When Less is More

Information, Emotional Arousal and the Ecological Reframing of the Yerkes–Dodson Law

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Abstract. Easterbrook's (1959) cue-utilization theory has been widely used to explain the inverted U-shaped relationship, initially established by Yerkes and Dodson, between emotional arousal and performance. The basic tenet of the theory assumes that high levels of arousal lead to restriction of the amount of information to which agents can pay attention. One fundamental derivative of the theory, as typically conceived in psychology, is the assumption that restriction of information or the ability to process a smaller set of data is fundamentally disadvantageous. To explore the merits of this point, we first argue that the relationship depicted by this collapsed version of the Yerkes–Dodson law is far too simplistic to account for the complex relationship between various cognitive functions and emotional arousal. Second, conceptualization of arousal as a unidimensional construct needs to be rejected. Finally, and most importantly, we challenge the notion that having more information available is necessarily preferable to having less information.

Key Words: arousal, attention, cue-utilization theory, decision making, ecological rationality, emotional arousal, memory, stopping rules, Yerkes–Dodson law

The writer Jorge Luis Borges (1998) tells the story of Ireneo Funes, who, after a fall from a horse, found that his ability to remember had become limitless. Most of us, at least at first glance, might envy Funes for his new-and-improved capabilities. Yet, as Borges maintains, despite his omnipotent mnemonic abilities, Funes 'was not very good at thinking' (p. 137). In fact, Funes 'was virtually incapable of general, platonic ideas . . . it irritated him that the "dog" of three-fourteen in the afternoon, seen in profile, should be indicated by the same noun as the dog of three-fifteen, seen frontally' (p. 136). Borges' story hints at the possibility that there might be a price tag

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associated with possessing too much information, such as an inability to think creatively and to form more abstract representations of things, becoming mentally impotent.

In contrast to Borges' story, a long tradition in psychology has assumed that possessing more information is necessarily preferable to having less information (Hertwig & Todd, 2003). One manifestation of this idea can be found, for example, in Easterbrook's (1959) explanation of the results reported by Yerkes and Dodson (1908)—in what later came to be known as the Yerkes–Dodson law (YDL). As only a few psychological findings have made it to the rank of a law since Gustav Theodor Fechner and the heydays of psychophysics, let us briefly highlight some of their findings.

Formulated in 1908, the YDL maintains that an inverted U-shaped relationship exists between stimulus strength and the rapidity of habit formation for tasks varying in discrimination difficulties (Yerkes & Dodson, 1908). The original study evaluated the speed with which dancing mice could learn to discriminate between two boxes—white and black—in relation to the levels of electrical shocks administered when the animal's choice was wrong.[1] Since the results were based on mice, Yerkes and Dodson concluded that the veracity of their findings needed further experimentation, this time with other animals—a task that they never managed to accomplish together.

The reception of their results was ill-fated practically from the beginning. Yerkes and Dodson (1908, p. 479) had, in fact, three graphs depicting the relationship between stimulus strength and habit formation, depending on the difficulty of the discrimination task. For their 'easy' condition, they did not find the notorious inverted U-shape, but a direct *linear* relationship between strength of shocks and learning success. But things are still more complicated than that: In a re-analysis of the original data, Bäumler and Lienert (1993) found that if the learning criterion is defined as series of errors (instead of series of hits), there is *no* effect for the easy task and a *linear* effect for the difficult task. So even the—much more detailed than typically reported—original results do crucially depend on the choice of the 'performance' variable. While Yerkes and Dodson still had an eye for the restricted scope of their 'law' and for the role of task definition and task difficulty, later researchers were mesmerized by the spell of the single inverted U.[2]

In the early 1950s, the initial constructs employed by Yerkes and Dodson were altered into the more familiar ones used today—those of (emotional) arousal and performance. The YDL, as depicted in current psychological textbooks (see Winton, 1987), no longer speaks of stimulus strength and habit formation, but utilizes a completely different set of constructs. Meanwhile, current researchers maintain that the shift has had no effect on the law's validity (Teigen, 1994). The relationship between emotional arousal and performance, it has been argued, forms an exact replica of the relationship found by Yerkes and Dodson (Broadhurst, 1957). Accordingly, it is of no significance whether investigators manipulate the levels of negative/ noxious stimulus strength or arousal, or whether researchers measure performance or habit formation. Or is it?[3] In order to answer this question, we use current research and findings on emotional arousal to highlight the problematic nature of the new YDL. Our main aim, however, is not to challenge the utility and validity of the YDL per se. Rather, via our conceptual critique, we hope to illustrate the beneficial and adaptive value of high emotional arousal states.

A Law with Many Faces

The YDL has been extensively used to explain the effects of emotional arousal on performance, assuming that high levels of emotional arousal are necessarily maladaptive and detrimental for information processing, decision making and performance. One question investigators have been grappling with is how to explain the relationship between high levels of arousal and performance. In other words, what are the mechanisms underlying the effects of emotional arousal on performance? One influential idea to emerge in the early 1950s was Easterbrook's (1959) cue-utilization theory.

Easterbrook's cue-utilization theory has been recurrently adopted to explain the inverted U-shape relationship between emotional arousal and performance (see also Eysenck, 1982; Mandler, 1975). The basic proposition of the theory assumes that at medium levels of emotional arousal (where optimal performance is expected), subjects can attend to a larger set of cues, whereas higher levels of emotional arousal negatively affect subjects' ability to pay attention to or process a large set of cues. That is, at high levels of arousal subjects can allocate attention to a restricted set of (internal or external) cues only, which, in turn, leads to lower performance levels.

