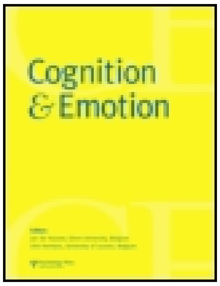

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Individual Differences and Arousal: Implications for the Study of Mood and Memory

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Individual Differences and Arousal: Implications for the Study of Mood and Memory

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Inconsistent findings in the study of mood-related effects on memory are discussed in terms of the effects of arousal on cognitive processes. Manipulations used in studies of mood and memory typically affect arousal as well as affective valence. Although mood-related effects on memory are often interpreted in terms of valence, a consideration of arousal-mediated effects rarely occurs. In the motivation and performance literature, however, variations in arousal have been shown to interact with retention interval to affect immediate and delayed recall. Arousal is hypothesised to hinder some aspect of short-term memory but facilitate both the speed of processing and some aspect of storage for long-term retrieval. The construct of arousal is also used more generally to organise the effects of stable individual differences in personality and a variety of motivational manipulations on cognitive performance. The implications of these effects of arousal for the pattern of inconsistent findings in the study of mood-related effects on memory are discussed in terms of the general effects of arousal on cognitive performance.

INTRODUCTION

That cognitive processes affect emotional states should be self-evident to readers of this journal. Individual differences in anxiety and depression have been related to differences in the way stimuli are encoded or the way various cognitive schemata are activated. Recommended therapeutic interventions to alleviate pathological levels of anxiety and depression include ways of changing biases in schema activation, encoding, and storage. For many cognitive psychologists, affective state is merely another memory code and the effects of mood on memory can be understood in terms of

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general models of memory processing. In this approach, mood is just a contextual cue in the memory network, similar in effect to the colour of the room in which material is learned.

A strikingly different approach is to examine the ways in which cognitive processes are modified by affective and motivational states. That is, the directional and energetic components of motivation can be used to explain complex relationships between individual differences in stable personality traits, a variety of situational manipulations, and at least three components of information processing (Humphreys & Revelle, 1984; Revelle, 1987, 1989; Revelle, Anderson, & Humphreys, 1987). In this article we discuss how an energetic component of motivation, *arousal*, has systematic effects upon memory. We further propose that arousal, as an important component of emotional experience, has effects upon memory that are partly responsible for previously inconsistent findings in the mood and memory literature.

A central theme to this article is that arousal is a useful hypothetical construct that can be used to organise a large and disparate body of literature. We will review findings suggesting that arousal influences many aspects of cognitive performance. In particular, we will show that arousal interacts with retention interval to affect the probability of immediate and delayed recall. Because most mood manipulations can affect arousal as well as affective valence, we believe that the arousal induced in mood and memory experiments could serve as a serious confound across different mood states, mood induction techniques, and retention intervals. Thus, the true relationship between mood and memory may be obscured by ignoring the interactive effects of arousal and retention interval.

In this article we will discuss the multiple sources and effects of arousal that need to be considered when studying the relationship between affect and cognition. These include individual differences in personality, such as impulsivity and extraversion; situational manipulations, such as mood induction techniques, stimulant drugs, exercise, or time of day; and task characteristics, such as memory load or retention interval.

Arousal as a Psychological Construct

Arousal is a conceptual variable that means many things to many people. Arousal is necessary for conditioning to occur at the neural level (Grossberg, 1987), is the cause of desynchronisation of the electroencephalogram (EEG), is a response to increases in task complexity (Berlyne, 1960), is a non-specific response to orienting stimuli (O'Gorman, 1977), is a determinant of sustained performance in vigilance situations (cf. Mackie, 1977), is an important component in the encoding of emotional experience (Bower, 1981; Clark, 1982; Clark, Milberg, & Ross, 1983) and leads to feelings of peppiness and vigour (Thayer, 1989). Arousal has been said by some to be an important determinant of efficient performance (Anderson, 1988; Hebb, 1955; Revelle, 1987), but by others to be a figment of overly loose scientific speculation (Neiss, 1988).

Although used in many different ways, there are several common themes in arousal theories. Arousal is a non-specific energising response to stimulation (Duffy, 1972). Arousal is a general preparedness to detect and to respond to stimuli. For longer intervals, arousal is the inverse probability of falling asleep (Corcoran, 1965, 1972). Just as incentive effects could be separated from drive (Hull, 1952), so are there unique effects due to specific manipulations thought to affect arousal (noise, stimulants, exercise, time of day, threat, feedback). In this sense, arousal is the residual variance remaining after specific and unique effects are removed. That is, arousal is the energetic analogue of the common factor of ability tests. Thus, arousal represents the variance shared among specific measures of activation.

Just as arousal seems to wax and wane throughout the day, the theoretical position of arousal in psychology seems to have a pronounced rhythm. Although an exciting topic of research in the late-1950s and early 1960s, for the late-1960s and much of the 1970s and 1980s arousal seems to have been an unpopular concept in much of American psychological theory. In fact, until recently, the primary research reports have been in the European literature. In this article we show that not only is arousal a useful construct in psychological theory and that individual differences in arousal are worthy of systematic investigation, but that a better understanding of the effects of arousal on memory helps to explain the relationship between affective states and memory.

Unfortunately, while arousal enjoyed a theoretical heyday in the mid-1960s, careful experimentation demonstrated that there seemed to be little in common between the arousal of the hand, the heart, and the head (Lacey, 1967). After the initial excitement associated with the identification of the Ascending Reticular Activating System (ARAS), more careful analyses suggested that equating arousal with activity of the the ARAS was an over-simplification of a complex set of excitatory and inhibitory pathways. Some responded that while there were certainly unique components to all arousal responses, there was also a common factor. Venables (1984), however, suggested that only a fool would carry the analogy of the *g* factor in general intelligence very far into the domain of arousal research. In this same light, Hockey (1979) has suggested that it is more fruitful to consider each arousal state as separate and not to search for the Holy Grail of a common arousal factor.

In more recent work supporting one or two common factors of arousal, Thayer (1989) has suggested that "arousal is a kind of simultaneous activation of many physiological and psychological systems in response to a variety of kinds of stimulation" (p. 31), and has shown that self-report measures of arousal co-vary more strongly with psychophysiological measures than these measures do with themselves. He has also shown that while two components of arousal (energetic vs. tiredness and tension vs. calmness) correlate positively at low to moderate levels of task or psychological demand, these two components correlate negatively at high levels of demand. He has suggested that energetic arousal is related to a behavioural approach system and that tense arousal is related to a behavioural inhibition system (see also Gray, 1987). Watson and Tellegen (1985), using scales derived from Thayer (1967, 1978), related these two arousal dimensions to positive and negative affect.

