CHAPTER 1

Empirical Tests and Theoretical Extensions of Arousal-Based Theories of Personality

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It has recently become increasingly popular to claim that individual differences in personality are not very important sources of variation in human behavior. It has been suggested that the noncognitive traits that can be identified show very little consistency across situations, and that although the search for consistent dimensions of personality was reasonable, it has not proved to be very useful and should be abandoned.

One of the alternative approaches that has been offered to replace the trait approach to personality is that of the "interactionists," who argue that the interaction between situations and traits accounts for more variance than simple main effects (Endler & Magnusson, 1976).

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Unfortunately, this approach does not specify when interactions will occur.

This question of what personality variables should interact with what situational variables is an underlying theme of this book. By studying dimensions of temperament and how individual differences in temperament relate to behavior, it is possible to show how personality variables interact with environmental variables to have systematic effects upon behavior.

One such personality dimension is introversion-extraversion (I-E). It has long been suggested (Claridge, 1967; Eysenck, 1967, 1981; Eysenck & Eysenck, 1985; Gray, 1964, 1981) that I-E may be related to individual differences in physiological arousal and to the neo-Pavlovian dimension of strength of the nervous system. Additionally, the theory of I-E specifies when and why I-E should interact with environmental and task conditions. Our research has been concerned with the relationship of I-E to cognitive performance. In this chapter, we will review the expected relationship between I-E and performance, summarize some of our recent findings, and suggest how we believe further studies should proceed. Our purpose is twofold: (a) to report some recent developments in the relationship between a dimension of temperament and cognitive performance; and (b) to suggest that the general approach of combining experimental psychology with the study of individual differences is a fruitful one.

INTROVERSION–EXTRAVERSION AND PERFORMANCE

Hans Eysenck's theory of I-E as it relates to cognitive performance may be summarized in two postulates: (a) Introverts are more aroused physiologically than extraverts; and (b) performance is curvilinearly related to arousal (an inverted U). Evidence for the first postulate was put forward by Claridge (1967) and Eysenck (1967) and has been reviewed by Eysenck and Eysenck (1985), and Stelmack (1981). Eysenck's second postulate is based on the "Yerkes–Dodson law", which has received substantial empirical support (Broadhurst, 1959; Duffy, 1972; Hebb, 1955; Yerkes & Dodson, 1908), although it is not accepted unequivocally.

In combination, these two postulates predict that on tasks of moderate difficulty, in comparison to extraverts, introverts will perform better in nonstimulating situations, as well in moderately stimulating situations, and less well when under high stimulation or stress. Thus superficially inconsistent relationships between personality and performance across situations are seen not as evidence for the lack of utility of personality traits but rather as evidence for their usefulness. This model predicts, then, that there should be a consistent (albeit complex) pattern of differences in cognitive performance as a function of individual differences in I-E in combination with variations in situationally induced stress.

We have conducted several experiments that test these predictions. The first of these was by Revelle, Amaral, and Turriff (1976). The dependent variable was performance on verbal ability items similar to those of the Graduate Record Examination (GRE). Three conditions were used in a within-subjects design: (a) A relaxed condition; (b) a time pressure condition; and (c) a time pressure condition in which subjects were given 200 mg of caffeine. The results were quite clear: The scores of introverts fell by about .6 standard deviations from the relaxed to the most stressed condition, whereas those of extraverts rose by about the same amount. Although these results are compatible with the curvilinearity assumption (if introverts were at their optimal arousal level in the relaxed condition, whereas extraverts were underaroused in that condition), they did not show curvilinearity *per se.*

Three studies that have shown curvilinearity are those of Gilliland (1976), Gupta (1977), and Anderson (1985). Gilliland studied the effects of three levels of caffeine (0, 2, and 4 mg/kg body weight) on the GRE performance of introverts and extraverts. Using change scores in a pre-post design, Gilliland found that there was a curvilinear relationship between caffeine and performance for introverts, but there was a monotonically increasing one for extraverts. Using an IQ test, Gupta found that performance decreased for introverts with increasing doses of amphetamine, but performance of extraverts showed an inverted-U relationship. Although both of these studies provided reliable evidence for curvilinearity and demonstrated that introverts are more susceptible to performance deficits than extraverts, both used between-subjects designs, and thus neither showed curvilinearity within subjects.