One question we would like to address in this paper is whether restriction of information or the ability to process a larger set of data is fundamentally disadvantageous, or whether under certain circumstances it could have an advantage. Following Easterbrook (though he did not specify the mechanisms), we challenge the basic premise that restriction of information is necessarily detrimental to performance; we dispute, in the process, the generalization power of *only* the new YDL formulation. In contrast to prevailing assumptions, we show that the adaptive value of high emotional arousal stems precisely from its ability to restrict agents' attention allocation, for by this process agents are able to perform two vital functions: (i) focus their attention on the most urgent and vital information within the environment while overlooking peripheral cues or information; and (ii) mobilize the body to deal quickly with urgent problems. Less information can lead to improved performance (for a similar line of argument, see

Gigerenzer, Todd, & the ABC Research Group, 1999): there are situations where, simultaneously, more (arousal) is better, and less (information uptake) is more. As Gigerenzer and Selten (2001) express it, 'limitations of knowledge and computational capacity need *not* be a disadvantage' (p. 7). *A fortiori*, acting on less information (at times on a single cue) can be highly beneficial, in the sense that high arousal states allowed humans to respond more rapidly to certain contingencies that have arisen during our evolution. By 'overruling' conscious control and behavioural flexibility, high levels of arousal may trigger a phylogenetically 'old' route that practically secures certain behavioural outputs (e.g. flight reactions or 'freeze' reactions). From an evolutionary perspective, panic is not a detrimental imbalance of the system; rather it is a focus on the essential.

This paper is organized as follows. Following Lacey (1967), we first question the general usage of the term 'emotional arousal' as one that represents the entire gamut of emotional arousal states. That is, we question the notion (and its usefulness) that a single 'emotional arousal' phenomenon exists. Second, we suggest that the cases in which the YDL has been confirmed do not represent the situations in which high emotional arousal has been designed to be adaptive and functional. Previous researchers working on the YDL have been largely oblivious to the idea that context can affect the type of research conducted, and, more importantly, the results obtained from such experiments. The experimental context—the link between the arousal state and the performance evaluated (i.e. ecological validity)—in which we have thus far subjected emotional arousal might not represent the domains where evolution has designed high arousal states to be functional; and a behavioural mechanism that was adaptive in the environment of evolutionary adaptedness (EEA) does not have to be adaptive in contemporary (modern) contexts (Tooby & Cosmides, 1990). There are no a priori reasons to presuppose that emotional arousal is a general-purpose mechanism; rather, it is more likely that different emotional arousal states or patterns serve as special-purpose mechanisms that have evolved to solve specific problems. Similarly, the performance dimension used to validate the YDL (and to illustrate the harmful nature of high arousal levels) needs to be reconsidered. Ecological performance is more than doing well in a paper-and-pencil test in the classroom (cf. Bäumler 1994; Mendl, 1999).

This means that *both* axes of the YDL need revision, and the performance construct has to be redefined in conjunction with the arousal construct. What Yerkes and Dodson had in mind was more sophisticated than what their U-entranced successors made of it: they had presented a three-dimensional law, one that took task difficulty into account. From an evolutionary perspective, it is of course not only relevant how difficult a task is (and how performance is defined and measured), but also *what* it is, and what consequences there are of solving or not solving it.[4] Instead of further elaborating on these multi-dimensional aspects of the YDL, later generations let the law collapse into one single curve with its idealized and highly abstract, quasi-unidimensional axes. In order to elucidate the ecological rationality of emotional arousal, it is necessary to bring the *task* back in focus. We will do so later on by introducing the concept of *arousal-congruent performance* (ACP).

Our line of reasoning follows Simon's (1956) notion that certain mental mechanisms (e.g. fear and detection of predators) exploit environmental regularities—hence the need to examine the relationship between our mental architecture(s) and the environment in which those mechanisms have evolved—what Gigerenzer et al. (1999, Ch. 1) have termed ecological rationality. We argue for a need to revise our perspective on the adaptability and functionality of high emotional arousal states. Each emotional arousal type, it is hypothesized, can be advantageous in a narrow spectrum of cases, whereas in other cases it might have an opposite effect. Since nowadays it is generally agreed that each emotion (or emotional state) serves a restricted and specific function (i.e. solves different problems), one can deduce that each emotional arousal associated with each emotional state is designed to aid in the process of solving a limited range of problems. This is exemplified in a growing body of research showing that different emotions have different, in fact opposite, effects on risk perception and risk taking (Ketelaar & Todd, 2001; Lerner & Keltner, 2001; Loewenstein, Weber, Hsee, & Welch, 2001). As Frijda (1986) has argued, 'emotions arise in response to the meaning structure of given situations, and different emotions arise in response to different meaning structure' (p. 349; see also Izard, 1993).

In light of these criticisms, we introduce the concept of *arousal-congruent performance* (ACP). The term ACP stands for the idea that there should be a connection between the emotional arousal state induced and the performance evaluated. Emotional arousal states, in other words, should *match* the contingencies or problems associated with the generation of the specific emotional arousal state—they should be task-relevant. If fear, for example, is understood as a mechanism for the detection of and reaction to potential threats (Öhman & Mineka, 2001), then researchers should devise their experiments to evaluate whether different levels of emotional arousal due to fearful stimuli facilitate or hinder subjects' ability to detect or react to these stimuli (see below).

This idea was advanced earlier by Cosmides and Tooby's (2000; Tooby & Cosmides, 1990) argument that each emotion can be seen as a specialized mechanism designed to aid individuals in confronting and solving certain adaptive problems that arose during our evolutionary history. If different arousal states have been designed to solve specific and recurrent adaptive problems, we can fairly assume that evolution has never 'intended' different and distinct emotional arousal states to facilitate a broad and heterogeneous spectrum of problems. It would not be surprising to find that fear is not a very conducive mechanism for mate selection, or that shame is not very useful when dealing with predators. If we wish to validate the usefulness of the YDL, then the logic driving the experimental design must incorporate and be based upon the fundamental fact that arousal states are specialized mechanisms designed to be functional, useful and beneficial in a limited number of cases and not as general-purpose tools. As Tomkins (1981) has argued, high arousal can be seen as a double-edged sword: it has positive and/or negative effects depending on, among other things, the circumstances and the task at hand (e.g. fear can have either a paralysing or a mobilizing effect).