If arousal is so loosely defined then why bother to discuss individual differences in arousal? Because in addition to being a non-specific physiological response, it also seems to be a non-specific theoretical construct that has been developed and used in most fields of psychology. Social psychologists have studied the drive to reduce arousal induced by dissonance. Personality theorists have used arousal as an explanatory concept in models of extraversion, neuroticism, anxiety, stimulation seeking, and attention deficit disorders. Applied experimentalists have made use of arousal to explain the effects of noise, stimulants, depressants, time of day, and sleep deprivation upon subsequent performance.

To its proponents, the explanatory and predictive capacity of theories of learning or performance are enhanced by the inclusion of the construct of arousal (Anderson, 1990). Grossberg (1987) has argued that non-specific activation is required for conditioning of previously unassociated stimuli. Hebb (1955) proposed that arousal affected the level of cue functioning. Performance was believed to be a curvilinear (inverted U) function of arousal. Hebb cited evidence from Yerkes and Dodson (1908), who had shown that discrimination learning was an inverted U-shaped function of external stimulation, and that the peak of this inverted U was obtained at lower levels of stimulation for more complex discrimination learning. The Yerkes–Dodson effect is frequently taken as implying that, at low levels of baseline arousal, increases in arousal facilitate performance; at moderate levels, increases in arousal facilitate performance on easy tasks, but hinder performance on more complex tasks; and at extremely high levels of arousal, arousal seems to hinder performance on all types of tasks. Further experimental support for the Yerkes–Dodson effect has been reported by Broadhurst (1959) and Anderson (1988). In a frequently cited theoretical explanation of this effect, Easterbrook (1959) proposed that arousal narrowed the range of cue utilisation with extraneous cues being lost first.

In addition to theories of performance, arousal has been used as an explanatory concept in several personality theories and descriptions of individual differences. Arousal plays a central role in Hans Eysenck's theory of Introversion-Extraversion (H. J. Eysenck, 1967, 1981; H. J. & M. W. Eysenck, 1985), and has been used to explain the intensely active behaviour associated with the trait labelled stimulation seeking (Zuckerman, 1979) as well as the childhood diagnosis of hyperactivity (Douglas, 1972; Rosenthal & Allen, 1978; Zentall & Zentall, 1983). In these theories an intermediate level of arousal is postulated to be most preferred. Variations from this ideal point are unpleasant. Individuals with a chronically low level of arousal are thought to seek arousal through external sources of stimulation, while individuals with a higher baseline level seek to avoid stimulation. Thus extraverted, stimulation seeking, or hyperactive behaviour is seen as an attempt to compensate for low internal levels of arousal by increasing external stimulation.

Even more important than arousal's use as a construct in theories of personality is the consistent effect of arousal (either manipulated, measured, or inferred) on cognitive tasks, particularly those involving aspects of memory. It follows that, without taking individual differences into account, arousal-performance relationships can be hidden or seriously weakened. When individual differences in stable personality traits are controlled for, much stronger arousal-performance relationships are found. It is perhaps due to a lack of concern for individual differences that arousal is viewed by some as a hopelessly muddled construct. But when these individual differences are taken into account it is possible to show consistent relationships between arousal manipulations and memory processes that might be useful in resolving some of the conflicting findings relating mood and memory.

Arousal and the Psychological Spectrum

It is helpful when discussing arousal's effects to consider the range of phenomena for which it has been used as a theoretical concept. Psychological phenomena range across a temporal spectrum of at least 12 orders of magnitude: from the milliseconds used to index firing rates of neurons, to the seconds of a verbal learning study, to the hours of a vigilance experiment, and finally to the decades that make up a lifetime (Revelle, 1989). Different psychological phenomena typically are measured at different temporal frequencies (or durations) across the spectrum. Thus, while some discuss Event Related Potentials (ERPs) which have durations of 100–400msec, others choose to discuss priming effects for reaction time over a few seconds, or changes in affect which take tens of seconds to occur, while others prefer to administer stimulants which have effects only after 20–40min (2×10^3sec), or to study differences in cognitive performance

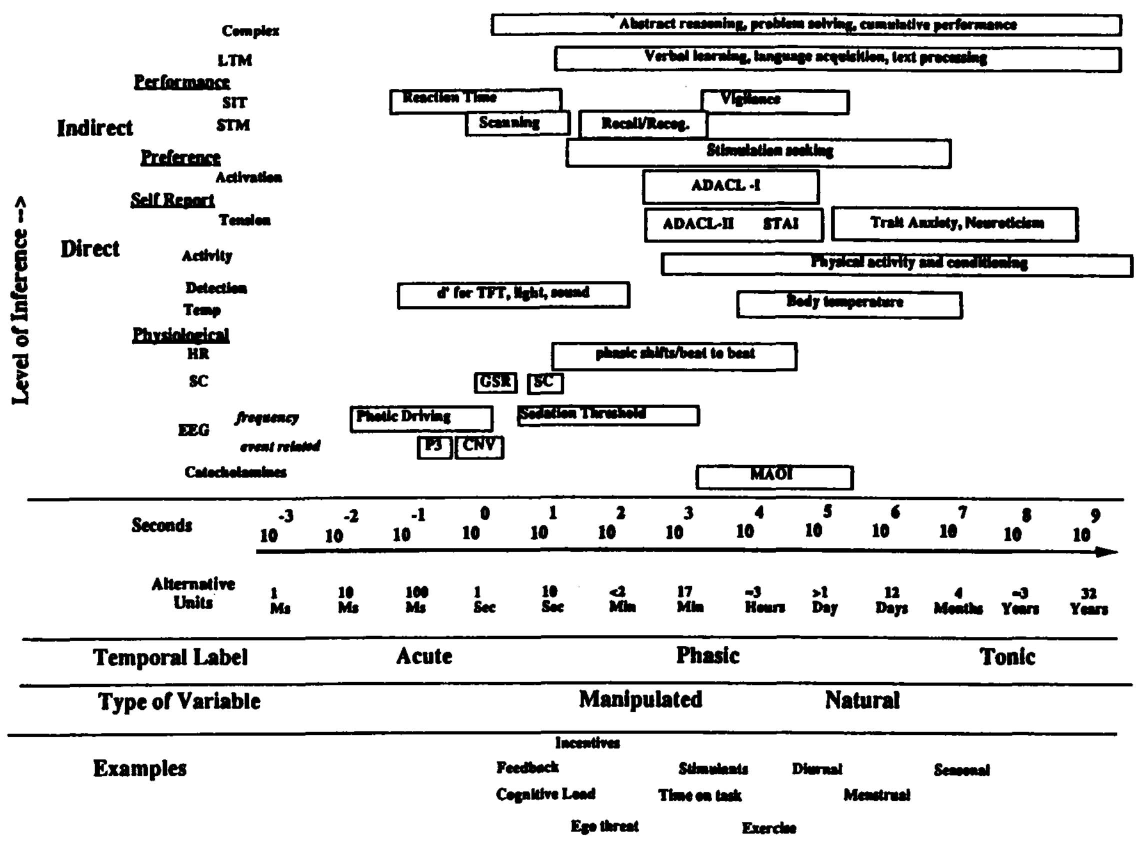

FIG. 1. The psychological spectrum applied to measures of arousal.

over the day (≈10^5sec), over the menstrual cycle (10^6sec), during a year (3×10^7sec), or over the life-span (≈3×10^9sec).

