both the emotional word and the preceding words. In a second experiment, drugs were administered that either increased (reboxetine) or decreased (propranolol) emotional arousal. As expected, the drug that increased arousal (reboxetine) enhanced the retrograde amnesia and hypermnesia effects, whereas the drug that decreased arousal reduced the retrograde amnesia and hypermnesia effects. Thus, the valence component of affect governed what to learn, and the arousal component governed what to remember.

Does arousal influence all types of memory?

Arousal not only enhances explicit, episodic memory but can also enhance implicit or association-based memories. Arousal-enhanced learning of implicit associations was shown in a study involving a repetition priming paradigm (Thomas & LaBar, 2005). The phenomenon consists of faster recognition of repeated words as the memory trace gets stronger. The results showed the largest repetition priming effects for negative, high arousing words compared with negative, low arousing or neutral words. Recent findings also suggest that arousal can enhance memories relevant to self-schemas (Rameson & Lieberman, 2007). Investigators observed that information relevant to self-schemas evokes an affectively arousing response that leads the information to be better remembered compared with information that was not self-relevant. These findings, moreover, indicate that emotional arousal can enhance implicit, as well as explicit memory.

Misattributed arousal

Arousal has the property of being sticky and attaching itself to any associated object, making that object seem important, and causing it to be well remembered. Extraneous arousal can be varied through the administration of either adrenergic beta-blockers to reduce arousal or beta-enhancers to increase arousal. Other techniques for increasing arousal include a cold presser task, which involves placing one hand in a bucket of ice water, and various anxiety inductions, such as engaging in public speaking. An example of such research is a study in which participants placed an arm in either a bucket of ice water or warm water after viewing emotional and non-emotional pictures (Cahill et al., 2003). One week later, participants were brought back for a memory test, and those in the ice water condition showed greater memory for emotional pictures compared with those in the warm water condition. Only emotional pictures benefited from the extraneous source of arousal perhaps because the additional arousal produced by these pictures signalled their potential importance relative to the neutral pictures.

Another approach to investigating arousal involves the administration of drugs to stimulate or suppress arousal (O'Carroll, Drysdale, Cahill, Shajahan, & Ebmeier, 1999). A stress hormone stimulant produced the strongest memory effects, whereas a stress hormone depressant produced the weakest memory for an emotionally arousing story relative to controls. Such results nicely demonstrate the relationship between level of arousal and memory. Imaging results also find a similar correlation between arousal and remembering. Specifically, several studies have found that the more arousing the stimulus, the more active the amygdala, and the more active the amygdala, the better the long-term memory (Cahill et al., 1996; Dolcos, LaBar, & Cabeza, 2004; Hamann, Eli, Grafton, & Kilts, 1999; Kilpatrick & Cahill, 2003).

Semantic relations

When words are semantically related, they are typically remembered better (Tulving & Pearlstone, 1966). Against this background, research has investigated whether emotional arousal can further enhance memory for semantically related words (Buchanan, Etzel, Adolphs, & Tranel, 2006). The results showed that in fact, semantically related words that elicited arousal, as detected by changes in heart rate, were especially likely to be remembered. In addition, arousing, non-related words and related, non-arousing words that elicited some arousal (as evidenced by heart rate change during learning) were more likely to be remembered than words that did not elicit arousal. Thus, physiological measures of arousal successfully predicted memory performance for both emotional and semantically related but non-emotional words.

Summary

In this section, we have reviewed research showing that arousal has consequences for processing and remembering information. High arousal served to enhance memory relative to low arousal by signaling importance implicitly through adrenergic hormones and explicitly through subjective experience. Subjective experience presumably directs attention to the arousing event and adrenergic hormones activate memory consolidation processes. The consolidation of information in long term memory can occur when adrenaline is administered after learning has taken place, so that arousal may operate mainly on information that was already slightly arousing during initial exposure.

Conclusions

We characterized affective experience along the dimensions of valence and arousal. Our research has been guided by an affect-as-information approach focused primarily on the valence dimension. The current article extends this approach to include an arousal-as-importance corollary. A review of relevant literature suggests several possible conclusions about the cognitive consequences of variations in arousal:

1. When people ask themselves how they feel about the object of judgment, they necessarily also ask, 'How *strongly* do I feel about it?' As a result, arousal can make judgments of positive objects more positive and of negative objects more negative. Similarly, arousal can make romantic attraction stronger, jokes funnier, and heights scarier.
2. Any source of arousal can affect judgment, processing, and memory when implicitly attributed to a relevant object. Indeed, arousal from irrelevant sources can be readily misattributed when associated in time with the relevant object.

3. The amygdala is more responsive to arousal than to valence. The increase in amygdala activation during arousing situations may play an important role in intensifying evaluations.
4. Although arousal and valence are often treated as independent, in actuality there is a tendency for high arousal stimuli to be treated as provisionally negative.
5. In addition to influences on judgment, arousal also affects cognitive processing, attention, and perception.
6. Arousal activates attentional processes. High arousal in particular may narrow attention to arousal-relevant objects, leaving peripheral information unattended.
7. Arousal experienced as information about importance or urgency can intensify dedication to whatever cognitive processing is currently dominant. For example, the tendency to process information relationally in positive states is increased when the positive states also involve high arousal.
8. Arousal influences perceptions in several ways. It was found to intensify the effect of fear on perceptions of height, to contribute to the effect of fear on visual sensitivity to perceptual contrasts, and to influence perceptions of the passage of time.
9. Whereas the valence component of affect signals what to learn, the arousal component signals what to remember. The effect of arousal on long term memory can operate implicitly through adrenergic hormones and explicitly through the effect of subjective experience on attention. The hormonal effect is evident after a delay of a couple of days, and it can occur even when arousal is induced after learning has already taken place.
10. Some evidence suggests that for general arousal to make objects or events memorable, they must be at least slightly arousing themselves, but evidence on this point is inconsistent.
11. Methods of varying arousal include the administration of beta-blockers to reduce arousal or beta-enhancers to increase arousal. Behavioral methods include the cold presser task, which involve placing one's hand in a bucket of ice water and inducing anxiety through techniques such as public speaking.
12. Sometimes, arousal is associated only with increases in the vividness of memories without also being associated with accuracy.

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Short Biography

Justin Storbeck's research is located at the intersection of social, cognitive, and affective-neuroscience. Current projects examine the influence that

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Endnote

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