Researchers have not always been oblivious to the need to design experiments that match the arousal state and the task evaluated. When such considerations are incorporated into the experimental design—that is, the arousal states are related to the performance—different results from the prediction of the YDL are usually obtained. Although no conclusive picture emerges from the literature, several researchers working on the relationship between arousal and motor performance have shown either no degradation of performance (Cox, 1983; Marteniuk & Wenger, 1970; Sage & Bennett, 1973) or, in accordance with our hypothesis, that higher levels of arousal lead to significantly improved performance (Marteniuk, 1969). Others have argued that the typical down-slope findings found after the optimal level of arousal stem from a lack of ecological representativeness in the experimental design, rather than from the deleterious effects of high levels of arousal (Näätänen, 1973). These findings provide further backing to the argument that the new formulation of the YDL has restricted, or no, explanatory value—the interaction between different arousal states and diverse cognitive functioning is a good deal more complex than the simple inverted U curve.

Arousal and Emotional Arousal

Ever since its introduction, the arousal construct has gained much attention in psychological research and has been widely used in various setting. Hebb (1955) and Duffy (1962), for example, conceptualized the arousal construct as one that represents all arousal states. It was assumed that the arousal construct is a unidimensional phenomenon, an energy axis from ‘low’ to ‘high’, in the sense that examining one arousal state reveals the nature of them all (with differences only in intensity). Furthermore, it has been generally believed (and practised) that similar emotional arousal states can be induced from diverse sources, for example caffeine (K.J. Anderson, Revelle, & Lynch, 1989), exercise (Adam, Teeken, Ypelaar, Verstappen, & Pass, 1997), noise (O’Malley & Gallas, 1977) and stress (C.A. Anderson, 1976), while producing similar phenomenological (both physiological and psychological) manifestations. The emotional arousal construct seems to have served as a host for almost any physiological change with little or no regard as to either its source or the actual bodily modification being produced, though, as some have argued, 'arousal in pure form cannot be created in the laboratory' (Neiss, 1988, p. 346). Researchers who have investigated the YDL have rarely questioned the nature of the unidimensional arousal concept, or its broad applicability to various domains (Robbins, 1997).

The arousal construct discussed in this paper is confined mainly to those instances that are associated with emotions. We focus primarily on emotional arousal, choosing not to discuss the potential roles of other types of arousal states—though the same rationale might be applicable to a wider range of cases. Arousal states—whether of low, medium or high intensity—can stem from various sources, including those that have no emotional signature, such as exercising or consuming caffeine. These cases, where no emotional components are present, are excluded from our discussion. This distinction is crucial, for it points precisely to where previous researchers have gone astray and have incorrectly assumed that both conceptualizations of arousal states (with or without emotional constituent) represent the same phenomenon, or that arousal can be completely detached from its functional sources.[5]

What do researchers mean when they use the term 'arousal'? Psychologists, for the most part, tend to employ the arousal construct as if it represents a wide range of physiological manifestations (Deffenbacher, 1994). In fact, one can view the arousal construct as a meta-construct, since it serves as a rubric for a wide range of physiological changes. In other words, any physiological change (e.g. increase in blood pressure, heart rate, hormonal surge or brain activity) fits into the rubric of arousal. It is not clear, therefore, whether the employment of the term 'arousal' in one experiment necessarily has any correspondence or similarities to its usage in any other experiment.

The problems associated with the arousal concept are even more acute and problematic when we discuss the nature and characteristics of emotional arousal (Sonnemans & Frijda, 1994). Frijda (1986), for example, argues for the existence of different types of arousal: 'sympathetic (or automatic) arousal; attentional arousal; behavioral activation; and electrocortical arousal' (pp. 170–171; see also Cattell, 1972, for an argument that we need at least six physiological indices to capture the term 'arousal'). There need not be covariation among the different physiological changes, nor does a change in magnitude or direction of one component merit a similar change in any of the other three (Derryberry & Rothbart, 1984; Elster, 1999). Furthermore, the systems are independent of each other: 'Cortical arousal is one thing, with its own function and its own regulation; behavioral activation another; automatic response another, or set of others, again' (Frijda, 1986, p. 170). Research by Frost, Burish and Holmes (1978) lends further support to Frijda's claim. They demonstrated that an index of electrical brain activity (EEG-alpha), often understood as a general measure of arousal, was not related to bodily changes such as skin conductance and pulse rate. This research indicates that there exists no necessary relationship between activity (high or low) in the automatic nervous system and global brain-wave activity, a finding that stands in sharp contrast to the idea of a unidimensional arousal construct.