As well as being able to show some order to the types of psychological phenomena that we all find interesting, it is useful to categorise various kinds of arousal measures in terms of this psychological spectrum. Furthermore, it is helpful to organise measures along two different dimensions: the typical duration over which measures are taken, and the type of inference we need to make to relate the observed measure to the underlying construct of physiological arousal. When we do this, we see that different measures of arousal reflect different parts of the psychological spectrum; measures requiring more complex inferences represent the longest temporal durations (Fig. 1).

At the shortest intervals are measures of physiological state. Measures here include indices of cortical activity such as the EEG, both event related and resting frequency. At somewhat longer intervals there are the autonomic measures of Skin Conductance (SC) and Heart Rate (HR). At even longer levels there are endocrine measures such as the level of Mono-Amine Oxidase (MAO) and general metabolic measures such as core Body Temperature (BT). Other measures with fine temporal resolution include psychophysical sensitivities to light and sound. At a less fine resolution are measures of activity level.

In addition to the physiological measures, it is possible to rely on self-report of arousal. By asking subjects how peppy, active, and vigorous they feel, general arousal effects with durations from a few minutes to a few hours are found. In fact, as Robert Thayer (1986, 1989) has shown, self-report measures seem to reflect the general factor of many of the finer grain physiological measures.

Arousal and Individual Differences

In the mid- to late-1960s, when arousal had become an interesting explanatory variable in a number of peformance tasks (e.g. Broadbent, 1971), several British investigators noted the similarity of arousal manipulations to differences between Introverts and Extraverts (Claridge, 1967; Corcoran, 1965; Eysenck, 1967). The basic findings were that extraverts did badly on those tasks on which sleep deprivation hindered performance, and that introverts did badly on those tasks on which noise stress hindered performance. That is, extraverts performed in a manner similar to low aroused subjects and introverts performed in the same way as did highly aroused subjects.

In 1967, Hans Eysenck proposed that a fundamental cause for behavioural differences between introverts and extraverts was their level of arousal. Specifically, he proposed that introverts had higher chronic levels of arousal than did extraverts. This hypothesis led to a series of investigations trying to show physiological differences between introverts and extraverts. In terms of arousal, the seemingly most simple measures were those of the dominant EEG frequency found in resting subjects. Later studies included examinations of other EEG parameters, as well as basal levels of skin conductance, habituation of the orienting response, body temperature, and pupil size.

Evidence for introversion-extraversion differences in arousal comes from multiple levels of inference. Some of the studies have shown differences as a function of introversion-extraversion, others have shown stronger results for a component of 1-E, impulsivity.[1] The most direct demonstrations are those using measures of EEG, OR habituation, and stimulus thresholds. Under appropriate conditions low impulsives and introverts have higher levels of EEG activation than do high impulsives or extraverts (Gale, 1981, 1986). In addition, low impulsives and introverts are more resistant to habituation of the Orienting Response (O'Gorman, 1977; Wigglesworth & Smith, 1976; Stelmack, Bourgeois, Chian, & Pickard, 1979), have higher levels of Skin Conductance (Revelle, 1973), and are more sensitive to the detection of weak stimuli than are high impulsives or extraverts (Stelmack & Michaud-Achorn, 1985).

Less direct measures of arousal require more inferences as to the state of the subject. These measures typically reflect one of two basic theoretical assumptions: (1) that there is some ideal level of arousal which is most preferred; or (2) that there is some curvilinear relationship (an inverted U) between arousal and task performance. Assumption 1 is used to relate differences in presumed stimulation seeking to presumed differences in arousal: Individuals thought to be highly aroused are thought to prefer lower levels of external stimulation. Assumption 2 is used to relate performance differences in response to stress to presumed individual differences in arousal: Individuals whose performance improves with stimulation are thought to have been initially less aroused than those individuals whose performance deteriorates with increased stimulation.

[1]Initial conceptions of introversion-extraversion included two sub-components, impulsivity and sociability. These two components were both included in the I-E scale of the Eysenck Personality Inventory (H. J. Eysenck & S. B. G. Eysenck, 1964). In the process of refining the measurement of I-E, Neuroticism (N) and Psychoticism (P) for the Eysenck Personality Questionnaire (EPQ, S. B. G. Eysenck & H. J. Eysenck, 1976) items with an impulsivity content were either deleted or moved to the P scale. Rocklin and Revelle (1981) have pointed out that because of this lack of impulsivity content in the EPQ I-E scale, the EPI and EPQ measures of Extraversion are not parallel forms. To what extent the arousal effects previously attributable to extraversion are related to the construct of psychoticism is not clear. For this reason, we have preferred to discuss arousal effects in terms of extraversion and impulsivity.

It is this second assumption that has been used to explain the pattern of results obtained when studying how the personality dimension of impulsivity interacts with time of day and the stimulant drug caffeine to affect cognitive performance. In five different experiments conducted in the morning, the performance of less impulsive subjects on complex reasoning tasks was impaired by the administration of caffeine while that of high impulsives was improved (Revelle, Humphreys, Simon, & Gilliland, 1980). From this it was inferred that the low impulsives were more aroused than were the high impulsive subjects. Similarly, in the evening, when this pattern of results reversed in four studies, Revelle et al. (1980) inferred that the high impulsives were more aroused at that time than were the low impulsives. That is, they proposed that the state of high arousal is an interactive effect of the trait of impulsivity and the time of day. Additional support for this idea came from studies that showed phase differences of the diurnal arousal rhythm with introverts having an earlier peak than did extraverts for body temperature (Blake, 1967a,b) as well as for pain (Folkard, 1976).

Individual Differences and the Rate of Change of Arousal

One of the more consistent effects of extraversion or impulsivity on performance is the inability of extraverts to maintain performance on vigilance-like tasks. The vigilance decrement in extraverts is larger and occurs sooner than that found in introverts (Bakan, Belton, & Toth, 1963; Keister & McLaughlin, 1972; Thackray, Jones & Touchstone, 1974). In a more applied setting, reaction time increases while driving a car over long distances are greater for extraverts than for introverts and the beneficial effect of listening to a taped radio programme are greater for extraverts than for introverts (Fagerström & Lisper, 1977).