Anderson (1985) has documented curvilinear effects within subjects. Using a Latin-square design, Anderson tested 100 subjects on easy (letter cancelation) and difficult (GRE verbal items) tasks at each of five different levels of caffeine (0, 1, 2, 3, and 4 mg/kg). Subjects were classified as low or high impulsive on the basis of the Eysenck Personality Inventory (EPI, Eysenck & Eysenck, 1964) impulsivity scale (Revelle, Humphreys, Simon, & Gilliland, 1980). Performance on the letter cancellation task (cancelling one letter from a page of randomly ordered capital letters) showed a significant linear increase with caffeine across all subjects. For the GRE items, however, there was a significant interaction of impulsivity with the quadratic trend of caffeine dose: The performance of low impulsives showed an inverted-U relationship to dose, whereas that of high impulsives improved with increases in caffeine dosage.

The results of these studies, as well as those of other investigators, are generally compatible with Eysenck's predictions, and the convergence of results from research using a wide variety of different experimental procedures and arousal manipulations is noteworthy. It is quite clear that under certain circumstances, the performance of introverts is hurt and that of extraverts is helped by increases in arousal.

IMPULSIVITY, TIME OF DAY, AND TASK VARIABLES

In our recent research, we have been concerned with two questions: (a) What are the personality, situational, and task characteristics that interact with arousal manipulations; and (b) how can we explain the presumed curvilinear relationship between arousal and performance? In this section, we will address the first question; in the next, we will consider several models that might help to answer the second.

Impulsivity and Time of Day

After our initial success in showing that cognitive performance is an interactive function of I-E, time pressure, and caffeine (Revelle *et al.*, 1976), we attempted to specify the conditions governing this relationship. As reported previously (Revelle *et al.*, 1980), we found that although the relationship between personality and caffeine was quite consistent, it was not as compatible with Eysenck's theory as we reported earlier (Revelle *et al.*, 1976). In a series of six follow-up studies, we found that the most consistent relationships were with a subscale of I-E, impulsivity, and that these relationships were moderated by time of day.

The first follow-up study was Gilliland's, which has already been briefly described. In his dissertation, Gilliland (1976) reports that I-E as assessed by the EPI (Eysenck & Eysenck, 1964) had the expected interactive relationship with caffeine in its effect on performance, but when I-E was measured by the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1976), it did not have the expected effects. The chief difference between these two scales is in the saturation of impulsivity (Rocklin & Revelle, 1981): The EPI I-E scale has two subscales, impulsivity and sociability, whereas the EPQ I-E scale has only sociability content. A *post hoc* examination of the results, which Gilliland did not report in the published version of his dissertation (Gilliland, 1980), showed that the interaction of I-E with caffeine was due to the impulsivity subscale.

The remaining five studies reported by Revelle *et al.* (1980) examined these impulsivity findings more closely. A similar paradigm was used in each study: College students were recruited for a study involving caffeine. They refrained from consuming stimulants for 6 hours preceding the study. After signing a consent form that screened for medical contraindications, they were given 200 to 300 mg of caffeine (roughly equivalent to 2 to 3 cups of coffee) or placebo using double-blind procedures. Subjects filled out personality inventories for 30 to 40 min and then completed a cognitive performance task, usually the practice GRE used by Revelle *et al.* (1976), although in one study it was a simple verbal analogies test and in another, the verbal, quantitative, and abstract reasoning portions of the Differential Aptitude Test (DAT). The tests were given under time pressure. In several studies, subjects came for multiple day sessions, but we will discuss only the first day results.

In each of the five studies run in the morning, the same pattern was found: With placebo, nonimpulsives (introverts) outscored impulsives (extraverts) by an average (median) of .45 standard deviations. With caffeine, however, this result was reversed: Impulsives did better than nonimpulsives by .36 standard deviations. In fact, in every study done in the morning, caffeine hindered the performance of nonimpulsives and facilitated that of impulsives.

These results were in contrast to those for the other component of I-E, sociability, which did not show such a consistent pattern. I-E, which is a combination of impulsivity and sociability, showed slightly more consistent interactions, as expected, given the impulsivity results.

Self-reports of caffeine consumption indicated no reliable differences between the *ad lib* caffeine consumption of high and low impulsives, rendering explanation in terms of differential familiarity with caffeine implausible.