There is now ample empirical evidence to suggest that certain emotional states have specific patterns of automatic activation and bodily signature (Ekman, Levenson, & Friesen, 1983; Levenson, Ekman, & Friesen, 1990). In light of this, Hockey (1983) has argued that 'arousal is a far more complex process than originally conceived. If we are to continue to attempt to relate bodily and mental function . . . it is clear that we need concepts more realistically suited to the task' (p. 364). Although the question of distinctiveness of emotional qualities from patterns of psychophysiological measures alone is a hot and still unresolved topic, there is no empirical evidence to date showing that the entire gambit of emotions would produce the same arousal characteristics. On the contrary, it has been theoretically argued and empirically shown that physiological changes can be emotion-specific, in the sense that each emotion (anger, fear, happiness, sadness, joy, etc.) can have distinct arousal patterns and characteristics. Ekman et al. (1983), for example, argue that one could potentially distinguish between the six basic emotions based on their physiological expressions; Panksepp (1998), in a similar vein, has shown that different brain circuits are of central importance to some emotions but not to others. Different emotional arousal states might have unique characteristics, in bodily changes and manifestations and in activating specific neural structures, which correspond to specific functions.[6]

Zajonc and McIntosh (1992, p. 72), in line with Ekman, provide a list of differences in physiological changes among six emotions (happiness, anger, fear, sadness, disgust and surprise), including changes in heart rate, finger temperature, skin conductance and muscle activity, that were found across several studies. They additionally point out that positive and negative emotions elicit activity foci in different brain hemispheres and changes in breathing and blood temperature entering the brain.[7] Hamann, Ely, Hoffman and Kilts (2002), using positron emission tomography (PET), report that both positive and negative emotions elicited activity in the amygdala, yet they also conclude that there are clear differences in the areas activated (p. 139). Further support can be found in Canli, Zhao, Desmond, Kang, Gross and Gabrieli (1998), using functional magnetic resonance imaging (fMRI). Similarly, Morris et al. (1996) were able to demonstrate that viewing fearful faces, as opposed to happy ones, selectively activates only the left part of the amygdala. That is, fearful faces produced an increase in amygdala activation, whereas happy faces decreased activation in the amygdala. Although the significance of these findings is not yet completely clear, activation of separate brain areas, structures or neural networks is associated with different functions, findings that lend further support to Levenson's (1999) suggestion that negative and positive emotions perform different functions. Levenson's argument goes much further, in fact calling for a set of emotion theories for different emotions and not a single all-encompassing one. If emotions do not fit into a single theory (Griffiths, 1997), there are no reasons to suppose that emotional arousal does.

Though our aim was not to provide an exhaustive survey (see Neiss, 1988), given the accumulating corpus of psychological, psychophysiological and neurological findings it seems only appropriate to repeat Lacey's concluding remarks:

> There is strong neuropsychological and psychophysiological evidence that different fractions of automatic, electroencephalographic, and motor response are mediated separately, by perhaps 'intimately related' but clearly dissociable mechanisms. The dissociation may be biologically useful because the different fractions of response can influence cortical and subcortical functioning in different, and sometimes opposing, ways. (Lacey, 1967, p. 36)

Emotional Arousal and Memory

We have thus far illustrated the problematic nature of conceptualizing emotional arousal as a unidimensional construct and have argued for the need to judge each emotional arousal in its own right. There is now sufficient empirical evidence as well as theoretical suppositions to indicate that the arousal construct merits far-reaching revision (Robbins, 1997), while others have argued that the mounting evidence has led to the complete demise of the arousal concept (Fowles, 1984). Given our argument regarding the unique and specific influence arousal might have on other mechanisms (neurological, physiological and psychological), which, in turn, regulate and affect behaviour, there is a growing need to explore what the functions are that the emotional arousal state serves, and how these functions mediate behaviour.

We now turn our attention to research on memory, where, on the one hand, the effects of (emotional) arousal on performance have been extensively investigated, and where, on the other hand, they illustrate the simplistic and problematic nature of the YDL. That is, memory research exemplifies how emotional arousal can extract both deleterious and beneficial effects, *depending on what the experimenter decides to measure* and on the relationship between the eliciting stimuli, the arousal state and the task evaluated.

In his review of the literature on eyewitness memory, Christianson (1992) shows the ubiquity of the assumptions that high levels of emotional arousal impair memory. He cites, however, a great number of studies that contradict this crude supposition. In fact, a large body of evidence presents precisely the opposite picture: high levels of emotional arousal can lead to improvement in performance. This depends on whether the investigators measure the effects of traumatic experience on eyewitness memory, or whether they evaluate memory performance while individuals are in the midst of a traumatic experience. This notion harbours a theoretical basis similar to the ACP notion introduced earlier. Like Christianson, we argue for the need to differentiate between cases in which experimenters have measured the effects of high emotional arousal on memory, where the items to be remembered were dissociated from the arousal state (arousal-incongruent performance), and cases in which the items to be remembered were associated with the arousal state (ACP).

In the memory literature there seems to be relatively little controversy over the merits of Easterbrook's (1959) cue-utilization theory. At high levels of emotional arousal, as Easterbrook's theory predicts, subjects are able to remember only a restricted amount of information (i.e. central events or cues, while neglecting to assimilate or recall more peripheral ones). Yet there appear to be divergent opinions regarding whether this phenomenon has negative or positive consequences. For example, Christianson and Hübinette (1993) found no differences between victims and bystanders in their ability to remember details from a crime scene, though one can fairly assume (as the authors did) that victims of crimes experience intense emotional arousal states. Others (Reisberg, Heuer, McLean, & O'Shaughnessy, 1988) have found a positive relationship between the degree of emotional intensity and confidence in memory. Researchers who examined victims from Nazi concentration camps reveal that these individuals could, though with some errors, remember many details with great accuracy and precision (Wagenaar & Groeneweg, 1990). Being in one of the most intense emotionally arousing conditions possible does not necessarily lead to memory deterioration.

Such findings can be partially explained by the effects of high emotional arousal states on the release and regulation of β-adrenergic hormones.[8] Several studies (Cahill, 2000; Cahill, Prins, Weber, & McGaugh, 1994; Packard & Cahill, 2001) have shown that during high emotional states animals and humans (McGaugh & Gold, 1989) release high amounts of β-adrenergic hormones. It has also long been known that β-adrenergic hormones are a central component in modulating memory storage; but these results should be qualified, for the role of β-adrenergic substances has been pronounced only in emotionally loaded events, while its role in emotionally neutral events is yet to be shown. More remarkably, 'the degree to which the activity of the human amygdala related to memory increased almost linearly with the degree of subjective arousal induced by the stimuli' (Packard & Cahill, 2001, p. 754). This point is important as the activation of β-adrenergic hormones is largely connected to activation of the amygdala, a brain structure that has long been implicated as one of the central subcortical areas involved in emotional experiences (LeDoux, 1996, 2000).