Bowyer, Humphreys & Revelle (1983) found that a similar decrement in performance can occur on a verbal learning task with a total presentation time of less than 15 minutes. Across trial blocks of 24, 80, 80, and 24 words, forced-choice recognition accuracy for the last 20 words presented in each block decreased for high impulsives from 0.97 to 0.84 while it fell from 0.92 to 0.88 for the low impulsives. With the addition of 4mg of caffeine per kg body weight, however, the performance of the high impulsives showed markedly less deterioration (from 0.96 to 0.91) and that of the low impulsives improved only slightly. Bowyer et al. (1983) interpreted this result as consistent with the greater vigilance decrements found in extraverts and consistent with the hypothesis that in a dull situation arousal decreases more rapidly for high impulsives than for low impulsives.

These consistent decreases in peformance over time for extraverts or high impulsives are important when we consider the consistency of the findings relating extraversion to the rate of habituation of the orienting response (O'Gorman, 1977). A very clear picture emerges when we see that the same type of individuals whose OR habituates rapidly do badly on sustained performance tasks as diverse as driving a car or studying a list of words in a verbal learning study. Thus, the stable personality dimension of impulsivity seems to relate to the rate of change in arousal. In a constant environment, highly impulsive individuals seem to decrease their arousal level faster than do the less impulsive. This finding is compatible with the suggestion that stable traits of personality represent the rate of change (or first derivative) of individual differences in states (Revelle, 1987, 1989).

AROUSAL AND INFORMATION PROCESSING

As well as demonstrating that impulsivity interacts with caffeine-induced arousal on a variety of tasks, Humphreys and Revelle (1984) suggested that arousal plays a fundamental role in affecting information processing. Specifically, they proposed that arousal hinders the retention or immediate availability of information held in short-term or working memory (STM) but facilitates the speed of information transfer (IT) from input to output (Humphreys & Revelle, 1984). In addition, they suggested that arousal increases the ability to sustain information transfer (SIT) over extended periods. Combining these two effects it is possible to decompose the observed curvilinear (inverted U) relationship between arousal and complex performance (Anderson, 1988; Broadhurst, 1959; Hebb, 1955; Yerkes & Dodson, 1908) in terms of two monotonic processes, one increasing with arousal (SIT) and one decreasing with arousal (STM). Performance at low levels of arousal is thought to be limited by a lack of SIT resources and is improved with increases in arousal. Performance at high levels of arousal is memory limited and is hindered with increases in arousal. More recently, Revelle (1989) suggested that arousal also facilitates the storage of information for later retrieval.

These ideas are not new, and were not first proposed by us (cf. Broadbent, 1971; Folkard, 1975; Hockey, 1979). They are, however, important and with some of our recent results suggest an interesting approach to the study of cognition and emotion. Emotion can be viewed as having an affective or directional component (positive–negative) as well as at least one activation or arousal component (high–low) (Russell, 1978; Thayer, 1989; Watson & Tellegen, 1985). To date, most of the research on emotional effects on memory has concentrated primarily on the cueing function of the directional aspects of emotional states. More specifically, studies of mood state-dependent effects on information processing and recall have emphasised the informational aspects of mood (Blaney, 1986; Bower, 1981; Clark, 1982). Unfortunately, this research area has proven to be a morass of conflicting results (Blaney, 1986; Bower & Mayer, 1985). We believe that a better understanding of the way that arousal affects memory will lead to much clearer and more accurate organisation of the effects of mood upon memory.

To show how such an arousal interpretation can be applied to the mood and memory literature it is first necessary to review some of the basic findings relating arousal at storage and retrieval to memory processes. In general, the conclusion we draw is that arousal hinders some aspect of short-term or working memory but has a beneficial effect on material learned for delayed recall or recognition. Representative findings include those studies showing detrimental effects of arousal on short-term memory, beneficial effects upon long-term memory, and a combination of both.

Detrimental Effects of Arousal on Short-term Memory

That increases in arousal have a detrimental effect upon some aspect of short-term or working memory may be shown indirectly by manipulating the memory load in various cognitive tasks. Folkard, Knauth, Monk, and Rutenfranz (1976) found that, as memory load is increased in a scanning task, the correlation with arousal as indexed by body temperature goes from positive (low memory load) to negative (high memory load). In a conceptual replication of this study using impulsivity and caffeine-induced arousal, Anderson and Revelle (1983) found that performance was facilitated by caffeine for the low memory load task but was hindered for the high memory load tasks.

That this effect of memory load was confounded with the motivational effects of task difficulty was shown in a proof-reading task where subjects were to look for contextual (high memory load), or non-contextual (low memory load) errors (Anderson & Revelle, 1982). Contextual errors were grammatical mistakes such as subject-verb agreement; non-contextual errors were such things as spelling. In one condition, subjects looked for both types of errors at the same time, while in two other conditions they were to look for one or the other type of error. On the high memory load task, caffeine-induced arousal facilitated the performance of the less aroused high impulsives but hindered that of the presumably more aroused less impulsives.

In contrast to the beneficial effects of heightened arousal on reaction time (Hamilton, Fowler, & Porlier, 1989), caffeine-induced arousal hinders the rate of scanning items in memory (Anderson, Revelle, & Lynch, 1990). Using Burrows and Okada's (1976) modification of the Sternberg task, the probe stimulus was a word that either matched a word in the memory set or was a category member of a word in the memory set. Using both single and dual task instructions, Anderson et al. (1990), found that caffeine reduced the intercept and increased the slope of reaction time as a function of memory set size independent of the category/word condition. The results were taken as supporting the Humphreys and Revelle hypothesis that arousal impairs access to or availability from some aspect of STM. They were seen as not supporting Easterbrook's hypothesis that arousal narrows the range of cue utilisation, for there was no interaction of caffeine with the single vs. dual task instructional set.

Apparently contadictory evidence to the Anderson et al. (1990) result comes from a study of the effects of ethanol, amphetamine, and nitrogen induced narcosis upon memory scanning (Fowler, Hamilton, & Porlier, 1987). Reaction times to probe digits either included or missing from a memory set of 1–5 digits were reliably improved by amphetamine and hindered by nitrogen narcosis and alcohol. These effects were completely due to changes of the intercept and not to changes of the slope of the reaction time as a function of set size. However, it is likely that the memory load of a set of 1–5 digits used by Fowler et al. (1987) is less than that of the words used by Anderson et al. (1990). We suspect that the detrimental effects of arousal on memory scanning are detectable only when the memory scanning task has a substantial load.