Further evidence that the performance changes in response to caffeine were not due to idiosyncratic sensitivity to caffeine but instead involved some more central process came from the results of the four studies conducted in the evening. In striking contrast to results from the morning sessions, in each of the evening studies the performance of high impulsives was hindered by caffeine. Low impulsives were helped by caffeine in three of these studies; in the fourth, there was a slight decrease in performance with caffeine for nonimpulsives and a very large decrease for impulsives. The median improvement for low impulsives given caffeine was .18 standard deviations and the median loss for high impulsives was .15 standard deviations.

To summarize, in the morning caffeine helped impulsives and hindered nonimpulsives, but in the evening these effects reversed: Caffeine hindered impulsives and helped nonimpulsives. Thus two subjects who performed equally well in the morning without caffeine could be made to differ by .8 standard deviations by the administration of caffeine or by .6 standard deviations by having them take the test in the evening.

The significance of these findings is twofold. First, they are consistent with the earlier findings of Blake (1967, 1971) that introverts differ from extraverts not in their basal arousal level but in the phase of their diurnal arousal rhythm: Extraverts are less aroused than introverts (in terms of body temperature) during the morning but are more aroused than introverts during the evening. Second, they show that the impulsivity component of I-E is probably responsible for previously reported relationships between I-E and arousal. This finding is congruent with other studies that have shown that many findings attributed to I-E are actually impulsivity effects (Eysenck & Levey, 1972; Eysenck & Folkard, 1980; Gray, 1972; Loo, 1980).

The interaction of impulsivity, caffeine, and time of day requires a reconsideration of the concept of stable (trait) differences in basal arousal. As noted by Gray (1981), much of Eysenck's theory of I-E hinges on the assumption of stable differences in arousal between introverts and extraverts. But if these differences reverse in the evening, why are not introverts extraverts at night? We suspect that impulsivity is a stable individual difference that does not change with diurnal variations in arousal and that there is some characteristic that leads to both impulsivity and a later diurnal arousal rhythm. This characteristic could be the speed of buildup of arousal or the speed of decay of arousal (habituation). If so, then nonimpulsives would build up arousal faster than impulsives, becoming alert sooner in the morning. After several hours, high and low impulsives would achieve the same arousal level, but impulsives would seek new stimulation constantly to maintain the arousal. By evening, nonimpulsives, who have been highly aroused for much of the day, would be fatigued and cease to seek arousal. Arousal would decay, and the nonimpulsive would retire for the evening. Impulsives would not have been as highly aroused for as long and would not be fatigued yet. Thus impulsives would still want to maintain a high arousal level and continue to seek stimulation. Eventually fatigue would set in and even impulsives would call it a night.

This interpretation introduces yet another concept, fatigue, into an already complex theory. Its advantage, however, is that it avoids the nonsensical prediction that introverts should prefer lively parties late in the evening, whereas extraverts should seek sex orgies in the morning.

An alternative way to fit our findings into the traditional I-E theory would be to assume that performance measures reflect within-subject differences in arousal, rather than absolute arousal levels. (Stimulation seeking would indicate between-subject differences.) Perhaps nonimpulsives are always more aroused than impulsives but are closer to their optimal level in the morning than in the evening. In contrast, high impulsives may have a lower optimal arousal level, to which they are closer in the evening. Both groups perform at their best when optimally aroused. This explanation assumes that performance is affected by within-subject arousal and that when subjects are optimally aroused absolute differences between them do not affect performance efficiency. This argument saves the assumption that introverts are always more aroused (in absolute, between-subject terms) than extraverts. But to do so, we added two postulates (low impulsives have higher optimal levels, and absolute level has no effect on performance), making any test of Eysenck's model using performance measures virtually impossible.

We prefer to believe that performance does reflect basal arousal differences and conclude that although nonimpulsives are more aroused than impulsives in the morning, they are less aroused in the evening. We feel that although these results are in conflict with the conventional formulation of I-E, they are strong enough to require a revision of that theory.

Even more important than our time-of-day results is the distinction between impulsivity and extraversion. Although psychometrically an inferior scale, the 9-item impulsivity subscale of the EPI has given us much more stable interactions with caffeine than either the sociability scale or the entire EPI extraversion scale.[1]

Arousal and Task Variables

The Revelle *et al.* (1980) studies examined very complex performance tasks. Once we specified those conditions that reliably led to impulsivity by caffeine interactions, however, we began to analyze the task parameters of this effect in terms of current cognitive theory.