Following this line of research, Parent, Varnhagen and Gold (1999; see also Blake, Varnhagen, & Parent, 2001)—working under the assumption that the catecholamine stress hormones (epinephrine/adrenaline and norephinephrine/noradrenaline) are positively related to blood glucose levels—were able to show that high arousal states increased subjects' blood glucose levels, which was positively related with the ability to remember emotionally arousing information. Buchanan and Lovallo (2001), likewise, found that subjects' memory performance was positively correlated with the degree of emotional intensity of the stimuli (slides) presented. That is, the most highly emotionally arousing stimuli were also remembered best.

The so-called 'flashbulb memories'[9] (starting with the research by R. Brown & Kulik, 1977) provide an additional layer of support for arousal-induced memory enhancement, showing repeatedly that traumatic experience can be remembered vividly for many years. High levels of emotional arousal are related with improved, rather than worsened, memory of the flashbulb conditions. Furthermore, 'ample studies have shown that high-arousal events are remembered at about the same level as low-arousal events at short retention intervals but that a *superior* memory performance for high-arousal events over low-arousal events is obtained at delayed test intervals' (Christianson, 1992, p. 291, emphasis added). Another vital area of eyewitness memory research that supports our proposition emerges from research on what is known as 'weapon focusing'. For instance, individuals who are robbed tend to remember vividly the weapon of the assaulting party, typically at the expense of other details related to the event.

The studies reported here support the notion that details of emotional events will be remembered quite well (at times even better) when the emotional arousal elicited is generated by the to-be-remembered event rather than being evoked by an unrelated source. In other words, when a fit exists between the arousal state and the task (ACP is taken into account), performance need not deteriorate; rather, performance can actually improve. To the authors' knowledge, not a single experiment exists—where a match between the emotional arousal state and the task at hand (ACP) was created—that was able to demonstrate negative effects of high arousal states on recollection: 'If the emotionally arousing agent is related to the TBR [to be remembered] event and if one is not distracted by an extraneous source of arousal that is stronger in intensity than the TBR event, there is no evidence that high arousal impairs memory performance' (Christianson, 1992, p. 297).

An Alternative Framework

In contrast, a growing body of evidence provides an alternative reading of the results obtained, while preserving the basic premises of, and being consistent with, Easterbrook's (1959) cue-utilization theory. That is, depending on what experimenters decide to measure—peripheral or central details, short-term or long-term, storage or retrieval (Eysenck, 1976)—different results are observed. Bock's research has shown that emotionally arousing words are better retained than less arousing ones (Bock, 1986; Bock & Klinger, 1986), and more recently, Jeffrey Brown (2003) has found that high levels of arousal, compared to low arousal levels, amplify memory for central details at the expense of peripheral ones. Findings of this kind have led Metcalfe and Jacobs (1998) to conclude that one of the major problems with the (over)generalized YDL is its failure to take into account the numerous examples that show how high arousal states can *increase* cue saliency, increase our ability to encode information, and via this process improve memory performance. A close examination of the arousal–memory literature reveals certain regularities and trends: high levels of arousal can be beneficial, depending, as we have indicated earlier on, on certain conditions. It seems, after all, that 'a memory system sensitive to the arousal level of an event is a broadly functional survival tool. Behaviors that demand high mobilization of resources . . . are good candidates for memory storage' (Bradley, Greenwald, Petry, & Lang, 1992, p. 388). Thus, the literature on memory presents a strong case against the simplistic depiction presented by the new formulation of the YDL. Finally, as William James so eloquently foreshadowed our argument, 'an impression may be so exciting emotionally as almost to leave a scar upon the cerebral tissues. . . . The primitive impression has been accompanied by an extraordinary degree of attention, either as being horrible or delightful' (James, 1890, quoted in Hamann, 2001, p. 394).

When Less is More

We do not think that there can be much opposition to the claim that under certain conditions high emotional arousal states can have negative influences on performance. We have enough evidence for that effect. The question is: does the experimental evidence reported in the literature accurately represent the functional value of high emotional arousal states? Furthermore, do the results obtained so far stem to a large extent from previous experimental designs and practices, rather than from the inherent value of high emotional arousal states?

While our aim up to this point has been to illuminate the theoretical as well as experimental bounds of previous research, we now turn our attention to exploring the possibility that high levels of emotional arousal might have a positive function, while working within the tenets of Easterbrook's cue-utilization theory. In our discussion we focus on fear, for fear can serve as a prime example of the power of high levels of emotional arousal to orchestrate diverse cognitive, perceptual and physiological systems.

In his book *The Rationality of Emotions*, de Sousa (1987) maintains that 'emotions are among the mechanisms that control the crucial factor of *salience* among what would otherwise be an unmanageable plethora of objects of attention, interpretations, and strategies of inference and conduct' (p. xv). Given our limited and imperfect mental and physical resources, emotions—and by a logical extension emotional arousal—are among the most important mental and physical architectures humans are endowed with, for they play a vital role in coping with changing and uncertain environments (Hanoch, 2002; Johnson-Laird & Oatley, 1992). Within this framework, high levels of emotional arousal states are a building block of what Gigerenzer et al. (1999, Ch. 1) call ecological rationality—rationality that is defined by its fit with reality. The construct of ecological rationality does not require agents to have perfect knowledge and boundless cognitive abilities. The notion of 'ecological rationality' signifies making good decisions by using mechanisms that can exploit particular aspects of environment structure in particular situations or domains. It is closely related to the idea that behaviour is more likely to be organized into relatively independent domain-specific modules rather than into a few general-purpose mechanisms. High emotional arousal states can be ecologically rational, for they exploit certain environmental regularities, though each emotional arousal state is functional and adaptive within a (very) limited range of domains and tasks.