Benzuly (1985; see also Revelle, 1989) reported further evidence supporting the role of arousal and memory load in performance tasks. Performance on multiple choice geometric analogies differing in the number of elements (SIT load) and transformations (STM load) was found to be an interactive function of caffeine-induced arousal and memory load. Although caffeine facilitated problems with one transformation per element (low memory load), it slightly hindered performance with three transformations per element (higher memory load). Caffeine did not interact with the number of elements (SIT load).

Beneficial Effects of Arousal on Long-term Memory

In striking contrast to the negative effects of arousal increases on short-term memory are the demonstrations that arousal decreases induced by benzodiazepines have little or no effect on measures of short-term memory but do impair performance on task components thought to require storage and retrieval from a long-term memory system (Mewaldt, Hinrichs, & Ghoneim, 1984). Hinrichs and his colleagues have demonstrated that the benzodiazepine, valium, does not affect the recency portion of a serial position curve, but does decrease the primacy and middle portion of the curve. Assuming that valium reduces arousal, these results suggest that increases in arousal might facilitate some aspect of long-term memory.

McGaugh (1990) has shown that stimulant drugs administered immediately after learning have a curvilinear effect upon delayed recall. Low to moderate doses of epinephrine and norepinephrine facilitate long-term retention of passive avoidance learning and of discrimination learning. These effects may be facilitated by opiate receptor antagonists such as naloxone and blocked by opiate receptor agonists such as morphine or beta-endorphin introduced to the amygdala. He suggests that these stimulants affect a noradrenergic memory modulation system associated with the amygdala, which in turn affects other brain regions through outputs mediated by the stria terminalis. This memory modulation system is affected by both peripheral stimulation (e.g. epinephrine) and central stimulation (e.g. norepinephrine), and is also sensitive to manipulations of opiate systems.

Berlyne and Carey (1968) reported results that seem to complicate the beneficial effects of arousal on long-term memory. In an incidental learning task, white noise facilitated long-term retention of Turkish–English word pairs (compatible with the arousal hypothesis) but extraverts had better recall than did introverts (incompatible with the hypothesis). However, given the large difference in preferred sound levels that has been observed between introverts and extraverts (Hockey, 1986) it is possible that the introverts were not only more aroused, but also more distracted when learning the initial list.

Interactive Effects of Arousal and Retention Interval

The most compelling evidence for arousal effects on memory comes from those studies that show detrimental effects of arousal on short-term or immediate memory and beneficial effects following a delay. What is most impressive about these studies is the consistency shown across a variety of manipulations. Arousal has been shown to hinder immediate but facilitate long-term recall using within-list manipulations or measurements of arousal; arousal induced by noise, evaluation apprehension, the presence of others, and exercise; natural variations in arousal as a function of the time of day; and finally, individual differences in arousal (Table 1).

Arousal induced by Stimulus Materials. Two early findings related GSR arousal (within subjects) to immediate and delayed recall (Kleinsmith & Kaplan, 1963, 1964). Word-digit pairs to which large GSRs were given were recalled less well immediately but better after a delay than were words to which small GSRs were given. In the first study (Kleinsmith &

TABLE 1
Studies Investigating the Effect of Arousal Manipulations and Delay Interval upon Memory Performance. (See text for details.)

Arousal Manipulation	*Study*	*Results*		
		Immediate	*Delayed*	*Effect*
Stimulus materials	Butter (1970)	Deficit	Benefit	Reminiscence
	Corteen (1969)	Benefit	Benefit	Differential
	Kaplan & Kaplan (1969)	Deficit	Benefit	Differential
	Kaplan, Kaplan, & Sampson (1968)	Deficit	Benefit	Reminiscence
	Kleinsmith & Kaplan (1963)	Deficit	Benefit	Reminiscence
	Kleinsmith & Kaplan (1964)	Deficit	Benefit	Reminiscence
	Levonian (1966)	Deficit	Benefit	Reminiscence
	Maltzman, Kantor, & Langdon (1966)	Benefit	Benefit	–
	Saufley & LaCava (1977)	–	–	–
	Schmitt & Forrester (1973)	–	–	–
	Walker & Tarte (1963)	Deficit	Benefit	Reminiscence
Presence of observers	Deffenbacher et al. (1974)	Deficit	Benefit	Reminiscence
	Geen (1973)	Deficit	Benefit	Reminiscence
	Geen (1974)	Deficit	Benefit	Reminiscence
White noise	Berlyne et al. (1965)	Deficit	Benefit	Differential
	McLean (1969)	Deficit	Benefit	Reminiscence
Exercise	Loftus (1990)	Deficit	Benefit	Differential
Introversion/extraversion	Howarth & H. J. Eysenck (1968)	Introverts< extraverts	Introverts> extraverts	Reminiscence
	McLaughlin (1968)	Introverts< extraverts	–	–
	Fuller (1978)	–	–	–
Time of day (a.m. < p.m.)	Folkard & Monk (1980)	p.m. < a.m.	p.m. > a.m.	Differential
	Oakhill (1986)		p.m. > a.m.	Differential
Time of day × Impulsivity (low > high in a.m. high > low in p.m.)	Puchalski (1988)	Low < high in a.m. High < low in p.m.	Low > high in a.m. High < low in p.m.	Differential

Kaplan, 1963), subjects were asked to learn digits paired with words differing in presumed arousal value. Recall was tested at 2min, 20min, 45min, 1 day, and 1 week after learning. Recall for those pairs associated with low arousal (defined as a relatively smaller drop in skin resistance within 4sec after pair presentation) was better in the short term (<20min) than in the longer term. For pairs which elicited a large arousal response at learning, immediate recall was poor, but delayed recall was better. That is, high arousal learning showed a marked reminiscence effect such that word-number pairs were remembered better after at least 45min delay than they had been at 2 and 20min. Recall increased by more than 100% from 2min to 20min and by 400% from 2min to 45min post-learning. Longer-term recall continued to increase up to 1 week after learning.

These findings were replicated in a later study which used nonsense syllables as stimuli rather than words differing in arousal value (Kleinsmith & Kaplan, 1964) and in two experiments performed by Butter (1970). The Kleinsmith and Kaplan replication established that the cross-over interaction between arousal level at learning and delay was independent of the influence of word characteristics. The results from these studies have been viewed as supporting Walker's theory of memory consolidation. Walker (1958; Walker & Tarte, 1963) had suggested that the apparent suppression of short-term and facilitation of longer-term learning associated with arousal is due to the activity of reverberating neural circuits. More specifically, Walker proposed that under high-arousal conditions increased neural activity produces an increase in reverberation of the memory trace that serves to enhance the consolidation of the trace. However, this heightened neural activity also makes it difficult to access the memory trace while the processing is taking place. Thus, Walker and Tarte (1963) suggested that arousal has a temporary inhibitory effect but leads to greater "ultimate memory".