Our primary concern in addressing task variables was to clarify the determinants of task difficulty, which as noted by Broadhurst (1959) and Yerkes and Dodson (1908), is a critical factor in the relationship between arousal and performance. One of our efforts involved an attempt to decompose the inverted-U relationship into two complementary monotonic functions, one increasing and one decreasing with arousal. The

[1]In some of our more recent studies we have used alternative measures of impulsivity, including items taken from experimental measures of impulsivity developed by S. B. G. Eysenck. We have not found any more consistent results with these measures than with the original nine items derived from the EPI.

logic behind this approach has been spelled out in more detail in Humphreys, Revelle, Simon and Gilliland (1980) and Humphreys and Revelle (1984).

Based on the work of Folkard (1975), Hamilton, Hockey, and Rejman (1977), and Hockey (1979), we (Humphreys *et al.*, 1980; Humphreys & Revelle, 1984) suggested that arousal facilitates tasks that require rapid and sustained information transfer (SIT) but hinders tasks that require storage or retrieval of information in short-term memory (STM).

We have recently completed five experiments with results compatible with the Humphreys and Revelle model. The first examined the effect of impulsivity and caffeine on a proofreading task in which we assessed the detection of two types of errors (Anderson & Revelle, 1982). The detection of intraword (noncontextual) errors, such as misspellings or typographical errors, was assumed to require fewer STM resources than that of interword (contextual) errors, such as faulty grammar or incorrect word usage.

Weinstein (1974, 1977) had found that although noise had no effect on the detection of intraword errors, fewer interword errors were detected in noise than in quiet. Although these results are consistent with our hypotheses, noise may affect performance through either its arousing or its distracting effects. We therefore conceptually replicated Weinstein's studies using our standard caffeine × impulsivity design. We presented 60 subjects with three forms of the proofreading task in a within-subjects design. The first task was given with instructions to mark all incorrect words; the second two tasks were given with instructions to mark either inter- or intraword errors only. All subjects were tested at 9:00 A.M. A significant interaction between impulsivity, drug, and type of error indicated that for the interword errors, caffeine reduced the sensitivity of nonimpulsives and slightly increased the sensitivity of impulsives, but for the intraword errors, caffeine had a detrimental effect for both high and low impulsives. For all three instruction conditions, caffeine reduced the number of words read by low impulsives and increased it for high impulsives.

These results suggested that tasks with a higher memory load are more sensitive to arousal-induced decrements than tasks with a lower memory load. The decreased sensitivity of high impulsives with caffeine to intraword errors is impossible to interpret because this group also read more rapidly: Their decreased sensitivity could have resulted from a speed–accuracy trade-off.

In a second experiment, we examined the effects of impulsivity and caffeine on a visual scanning task (Anderson & Revelle, 1983). This task involves searching through strings of 20 letters looking for those strings that contain all of a set of target stimuli. The target set consisted of either 2 letters (low memory load) or 6 letters (high memory load). Folkard, Knauth, Monk, and Rutenfranz (1976) have shown that these two tasks are differentially affected by arousal as indexed by body temperature: Performance on the two-letter task is a direct function of arousal, whereas performance on the six-letter task is an inverse function of arousal.

We conceptually replicated the Folkard *et al.* study using caffeine and impulsivity as indexes of arousal. At 9:00 A.M. using our standard procedures 84 subjects were tested. As expected, there was a reliable interaction between drug and target size, indicating that caffeine was associated with greater accuracy and more rapid performance on the 2-letter task, but decreased accuracy at about the same pace on the six-letter task. If caffeine and impulsivity affect a similar activational state (arousal), then there should have been a parallel interaction between impulsivity and task. This interaction did not occur, but there was a reliable interaction between impulsivity, target size, and task sequence. (Target size was counterbalanced using two task sequences.) The proportion of targets correctly detected by low impulsives did not vary with target size or sequence. High impulsives, in contrast, were more accurate on the version of the task that was in the first and last of four positions.

These results indicate that high and low impulsives differ from each other in more than just arousal—otherwise, caffeine and impulsivity would have had similar effects. It could be that high impulsives adopted a strategy that was appropriate for the first task they did but did not switch to a strategy appropriate for the second task. An alternative explanation is that in comparison to nonimpulsives, impulsives expended more effort at the beginning (when the stimuli were novel) and end (in anticipation of finishing the task) than during the middle of the experiment.