In his 1980 article, Zajonc attempts, among other things, to show that high emotional arousal states have an important survival value. He writes:

> A rabbit confronted by a snake has no time to consider all the perceivable attributes of the snake in the hope that he might be able to infer from the likelihood of the snake's attack, the timing of the attack, or its direction. The rabbit cannot stop to contemplate the length of the snake's fangs or the geometry of its markings. If the rabbit is to escape, the action must be undertaken long before the completion of even a simple cognitive process—before, in fact, the rabbit has fully established and verified that the nearby movement might reveal a snake in all its coiled glory. (p. 156)

The highest emotional arousal (the most intense fear) directs our attention and actions along the correct path towards survival.[10] The rabbit, according to Zajonc, need not allocate its attention towards a diverse range of cues and therefore does not need to assimilate a wide range of information. It is sufficient, and in fact necessary, to limit one's attention to and focus on a single cue, while ignoring (consciously or unconsciously) all other information in the environment; suggesting, in the process, that having more information can actually be disadvantageous. In other words, the method by which agents allocate attention during events or tasks determines, subsequently, the information available for effective performance.

While Zajonc was lacking at the time the necessary neuroscientific evidence to support this claim, more recent research by LeDoux (1994, 1996) and others (Berkowitz, 1993; Panksepp, 1982) provides precisely the empirical data needed. These subsequent researchers have been able to demonstrate empirically that information processing can occur via two different channels. The first, the emotional channel, is faster though less precise ('quick but dirty', as LeDoux terms it); the second, the reflective channel, is slower, though more precise. Evolution has, in a sense, given us two options: (i) act fast (based on as little information as possible), with the risk of higher rates of false positives; or (ii) act slowly (integrating a larger set of data), though with more precision and flexibility. There are advantages, of course, to each option, but in cases of danger, as Zajonc (1980) points out, 'the decision to run must be made on the basis of minimal cognitive engagement' (p. 156). The 'decision' reached on which path to take is executed automatically without conscious involvement (Ekman, 1992; Panksepp, 1982). That is, if the information carries with it a particular signal such as danger, then an emotional arousal schema is activated that automatically produces a reaction; but if the information does not correspond to a pre-programmed criterion, a more elaborate deliberation can occur. In a way, the emotional arousal systems are designed to react to stimuli (e.g. predators) in a schematic fashion with 'the most-likely-to-succeed behavior' (LeDoux, 1996, p. 175).[11]

One crucial point for our discussion is the trade-off between the quantity of information available and the *rapidity* with which action must be carried out. The process of acquiring additional information has at least three potential drawbacks: (i) one needs longer periods of time to obtain additional information (at least insofar as we do not think in terms of heavy parallel processing); (ii) old information (i.e. information that we already possess) may already be outdated, irrelevant or even harmful by the time the decision is made; and (iii) the more information we have, the longer it takes to process it, up to the point of a system overload (Simon, 1983). This raises the question about what mechanisms are responsible for deciding when to *stop* acquiring more information and to act (see Gigerenzer et al., 1999).

The short cuts described by LeDoux can serve as a prime example for several points discussed thus far. First, they provide a glimpse into evolutionary working: evolution has wired us as to react to specific stimuli as fast as possible, with as little information as necessary, yet with the highest rate of success (Öhman & Mineka, 2001). As Tooby and Cosmides (2000) have argued,

> . . . natural selection has retained neural structures on their ability to create adaptively organized relationships between information and behavior (e.g., the sight of a predator activates inference procedures that cause the

> organism to hide or flee) or between information and physiology (e.g., the sight of a predator increases the organism's heart rate, in preparation for flight). (p. 1172)

The evolution of neural structures has also implemented *stopping rules*: when a threshold of arousal is reached, interrupt all ongoing activities and set new priorities. This can work as an 'if–then . . .' rule: if a situation of type S is encountered, an action of the type A is an appropriate response (is ecologically rational). For example, if a pre-programmed arousal level is reached, act according to a pre-selected procedure (e.g. if you encounter a predator, run or freeze).

These ideas question the claims that in situations of high emotional arousal 'behavior is *less than fully rational* because emotions either make preferences no longer well ordered or disrupt the agent's ability to determine optimal outcomes' (Kaufman, 1999, p. 139, emphasis added). High states of emotional arousal can serve both as an alarm call forcing us to respond automatically (e.g. running away from a fire), and to restrict our attention to the most important object(s) in the environment while producing the physiological changes necessary for producing the appropriate response (e.g. increasing heart rate and blood pressure; for a similar argument, see Simon, 1967). High emotional arousal states prompt actions that, along our evolutionary history, have resulted in better outcomes than any other solutions in recurring circumstances that are relevant to our survival (Ekman, 1999). We therefore can view high emotional arousal states as adaptive, since they lead to optimal results given environmental demands and restricted resources (Frijda, 1986; Keltner & Gross, 1999; Öhman, 2000).

High levels of arousal can shift one's focus of attention, creating in the process what is known as 'tunnel vision'. This process obviously has a price, for narrowing one's attention causes the obliteration of all other information that could be processed. In other words, high emotional arousal states can, as Easterbrook (1959) has theorized, force our attention to focus on a restricted amount of information, information that has brought about or caused the high arousal states in the first place. One can see how the detection of a predator can cause a shift of attention, and once the focus of attention has shifted to the predator all attention resources are devoted to fixating on the predator and searching for escape paths.