Arousal induced by the Situation. In a conceptual replication of the Kleinsmith and Kaplan studies, Geen (1973, 1974) used the presence of an evaluative observer as a between-subjects arousal manipulation rather than relying on differential arousal induced within subjects by the stimulus material. The first study established that direct observation—rather than the mere presence of an experimenter—led to a cross-over interaction much like Kleinsmith and Kaplan's. Four subject conditions were run: subject alone; experimenter present but not observing; experimenter present and observing; and experimenter not present but observing through a TV monitor. The pattern of recall was as predicted. Those subjects who had been observed (either directly or through a TV monitor) showed decreased shorter-term but increased longer-term recall when compared to those subjects who had not been observed.

The second experiment was a follow-up of the first. An observation vs. no observation manipulation was used in combination with an evaluation ("performance on this test is correlated with intelligence") vs. a no evaluation manipulation. Geen found that those subjects who felt they were being evaluated exhibited short-term detriment and long-term benefit in their recall scores as compared to those subjects who were not evaluated. Geen concluded that these results suggest that the arousal effects produced by social observation (cf. the social facilitation effect discussed by Zajonc, 1964) occur because of apprehension over being evaluated.

Deffenbacher, Platt, and Williams (1974) conceptually replicated the first Geen experiment. Subjects were asked to learn nonsense syllables paired with digits under either an Observation or a No Observation condition. Recall was tested at either 2 or 45min. The results exhibited an Observation × Retention Interval interaction. After 2min, those subjects who had been observed recalled less well than those who had not been observed. After 45min, however, the observed subjects remembered more digits than the unobserved subjects.

Recent findings in our lab have shown that light exercise has similar effects to those shown by noise or presence of others (Loftus, 1990). Subjects were presented with 20 paired associates immediately after 8min of light exercise (jogging in place or stepping up on to a brick), or relaxation. Immediate recall (after 2min) was compared to recall after 1 hour. Although the direct effects of the exercise manipulation did not have a reliable effect upon memory, exercise did have an effect upon self-reported arousal (general activation-energy and deactivation-sleep, Thayer, 1989) which in turn interacted reliably with retention interval to affect recall Fig. 2). We interpret these results in terms of naturally occurring individual differences in arousal which are in turn affected by exercise. That is, some experimental participants are less aroused in a resting state than are others and there are large individual differences in the arousal induced by a brief period of exercise. By taking advantage of these naturally occurring individual differences, it is possible to tease out effects of exercise that are not otherwise noticeable.

Replications and Variations. Various other procedural variations on the original Kleinsmith and Kaplan studies have garnered results exhibiting the interaction between arousal and retention interval. Results from studies using white-noise arousal manipulations (Berlyne et al., 1965; McLean, 1969); incidental and intentional learning paradigms (McLean, 1969; Geen, 1973); within-subjects repeated testing (Levonian, 1966; Kaplan, Kaplan, & Sampson, 1968); single trial learning (Kaplan & Kaplan, 1969); and free rather than cued recall (Kaplan et al., 1968) evidence either differential forgetting between groups (less forgetting for

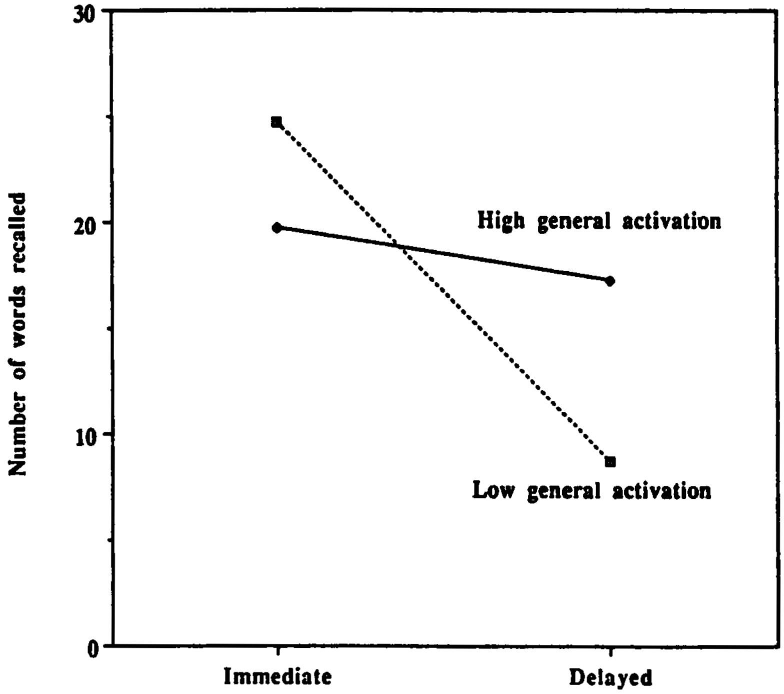

FIG. 2. Words recalled in a paired-associate learning task as a function of delay interval and self-reported general activation (energy).

the high-aroused than the low-aroused groups) or a reminiscence effect in the high-arousal subjects.

The number and variety of replication attempts suggest that the interaction of arousal and retention interval is not dependent upon either naturally occurring arousal changes or specific experimental paradigms. Arousal induced through external means also interacts reliably with delay of recall. Learning that occurs under incidental, intentional, or single exposure conditions interacts reliably with level of arousal. The pattern of findings throughout these studies is the same as that exhibited in Walker's, and Kleinsmith and Kaplan's earlier works: Namely, learning while aroused hinders shorter-term recall but facilitates long-term recall. What is intriguing from these earlier studies is the number that show a reminiscence effect with recall at the delayed interval actually greater than that immediately after learning (Table 1).

Arousal Differences between Subjects. Another conceptual replication of the Kleinsmith and Kaplan paradigm used introversion-extraversion as a between-subjects variable and found that the immediate recall of extraverts was superior to that of introverts, but with a delay > 45min, this superiority was reversed (Howarth & H. J. Eysenck, 1968). The pattern of results across the time intervals using a between-subjects personality variable (I/E) was remarkably similar to the between-subjects manipulations of arousal (Deffenbacher et al., 1974; Geen, 1973) and that found with within-subjects measure of arousal to the individual words (Kleinsmith & Kaplan, 1963, 1964).