Our third study (Anderson, Revelle, & Lynch, 1985) examined the effect of arousal on a modified Sternberg (1966) memory scanning task similar to that used by M. W. Eysenck and M. C. Eysenck (1979). A memory set of one to four words was presented by an APPLE II computer, followed by a single probe word that either did or did not come from the memory set. Probe words varied in semantic similarity to the memory set: Some were exact matches of a memory set word, and some were exemplars of a category named in the memory set. At 9:00 A.M. 79 subjects were given either caffeine or placebo. Latencies to correct responses were analyzed. Besides the obvious main effects, caffeine reduced the time needed to prepare to respond (the intercept) but increased the time to scan STM for each additional item (the slope).

The fourth study examined the effect of caffeine and impulsivity on complex analogies (Revelle & Benzuly, 1985). An APPLE II computer using a program developed by Onken and Revelle (1984) presented 48 geometric analogies. These analogies differed in difficulty along two dimensions: the number of elements in each term of the analogy and the number of transformations applied to each element. Following Mulholland, Pellegrino, and Glaser (1980), the number of elements was thought to reflect information transfer load; the number of transformations was assumed to be related to memory load. At 10:00 A.M. 61 subjects were given either 0 or 4 mg/kg of caffeine. Potential speed–accuracy trade-offs were controlled by presenting each item for a fixed period of time before it was removed and the response requested. Caffeine interacted significantly with the number of transformations, facilitating performance for analogies with one transformation (independent of the number of elements) but hindering performance on analogies with three transformations.

The fifth study in this series (Anderson, 1985) has been described earlier; it compared the effects of five levels of caffeine and two levels of impulsivity on performance on two tasks. For the low memory load task (letter canceling), the performance of both high and low impulsives improved across the five levels of caffeine. For the high memory load task (GREs), however, the performance of high impulsives was facilitated, whereas that of low impulsives was an inverted-U function of caffeine dose.

In summary, the studies by Gilliland (1976), Gupta (1977), and Anderson (1985) lend strong support to the hypothesis that performance is a curvilinear function of arousal and that this relationship is moderated by individual differences in impulsivity (Gilliland and Anderson) or extraversion (Gupta). In addition, the studies by Blake (1967) and Revelle *et al.* (1980) suggest that the arousal differences between high and low impulsives reflect temporary state differences rather than stable trait differences. Finally, the Anderson (1985), Anderson and Revelle (1982, 1983), Anderson *et al.* (1985), Folkard *et al.* (1976), and Revelle and Benzuly (1985) studies suggest what some of the task parameters that moderate the arousal–performance relationship might be.

It should be noted that in several studies, caffeine and impulsivity did not interact, and only caffeine showed statistically reliable effects, thus suggesting that high and low impulsives differ from each other in more than just arousal. This conclusion is understandable in light of our time-of-day effects, for although impulsivity can be thought of as a stable dimension of individual differences, the arousal differences between high and low impulsives reverse as a function of time of day.

It is clear from these experiments that the impulsivity by caffeine

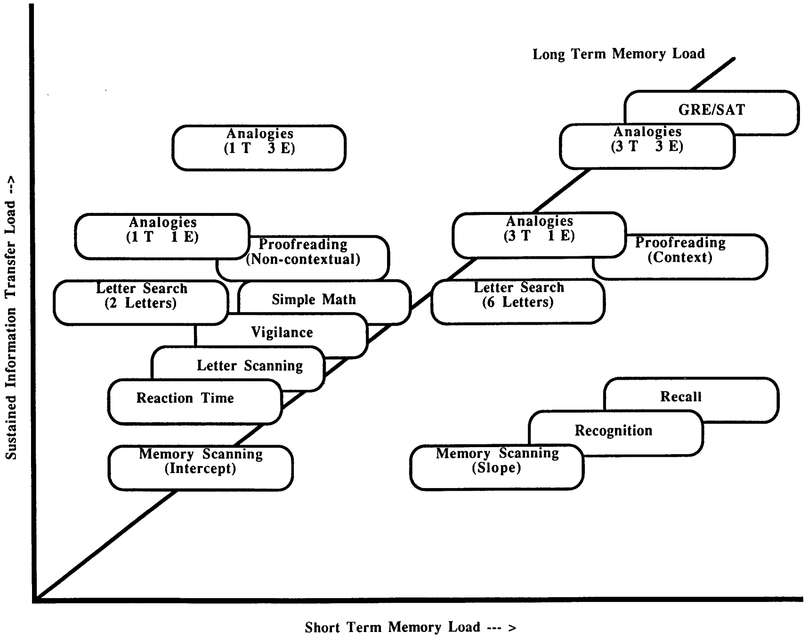

Figure 1. A conceptual organization of cognitive performance tasks along three dimensions of information processing (short-term memory, sustained information transfer, and long-term memory). Tasks further to the right require more short-term memory resources than those to the left. Tasks further up require more sustained information transfer resources than those nearer the bottom. Tasks shown behind other tasks are thought to require more long-term memory components than those drawn closer to the front of the figure. In general, our research has shown that performance on those tasks to the left of the center are facilitated by caffeine or other arousal manipulations, whereas performance on those tasks to the right of the figure is either hindered or shows an interactive effect of caffeine and impulsivity.