Attention, Emotion and the Perception of Feared Stimuli

The role of attention, and how agents 'decide' to allocate it, is an essential factor in determining agents' interaction with environmental demands. Ignoring a dangerous stimulus (e.g. spiders and snakes) can carry a heavy price tag, that of the agent's life. We can fairly assume that detecting dangerous stimuli in the environment, and allocating attention to the right objects, can be of the highest importance.

In light of our argument, we would like to present one empirical study (Öhman, Flykt, & Esteves, 2001) that captures many of the ideas developed in this paper, though the research was not conducted with the YDL specifically in mind.

The research by Öhman, Flykt and Esteves (2001) provides, we believe, the necessary empirical evidence to support our claims that (i) experimenters need to have a greater concern for ecological validity, (ii) narrowing of attention can be beneficial, and (iii) high levels of arousal can lead to improved performance.[12]

In their study, Öhman and his colleagues investigated subjects' reaction time to fear-relevant (snakes and spiders) and fear-irrelevant (flowers or mushrooms) stimuli. Though they did not directly manipulate subjects' arousal levels, one group of subjects in their experiment were highly fearful of either snakes or spiders (in the phobic range; see Experiment 3). That is, the researchers investigated whether 'fearful participants show evidence of more biased attention control setting than nonfearful participants' (Öhman, Flykt, & Esteves, 2001, p. 471). In other words, they studied whether being highly fearful has positive or negative effects on performance.

Two points are important for our argument. First, individuals highly fearful of snakes and spiders react to pictorial representations as if they were indeed dangerous (Globisch, Hamm, Esteves, & Öhman, 1999; Hamm, Globisch, Cuthbert, & Vaitl, 1997). According to Öhman, Flykt and Esteves (2001), 'among the highly fearful participants they [the pictures of snakes and spiders] would be rated as very negative and arousing' (p. 474). In other words, qualitatively similar reactions—emotionally and physiologically—are exhibited by subjects who are presented with pictorial representation of snakes and spiders and subjects who are presented with real animals. Second, given ethical considerations and limitations (see note 1), there are no experiments that have created very high levels of arousal. We can safely argue, therefore, that the fearful subjects in the Öhman, Flykt and Esteves (2001) study are a good match to normal subjects in the display of high levels of emotional arousal.

In the experiment, subjects had to perform an 'embedding' task under speed conditions: they 'searched for discrepant fear-relevant pictures (snakes and spiders) in grid-pattern arrays of fear-irrelevant pictures belonging to the same category (flowers and mushrooms) and vice versa' (Öhman, Flykt, & Esteves, 2001, p. 466). The participants' task was not confined to searching for the existence of an object, but also included indicating its location. This experimental design has a supplementary value, for it shows the adaptive value of being able not only to indicate the existence of a threatening object but, more importantly, also to pinpoint its location. Knowing that a threat exists is not sufficient, for one must also have knowledge about its location to escape in the correct path.

In contrast to what would be expected from a generalization of the YDL, it was found that being in a highly emotionally aroused state led to an *enhancement* in participants' performance. That is, 'the *fastest* responses of all were responses to the *feared* stimuli by *fearful* participants' (Öhman, Flykt, & Esteves, 2001, p. 473, emphasis added). One of the main findings was that snake-fearful participants (those who experienced higher arousal levels) were faster in detecting snakes than both control subjects and spider-fearful participants; similar results were obtained, *mutatis mutandis,* for the spider-fearful participants. Furthermore, overall, subjects made fewer errors in locating fearful-relevant compared to fear-irrelevant targets.

This line of research, we believe, manages to capture and overcome several of the criticisms we have presented throughout this paper. First, the research employed what we have termed arousal-congruent performance. That is, the investigators were sensitive to the notion that there should be a connection between the emotional arousal state induced and the performance evaluated. Participants' arousal states stemmed directly from the fearful objects (snakes and spiders) that they were to locate. This research also points to the adaptive role of emotional arousal (and emotions in general) in making specific cues or stimuli salient, and in driving attention towards objects that have posed danger in our evolutionary history. Finally, while providing empirical data necessary to challenge overly simplistic accounts of the YDL, this research allows us to retain, and work within, both Easterbrook's theory and the notion of ecological rationality.

Conclusion

The psychological tradition of assuming that more information is necessarily better has come under attack in recent years (Hertwig & Todd, 2003). Gigerenzer et al. (1999), for instance, have been able to demonstrate that having less information can lead to better performance. At the same time, a growing number of researchers are acknowledging that humans possess limited mental resources; yet they are able to demonstrate that these limitations can be advantageous (Kareev, 2001). Emotional arousal can, as Easterbrook has argued, restrict the amount of information agents are able to assimilate or process; however, from an ecological rationality perspective, restriction of information can have an adaptive and beneficial rather than a detrimental function. We have illustrated how the effects of high emotional arousal elicited by fearful-relevant situations can be seen as adaptive and functional. Fear, however, is only meant as an illustrative example (fear is one of the best researched and understood emotions). That is, there are no a priori reasons to assume that high levels of emotional arousal due to joy or love would not be functional and beneficial. We are not aware of any research that has been able to demonstrate that high levels of arousal due to parents' love hamper their care for their children, or research that demonstrates that high levels of arousal stemming from feelings of joy interfere with performance.

The ideas presented in this paper, while accepting the basic framework advocated by Easterbrook, challenge the simplistic generalizations that characterize the new formulation of the YDL. It advocates an ecological reframing of the law's constituting axes, 'arousal' and 'performance' (traditionally viewed at a high level of abstraction). We have argued that when high emotional arousal states correspond to the type of performance required, performance does not need to deteriorate. That is, if psychologists will pay close attention to the ecological validity of their experiments (i.e. the ACP), and as a consequence alter their experimental designs, divergent results may emerge.