Arousal Changes across the Day. Using a different manipulation of arousal, diurnal variation, Simon Folkard and his associates have examined the effects of arousal on memory. Folkard, Monk, Bradbury, and Rosenthal (1977) observed that, for schoolchildren, aural material learned in the morning (a time of presumed low arousal) was recalled quite well immediately, but quite poorly a week later. However, for material learned in the afternoon when arousal was thought to be higher, the opposite pattern was observed: Immediate retention was not very good, but delayed retention was superior. That this effect was not due to state-specific learning was shown by the failure of time of day at retrieval to interact with time of day of learning. Further study suggested that the time of day effect interacted with the importance of the material to be learned (Folkard & Monk, 1980).

Individual Differences in Diurnal Arousal Variation. As is often the case with exciting findings, parts of the Folkard study have been somewhat resistant to replication. Although Oakhill (1986) replicated parts of the Folkard et al. (1977) study (specifically, the benefit for long-term recall of learning material in the afternoon), she failed to show differences in immediate recall as a function of time of day. Mark Puchalski (1988; Puchalski & Revelle, 1989) has recently shown that failure to replicate these findings might be due to overlooking personality factors. Puchalski replicated the Folkard study with the addition of impulsivity as a subject variable. The results were quite clear. There was a reliable three-way interaction of impulsivity, time of day, and retention interval: For high impulsives immediate memory was superior for materials learned in the morning and delayed recall was superior for material learned in the afternoon (replicating Folkard's result); for low impulsives, on the other hand, immediate recall was better for material learned in the afternoon, and delayed recall was better for material studied in the morning than in the afternoon. That is, the original Folkard et al. (1977) results were replicated for the high impulsives and reversed for the low impulsives. This result is compatible with the hypothesis that the relationship between impulsivity and arousal is a function of time of day. Low impulsives appear to be more aroused in the morning and less aroused in the afternoon than high impulsives.

More recent results reported by Wilson (1990) show that the skin conductance of introverts achieves a maximum almost 4 hours before that of extraverts (13 : 42 vs. 17 : 36) but that this difference does not occur for low vs. high impulsives. Wilson suggests that part of this difference may be attributable to the arousing properties of different activities sought out by introverts and extraverts (extraverts are more likely to engage in social activity which typically occurs later in the day). One important conclusion to draw from Wilson's study is that arousal shows large variations over the day, and that at least some of this variation reflects individual differences.

Other examples of the problems encountered when studying the interaction of arousal and retention interval may be found in studies by Maltzman, Kantor, & Langdon (1966), Saufley & LaCava (1977), and Schmitt & Forrester (1973). Maltzman et al. (1966) failed to replicate the Kleinsmith and Kaplan interaction using a serial recall paradigm. In contrast to the earlier findings, they found that high arousal words resulted in both superior immediate and delayed recall. Saufley and LaCava (1977) reviewed the evidence for the Kleinsmith and Kaplan arousal effects after their failure to replicate the interaction between arousal and retention interval. Although their own attempt failed, they concluded that evidence supplied by several different procedural variations on the original design suggests that this effect is robust. It is quite likely, given the time of day effects shown by Folkard and his colleagues as well as the personality by time of day results of Puchalski, that some of these failures to replicate may be due to a failure to control for these other sources of arousal.

Based upon our own data as well as the literature we have reviewed here and elsewhere, we believe that the effect of arousal on cognitive performance is systematic, although complex. Part of this complexity is that different experiments use different operationalisations of arousal and that each experimental manipulation has specific as well as general effects on arousal. In order to see the consistency across studies, it is necessary to exclude as many extraneous sources of variation as possible. One way to do this that we have found to be most useful is to focus on effects showing consistent interactions with stable individual differences such as impulsivity. Interactions of this nature allow us to exclude competing hypotheses more readily than if we find mere main effects (Revelle & Anderson, in press). When searching for such interactions, however, we find it important to look for effects that are robust to specific modifications and that are common across many sources of variations in arousal.

Given these caveats, a consistent finding in the literature relating motivation to cognition and particularly to aspects of memory performance is the importance of arousal (Humphreys & Revelle, 1984). Arousal as induced by stimulus materials, drugs, time of day, or exercise, or naturally varying as a function of personality, interacts with retention interval to affect the recall of neutral or affective stimuli (Table 1). What is unfortunate is that there is another body of literature, more familiar to readers of this journal, that studies the relationship between mood and memory without considering that arousal is an important component of most mood manipulations. We now review some of the contradictory findings relating mood and memory to suggest that an arousal interpretation might clarify this relationship.

AROUSAL INTERPRETATIONS OF MOOD AND MEMORY EFFECTS

One of the most researched effects of mood on memory has been labelled "mood state-dependent retention". This effect refers to a tendency to recall information better when retrieval mood state matches the mood state present during the original learning. Bower (1981) developed a fairly comprehensive "associative network theory" that purported to explain this tendency. Unfortunately, as interest increased in the possibility of mood-related effects on memory, so did the contradictory findings (Bower & Mayer, 1985; Foa, McNally, & Murdock, 1989; Leight & Ellis, 1981; Perrig & Perrig, 1988; Wetzler, 1985). Many attempts to quantify mood-related effects and render them predictable have met with frustration. Bower & Mayer (1985) went so far as to deem mood-dependent retrieval "an evanescent will-o'-the-wisp" (p. 42) while expressing their frustration with the seemingly incomprehensible pattern of mixed findings within the literature.

An effect of mood on memory that does seem to have shown some consistency is called mood congruency (Blaney, 1986). This effect is a tendency to recall material of the same hedonic quality as the existent mood state. To the extent that arousal varies as a consequence of individual differences or the mood induction procedures used in mood congruency experiments, some of the issues raised in this article remain relevant. We do not address these directly, however, because the strongest demonstrations of mood congruent effects come from studies that varied mood only at recall (Clark & Teasdale, 1985; Teasdale & Russell, 1983) which would not involve the type of process-based effects we are discussing.

Returning to the phenomenon of mood state-dependent recall, evidence gleaned from the arousal literature reviewed here suggests that the presence of uncontrolled and unmeasured arousal levels in this research may explain this pattern of disappointing findings. The arousal present in these mood and memory experiments could serve as a serious confound across different conditions, mood induction techniques and mood states. For instance different studies regularly employed different mood induction techniques (hyponosis, reading valenced statements, listening to music, false feedback, etc.) to achieve what are considered comparable levels of sadness, happiness, and even neutrality across studies. From the perspective of differences in arousal levels, however, the results of these different techniques might be appreciably different. It seems likely that listening to uplifting, bubbly music might induce a higher arousal state than hypnosis which involves deep relaxation—although both might result in superficially similar positive mood states.