interaction can be moderated by task variables. We have thus gone beyond mere demonstrations of curvilinearity and are now able to study what determines the task difficulty parameter of the Yerkes–Dodson law. We can summarize our research results (as well as that of others) by classifying tasks along three dimensions of cognitive resources: SIT, STM, and long-term memory (see Figure 1). In general, those tasks with low STM requirements are facilitated by caffeine or other stimulants, whereas those with high STM but low SIT requirements are hindered by caffeine. Finally, those tasks with both high STM and SIT requirements (and perhaps a large long-term memory component) show interactive effects of caffeine and impulsivity.

THEORIES OF AROUSAL AND PERFORMANCE

Many theories have been proposed to explain the inverted-U relationship between arousal and performance. Several are unable to account for all the findings we have discussed, whereas several others are compatible with most of this evidence.

Transmarginal Inhibition

One explanation for inverted-U phenomena is that performance is a monotonic function of arousal but that arousal is an inverted-U function of "arousal potential," which is the sum of all of those properties of the environment that stimulate the person. Arousal increases with increases in arousal potential up to the point at which further increases in stimulation instigate an inhibitory mechanism that protects the organism from too much excitation. Further increases in arousal potential lead to even higher levels of inhibition and hence greater decreases in arousal level.

While this model is likely to be true at extremely high levels of stimulation, it is unlikely that our subjects have been exposed to such extreme levels of arousal potential. Our task variable effects also argue against this explanation. For example, if the poor performance of highly aroused subjects on the six-letter search task is due to the effects of transmarginal inhibition (TMI), why do the same subjects do better on the two-letter task (Anderson & Revelle, 1983; Folkard *et al.*, 1976)? It is possible that different tasks change arousal potential, with the six-letter search task raising the arousal potential enough to induce TMI but the two-letter task not producing TMI. But this view cannot easily account for task effects in the proofreading study (Anderson & Revelle, 1982), in which subjects simultaneously scanned for both types of errors.

Response Competition

Perhaps the best known theory relating motivation to performance is Hull's drive theory (1952). There are several different explanations that have been derived from drive theory, all of which assume that the probability of making a response is a function of the difference in excitation of two or more competing response potentials.

Spence and Spence (1966) assumed that drive and incentive motivation have a multiplicative effect on habit strength. Thus well-learned responses are facilitated more by increases in drive than less well-learned responses. This theory can explain increases in performance with increases in arousal for dominant or well-learned habits and decreases in performance with increases in arousal for difficult or poorly learned tasks. With additional assumptions about thresholds for excitation, it is even possible to explain inverted-U phenomena. As M. W. Eysenck (1981) has made clear, however, the theory is better at postdicting than at predicting results.

Broen and Storms (1961) proposed that there is a ceiling to excitatory potential: Increases in drive lead to increases in excitatory potential up to this ceiling, but increases in drive beyond that point do not increase the excitatory potential. Thus at low initial drive levels, easy or well-learned tasks would be facilitated by increases in drive, but once the excitatory ceiling has been reached, further increases in drive would increase the likelihood of subdominant responses. Although this model does predict inverted-U phenomena, it predicts that well-learned habits should achieve their maximum probability of response at lower drive levels than less well-learned habits. This prediction is, however, opposite to the initial Yerkes and Dodson (1908) findings, as well as to our own results (Anderson & Revelle, 1983; Anderson, 1985).

Broadbent (1971) modified drive theory to take into account the subject's criteria for responding. Applying a signal detection analysis to the problem of response competition, Broadbent showed that if a response threshold remains constant while drive increases, the probability of making the dominant response will be an inverted-U function of drive. This model also predicts that at low drive levels, subjects should make errors of omission, but at high drive levels, they should make errors of commission. Although this interpretation is consistent with some of our results, it is difficult to see how it could be applied to the pattern of results from the geometric analogies task (Revelle & Benzuly, 1985).