The research of Öhman and his colleagues (2001) is an exemplary case in this respect, for it illustrates many of the arguments discussed in this paper. Their experimental design precisely captures what we have advocated (ACP), as the arousal states were naturally related to the task being measured. They were able to demonstrate that arousal does affect (i) attention and (ii) the information processed; furthermore, they showed that high levels of emotional arousal, though possibly restricting the number of cues integrated, can lead to improvement in performance. It is precisely via the restriction of the amount of information (focusing on the essential) that the beneficial role of high emotional arousal states is manifested. High emotional arousal states can be viewed as a vital mechanism allowing humans, despite their naturally limited resources and computational capabilities, to cope with the unpredictability and complexity of the environment: it facilitates decision speed by narrowing the range of cues and focusing the agent on those that are goal-relevant, reduces the range of options considered, and mobilizes the body to react to specific contingencies we face. High emotional arousal, if one adopts this view, may turn out to be an ally to performance, not a foe.

Notes

1. Yerkes and Dodson did not administer high levels of electrical shock due to both ethical and experimental considerations: that is, they did not want to hurt their animals, and hence it is not clear what 'high levels of arousal' means. This problem is endemic to most of the studies on the YDL. Although Yerkes and Dodson published their results over 90 years ago, we are still lacking criteria by which to judge the borders of each arousal level (i.e. where each level, or rather label—low, medium, and high—starts and ends).
2. Even experts are not immune against false memories in this context: for instance, one of the published abstracts (see Andreassi, 1998) for a conference

session devoted to the YDL and its origins ('90 Years after Yerkes–Dodson', held at the 9th World Congress of the International Organization of Psychophysiology, IOP) reported no contingency, instead of a linear contingency, for the 'simple' discrimination condition in the original paper.

3. The YDL has been questioned and criticized on several grounds (for a review, see Bäumler, 1994; Neiss, 1988; Teigen, 1994). These criticisms include, but are not limited to, the fact that no experiment has evaluated whether the effects of emotional arousal stemming from positive emotions (maybe because 'positive emotions typically bring positive benefits'; Izard, 2002, p. 799) have similar effects on performance (Fantino, Kasdon, & Stringer, 1970), and that no proper range or location for the medium level of arousal has been formed (W.P. Brown, 1965; see also Yerkes & Dodson, 1908).
4. In line with the results of Bäumler and Lienert (1993), the choice of the performance criterion (hit rate, error rate, performance speed . . .) may well make an ecologically relevant difference. For instance, there are situations where an agent may be best off by avoiding as many 'misses' as possible (e.g. when detecting potentially willing mates, or willing war allies), and others where the number of false alarms should be minimized.
5. This is quite exactly the essence of the historically most influential, but poorly replicated (e.g. Marshall & Zimbardo, 1979), cognitive theory of emotion, the 'two-component theory' by Schachter and Singer (1962; an important building block of the 'cognitive revolution' in psychology): that there is an unspecific, content-free quantitative level of physiological arousal (e.g. as experimentally induced by an adrenaline injection) which receives its quality or 'label' only via appropriate cognitive assessment/appraisal of the situation. Schachter and Singer (1962) maintain that '[p]recisely the same state of physiological arousal could be labelled joy or fury or jealousy or any of the great diversity of emotional labels depending on the cognitive aspects of the situation' (p. 398). Reisenzein (1983), in reviewing the literature, reports that only 'transfer of arousal' phenomena (rudimentary arousal influencing the strength of subsequent emotional states) seem to be substantial in this context.
6. Still, '[c]ontroversy abounds over . . . the number of emotions that exist . . . the commonality of certain emotional response patterns across cultures and across species, [and] *whether different emotions have different physiological signatures* . . . . Although there has been no shortage of psychological research on these topics, the findings have not resolved many of the issues in a compelling manner' (LeDoux, 1995, pp. 209–210, emphasis added).
7. The picture that emerges from research on autonomous nervous system (ANS) activity during emotional states is far more complex than the one presented here. Zajonc and McIntosh (1992; for similar results see Lang, Levin, Miller, & Kozak, 1983) have argued that different ANS activity can be observed and expected during the same emotion (e.g. fear) depending on the eliciting stimuli (e.g. failing an exam or facing a predator). Our aim is not, however, to provide an exhaustive survey, but only to point out the problematic nature of the term 'arousal'.
8. Owing to space constraints, we cannot provide a comprehensive neuroscientific account regarding the interplay between emotions and memory (for a review, see Cahill, 2000; McGaugh, Cahill, Ferry, & Roozendaal, 2000).

9. The flashbulb term refers to the phenomenon 'that a person who experiences a traumatic newsworthy event often reports a vivid memory for the emotionally shocking news itself but also for the specific circumstances under which the unpleasant news were told' (Christianson, 1992, p. 287).
10. Imagine experimenters inducing fear in rabbits and then proceeding to evaluate the effects of fear on mate choice performance. In cases like this, it will not be surprising to find deterioration in performance (see Mendl, 1999).
11. The idea that emotions may be defined solely by their associated pre-wired responses is problematic. While it might be applicable to some cases of fear reaction, as LeDoux's research shows, it does pose conceptual problems when dealing with more modern cases such as being fired from a job. Our aim was not to equate emotions with their hard-wired mechanism. Rather, the goal was to illustrate the complexities engulfing the discourse on emotion and emotional arousal.
12. The research of Öhman, Lundqvist and Esteves (2001; see also Gilboa-Schechtman, Foa, & Amir, 1999; Hansen & Hansen, 1988; Tipples, Atkinson, & Young, 2002) shows that subjects are faster and more accurate in detecting threatening, rather than friendly or neutral, faces in a crowd. This line of investigation provides another layer of evidence supporting our claim, though further research is needed to explore the effects of high emotional arousal states on detecting fearful faces in the crowd.

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