Measurement of the changes in arousal level concomitant with changes in affective valence is the exception rather than the rule. When measurement has been attempted, evidence of significant covariation of affect state and arousal level under certain inductions has resulted (Eich & Metcalfe, 1989). Whissell and Levesque (1988) assessed the evaluative and activational aspects of the three sets (elation, depression, and neutral) of the widely used Velten mood-induction statements. Their results highlight several important contrasts between the different conditions. First, the neutral condition was found to possess a significantly higher proportion of low-activation words (44%) compared to both the elation (19%) and depression (31%) conditions. The difference between the elation and depression conditions was also significant. In addition, the elation condition was also assessed as having a significantly higher proportion of high-activation words (35%) than either the depression (22%) or neutral (16%) conditions. This pattern of findings clearly suggests that the potential for differential induction of arousal along with affective state is significant. Whissell and Levesque conclude: "... the neutral induction ... is not entirely neutral but rather pronouncedly inactive (boring, sleep-inducing) ... If activation is mediating the effects observed after induction, the low-activation character of the neutral condition may be an important point to consider" (p. 520). Furthermore, because arousal information is not routinely gathered in studies of mood and memory, analyses of the potential contributory role of arousal as both a cue and a mediator of process can not be performed.

In addition to a lack of measurement of arousal levels, little apparent control (or report) across studies of the intervals between single or sometimes multiple learning and recall sessions can be found. Once again, from the perspective of the differential effects of arousal over short-term vs. longer-term recall, this lack of control seems a significant confound. One study may be tapping into all short-term effects while another might tap into longer-term effects or some mixture of both.

Recall intervals range from immediate recall to recall some 20min (Schare, Lisman, & Spear, 1984), 40min (Bower & Mayer, 1985), 5h

(Bower, Gilligan, & Montiero, 1981), 24h (Wetzler, 1985), and even 4 days (Weingartner, Miller, & Murphy, 1977) after initial learning. From a processing perspective, this chaotic mixture of shorter-term and longer-term retention makes cross-study comparability and systematic review virtually impossible. Moreover, in the studies that utilise multiple list learning and/or multiple recall paradigms that are strung out in some random time sequence, these variable intervals stand as a potentially significant source of unreliable or confounded results.

In the light of the limitations that result from adopting a focus on the cueing function of the affective component of emotion states, we suggest that a more profitable approach may exist in examining the effects of emotional activation on the underlying processes themselves. Thus, while the oft-used cue perspective attempts to characterise how emotion might function under standard information processing conditions, the proposed process perspective seeks to understand how emotion might alter the very operation of standard processing. Ellis and colleagues (Ellis, Thomas, McFarland, & Lane, 1985; Ellis, Thomas, & Rodriguez, 1984) have adopted a perspective similar to ours in their attempts to explicate the effects of depression on processing capacity as have Mathews (M. W. Eysenck & Mathews, 1987; Mathews & M. W. Eysenck, 1987) and M. W. Eysenck (1977, 1981b) for the effects of anxiety. We feel that this change in perspective may help to explain the inconsistent findings in the study of the effects of mood on memory. Studies along these lines are now being conducted in our lab.

Explanations of the Arousal Effect

Unfortunately, although a great deal of theoretical effort has been expended trying to explain the effects of mood on memory (e.g. Blaney, 1986; Bower, 1981, 1987), much less work has been done to explain how arousal effects memory. The most frequently cited explanation is that of Walker's (1958) theory of consolidation, which does not map easily into any current theory of memory process. An alternative model, the "tick rate hypothesis" (Humphreys & Revelle, 1984; Revelle, 1989), suggests that arousal increases the speed of information processing in a manner analogous to increasing the clock speed in a computer. Such an increase in speed will lead to faster *information transfer* by increasing the rate at which the environment is sampled, and will also lead to more rapid loss due to interference in a short-term store. If the overall speed of processing is increased by arousal, however, more samples of the environment will be taken and stored for long-term retrieval. Thus, an arousal-induced change in one central process, the speed of processing, will produce the observed improvements in SIT, decrements in STM, and improvements in LTM. A similar model that is more compatible with current theories of memory is that increased arousal reduces the firing threshold of the neural structures associated with a stimulus trace. Such reductions in threshold will simultaneously increase the speed at which information is processed but at a cost of increased interference in the short run. To the extent that a lowered threshold increases context updating, and the formation of associations with that context, increased arousal should facilitate the storage of memories for later retrieval.

McGaugh (1990) suggests that there is an evolutionary utility of arousal effects upon memory. Events immediately preceding or following high levels of arousal are likely to be of more significance than are events associated with low levels of arousal. For organisms with limited memory capacity, it would be advantageous to store information associated with high rather than low arousal. Organisms as small as honey bees and as complex as humans seem to show similar effects of arousal on memory.

SUMMARY AND CONCLUSIONS

Arousal, either naturally varying as a function of the stimulus materials, as a function of the situation, or as a characteristic of the subject, has an important effect upon information processing in general, and on memory in particular. By ignoring such variations in arousal, research on the relationship between cognition and affect has tended to emphasise the cue properties of the positive/negative dimension of emotion rather than the processing effects of the high/low arousal dimension. That is, the primary emphasis has been on the operation of standard information processes under emotional states rather than the possibility of the alteration of those processes in the presence of emotional states. We suggest that the presence of interactions between uncontrolled and unmeasured arousal levels and recall intervals in these studies may help to explain the pattern of confusing results in the mood state-dependent literature. Furthermore, considerations of time of day and individual differences in impulsivity should also shed additional insight into these results.

Many of the effects of arousal upon memory and information processing are difficult to tease out because of the many ways in which arousal can vary. It is perhaps understandable that researchers interested in tight experimental control will eschew a theoretical construct that varies between subjects, as a function of the time of day, and even as a function of the presence of others. In addition to these seemingly endless sources of variation in arousal, arousal is poorly measured by any single index. Taking all of this into account, however, arousal is still a fundamentally important component of the energetic aspect of motivation and emotion. Given the importance to an organism of being able to adapt its energetic response to environmental demands, it is not surprising that arousal affects many aspects of cognitive performance. Nor is it surprising that many emotional and mood-related phenomena may be affected by arousal, given that a fundamental effect of emotional reactions is to modulate both the energetic as well as the affective response to a situation.

The challenge to future research is to explore the mechanisms by which arousal and affect influence memory and cognition. This search can not be done without first mounting systematic investigations of the many ways in which arousal can be varied and searching for common effects amidst the clutter of specific effects. The wealth of evidence suggests that natural and induced variations in arousal affect shorter- and longer-term memory differently. This perspective has broad implications for ongoing research on the effects of cognition and emotion. Arousal effects may serve as potent explanatory vehicles for the conflicting findings existent in the research on mood and memory.

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