Range of Cue Utilization

The other well-known explanation for inverted-U phenomena is that of Easterbrook (1959), who proposed that increases in arousal lead to decreases in the range of cues that an organism can use. This model can account for the Yerkes–Dodson effect by making the additional assumptions that (a) simultaneous use of relevant and irrelevant cues reduces response efficiency; (b) irrelevant cues are eliminated before relevant ones as the range of cue utilization decreases; and (c) complex tasks require a broader range of cue utilization than less complex tasks.

A serious problem with many tests of Easterbrook's hypothesis is in their operational definitions of arousal. As we have argued previously (Anderson, 1981; Anderson & Revelle, 1982; Humphreys & Revelle, 1984; Humphreys *et al.*, 1980; Revelle *et al.*, 1980), arousal should be construed as a conceptual dimension ranging from extreme drowsiness at one end to extreme excitement at the other. It may be manipulated, physiologically indexed, or behaviorally observed. Any particular measure or manipulation will, however, introduce some irrelevancies. To strengthen the conclusion that observed effects are in fact due to arousal, research on the effects of arousal should therefore include several types of arousal variables to test for convergence between the alternative indexes. Unfortunately, most tests of Easterbrook's hypothesis have used indexes of arousal that have powerful but nonarousal-related effects on the allocation of cognitive resources (Anderson, 1981). For example, although inducing anxiety may increase arousal and consequently narrow the range of cue utilization, it may also lead to an increase in off-task thoughts (Wine, 1971). Thus performance decrements with increased anxiety may be due to arousal, off-task thoughts, or both. Many of our findings are consistent with Easterbrook's model, although it is not clear that it can explain the results of our memory-scanning study (Anderson *et al.*, 1985).

Information Transfer and Memory

An alternative model, which is hard to distinguish empirically from Easterbrook's, is that arousal has different effects on the rate of information transfer and memory availability (Folkard, 1975; Hockey, 1979; Humphreys & Revelle, 1984; Humphreys *et al.*, 1980). In a review of the performance literature (Humphreys & Revelle, 1984), we concluded that arousal facilitates those tasks that require sustained information transfer (SIT)—staying prepared to process incoming stimuli, transmit information, or rapidly execute responses. We also proposed that arousal is monotonically and negatively related to short-term memory (STM) processes such as those involved in digit span, paired associate, or incidental recall after short intervals.

We assume that efficient cognitive performance generally requires both information transfer and memory. The combination of a monotonically increasing function (SIT) with a monotonically decreasing function (STM) can lead to an inverted-U function. Performance at low arousal is limited by the SIT component; performance at high arousal is limited by the STM component.

We also suggested (Humphreys *et al.*, 1980; Humphreys & Revelle, 1984) that incentive motivation, rather than affecting arousal, has a monotonically increasing effect on SIT but no direct effect on STM. Thus, manipulations such as competition, monetary incentives, or ego-involving instructions (e.g., Revelle, 1973) should improve the rate of information transfer but not memory. Because we assume a data-limited

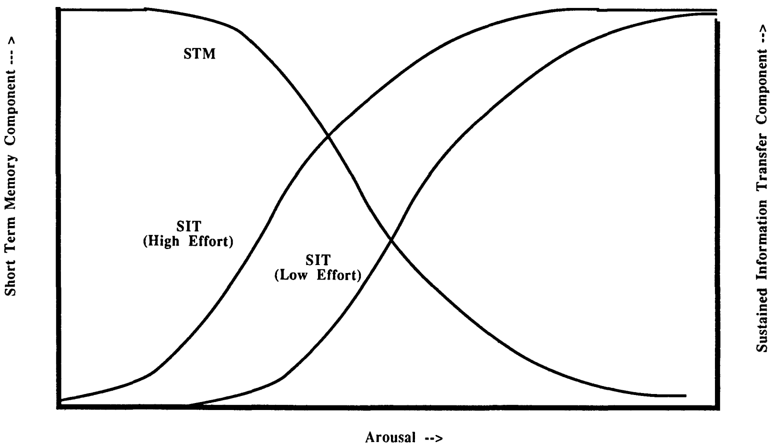

Figure 2. The effects of effort and arousal on two components of information processing. Sustained information transfer is a monotonically increasing function of arousal; availability in short-term memory is a monotonically decreasing function of arousal. Curvilinearity is a result of tasks being limited by a lack of resources for sustained information transfer at low levels of arousal and a lack of memory resources at high levels of arousal. Effort is thought to increase information transfer but not to hinder memory availability. Thus increased effort facilitates performance at low to middle levels of arousal but has little to no benefit at high levels of arousal.

ceiling for both components, incentives would thus lead to improved performance at low arousal levels but have no effect at high arousal.

Although the complete theory (Humphreys & Revelle, 1984) is too complicated to present here, some of these effects can be summarized figurally. In Figure 2, we show the hypothesized effects of two levels of effort for tasks involving both a STM and a SIT component.

This two-component model of performance predicts what variables should interact rather than just describing the interactions. We should note, however, that much of the evidence consistent with this model also supports Easterbrook's hypothesis, as most tasks with a high memory load (which are thus more susceptible to arousal-based deficits) also require a broad range of cue utilization.

General Theoretical Issues

When discussing theories of performance decrements, it is important to remember that the link between theory and data is sometimes quite complex. Many assumptions are necessary to relate our theory (Humphreys & Revelle, 1984) to the results of any particular study, including assumptions about the construct validity of measures of both arousal and task parameters. Implicit in our tests of arousal predictions are assumptions about the nature of tasks and vice versa. What is missing is a direct way to test both a theory of motivational effects and a theory of tasks.

Moreover, we assume that arousal facilitates information transfer processes and hinders memory processes, but we are as yet unable to specify exactly how these processes combine to affect performance. This inability is partly due to incomplete understanding of the determinants of task performance and partly due to the ambiguity of such terms as SIT and STM.

To a large extent, SIT and "attention" are similar constructs. Attention, however, has many different meanings that have been used in a variety of different ways. We believe that the concept of sustained attention is related to sustained information transfer and arousal. For example, we have shown (Bowyer, Humphreys, & Revelle, 1983) that on a recognition memory test, high impulsives experienced a vigilancelike decrement over trials, and this effect was reduced by caffeine. The similarity of this result to earlier studies of vigilance suggests that a common explanation should be applied to tasks that require staying prepared to process incoming stimuli, transmit information, or execute responses rapidly.

We are faced with a similar definitional problem with respect to the presumed detrimental effect of arousal on STM. There are several different theories of the processes involved in STM (specifically, capacity and strength); without a specification of the effects of arousal on these processes, we can make only very general predictions (cf. Humphreys, Lynch, Revelle, & Hall, 1983). Is STM hurt by arousal because the size of a memory buffer has been reduced or because the strength of the codes decays faster? Is an inability to recover appropriate memory codes due to their weakness or to increased strength of competing codes? Once again, what is needed is a theory of tasks as well as a theory of motivation.

SUMMARY AND CONCLUSIONS

Finally, we again note our use of impulsivity rather than the higher order construct of I-E. We have studied impulsivity because our results have shown that it has more consistent interactions with arousal manipulations than does I-E, suggesting that it is impulsivity rather than introversion–extraversion that is related to individual differences in arousal. We have persisted in studying impulsivity (rather than trying to develop a scale that assesses phase differences in diurnal rhythm or responsivity to caffeine) because we are not interested in just any individual differences but those that have been found to be influential in the domain of interpersonal behavior. H. J. Eysenck's three dimensional description of personality (1967, 1976, 1981; H. J. Eysenck and M. W. Eysenck, 1985), in which individual differences in impulsivity are presumably captured (Gray, 1981), is a well-developed theoretical structure. This theory may be wrong, but we feel that it is more beneficial to work within that framework, even as critics, than it is to explore individual differences that lack such a theoretical foundation.[2]

In this chapter, we have reviewed evidence relating the personality dimension of introversion–extraversion, or at least the lower order factor of impulsivity, to cognitive performance, and we have discussed various theoretical explanations for the observed results. We have suggested that seeming inconsistencies in behavior may be understood with an appropriate theory of personality, arousal, and performance. We hope we have shown that the combination of the study of individual differences with the study of human performance is a fruitful and worthwhile area.

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[2]We do not have the space to analyze the claim (H. J. Eysenck & M. W. Eysenck, 1985) that impulsivity is best thought of as a combination of E and P, nor the claim that impulsivity is quite adequately measured by the P scale. In terms of consistent effects upon performance, we find that impulsivity produces a clearer pattern of results than do P, E, or N. Much of our recent work has been devoted to a description of the components of tasks that are affected by arousal rather than a detailed examination of the place of impulsivity in a dimensional taxonomy of personality.

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