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**Individual Differences in personality and motivation:  
'Non-cognitive' determinants of cognitive performance**

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**Personality and Motivation- Introduction**

Donald Broadbent's career has been an exception to the rule that serious cognitive psychologists should treat individual differences as nuisance variables to be ignored. Donald has recognized the complexities of individual differences, has commented about the messiness of the findings relating individual differences to performance, but none-the-less has insisted that a proper understanding of human information processing needs to take into account individual differences in personality and motivation. For this, as well as the many other accomplishments discussed in the chapters in this book, he is to be admired.

In this chapter I review some of the historical and current evidence showing that Donald's concern for individual differences has been well founded. I emphasize how individual differences combine with situational manipulations to affect the availability and allocation of cognitive resources. More importantly, I argue that personality effects can be understood in terms of differences in the way and in the rate at which parameters of the cognitive control system are adjusted to cope with changes in a constantly varying world. I conclude with the suggestion that an analysis of the motivational states that result from the interaction of individuals with their environment improves models both of cognitive performance as well as theories of personality.[[1]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html" \l "fn0)

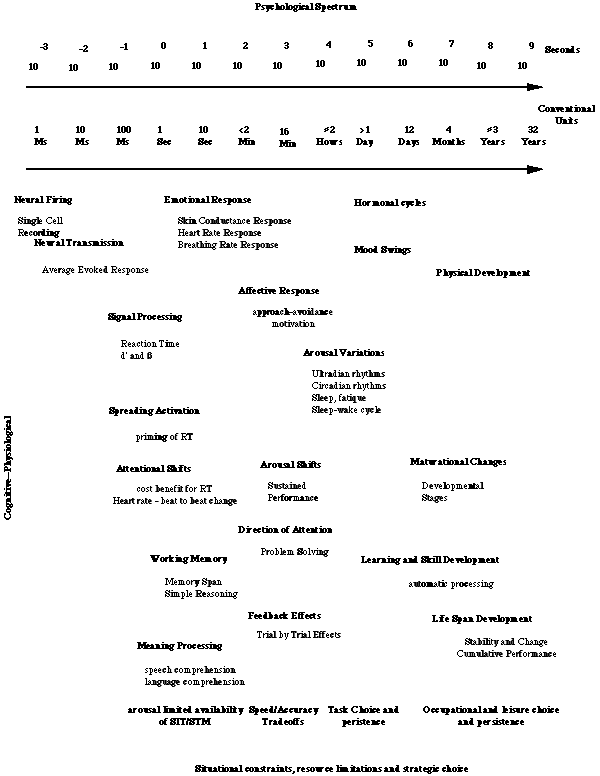
When reviewing current research it is somewhat disheartening to realize that although many of the questions about individual differences were first raised in *Perception and Communication*(Broadbent, 1958) and discussed later in *Decision and Stress* (Broadbent, 1971), after three decades we have not made much progress on finding answers to these questions. There has been some progress, however, in determining the motivational states and individual differences most associated with efficient performance.[[2]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html" \l "fn1)

Broadbent's primary observation about individual differences was that "It has been noticed many times that some individuals show larger decrements from prolonged work than others do." (Broadbent, 1958, p 140). Who are these people and what causes these decrements was and remains an important question. A subsequent question is whether there are reliable individual differences in performance decrements associated with other stressful conditions.

In general, decrements from optimal performance may be understood in terms of motivational effects (e.g., Anderson, 1990; Blodgett, 1929; Broadhurst, 1959; Hebb, 1955; Hockey, Gaillard & Coles, 1986; Humphreys and Revelle, 1984; Revelle, 1987, 1989; Sanders, 1983, 1986; Yerkes and Dodson, 1908). Motivation is the vital link between knowing and doing, between thinking and action, between competence and performance. Theories of motivation explain why rats solve mazes faster when hungry than well fed, why bricklayers lay more bricks when given harder goals than easier ones, why assistant professors write more articles just before tenure review than after, and why people choose to be fighter pilots rather than dentists. How to motivate employees to produce more widgets and how to motivate oneself to do onerous tasks are the subjects of many management and self help courses.

Fundamental questions of motivation are concerned with the direction, intensity, and duration of behavior. Within each of these broad categories are sub-questions such as the distinctions between quality and quantity, effort and arousal, and latency and persistence. Cutting across all these questions are the relative contributions of individual differences and situational constraints to the level of motivation and of subsequent performance.

Individual differences in motivation and performance may be analyzed at multiple, loosely coupled, levels of generality (Figure 1). These levels reflect the time frame over which behavior is sampled. Over short time periods (e.g. the milliseconds of an evoked potential study), situational constraints are extremely important. As the sampling frame is increased (e.g., to the seconds of a reaction time study), energetic components of motivation as well as strategic tradeoffs of speed for accuracy become more important. At somewhat longer sampling frames (e.g. the tens of minutes of a typical psychology experiment), individual differences and situational demands for sustaining performance take precedence. At even longer intervals, differential sensitivities to positive and negative feedback affect task persistence and choice. At much longer intervals, individual differences in preference affect occupational choice and the allocation of time between alternative activities. At all of these levels it is possible to distinguish between effects related to resource availability and to resource allocation. Although an adequate theory of motivation and performance should explain behavior at all of these levels, motivational effects at intermediate time frames have been most frequently examined. In particular, the focus of this chapter are those motivational effects that can affect the link between thinking and doing within periods of several minutes to several hours.

  
1) Levels of analysis and the psychological spectrum. Psychological phenomena occur across at least 12 orders of temporal magnitude. Cognitive and motivational theories at each frequency make use of directional and energetic constructs. Outcome measures may be organized in terms of their temporal resolution as well as their physiological emphasis. (Adapted from Revelle, 1989).

For psychologists concerned with linking cognition to action, it is essential to consider how motivational variables affect the competence-performance relationship. Ever since Blodgett's (1929) demonstration that well fed rats will learn mazes but that only hungry rats will show their knowledge by running rapidly through the maze, psychologists have been aware that competence is a necessary but not sufficient determinate of performance. An even more important study was Yerkes and Dodson's demonstration (1908) that motivational intensity (induced by foot shock) has a non-monotonic affect upon rates of learning a discrimination task and that task difficulty interacts with intensity.

Unfortunately many cognitive psychologists pay only lip service to the competence-performance distinction and will report that their subjects are well motivated and thus it is not necessary to worry about motivation. For such researchers, motivation is a nuisance variable that can be ignored by increasing sample size. The possibility that individual differences in personality might interact with situational manipulations in ways that can completely obscure important relationships is so foreign as to not even be considered.

An exception to this rule is those who have worked with or been inspired by Donald Broadbent. The best work on the effect on cognitive performance of non-cognitive manipulations such as noise, time of day, distraction, and incentives has been done by those who have followed the traditions established at the Applied Psychology Unit in Cambridge and continued at Oxford. Discussing motivational and stress effects before such a group is equivalent to bringing coals to Newcastle.

The emphasis of much of the work at the APU has been how stressors combine to affect performance[[3]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html" \l "fn2). Within this tradition, there has been great concern with the similarity and differences between the effects of different stressors. So, for example, while the effect of sleep deprivation is to hinder certain tasks, and noise to hinder other tasks, the combination of the two stressors can be shown to facilitate performance. An explanation that subsumes both effects is then proposed, tested and accepted or rejected (Broadbent, 1971).

This logic can equally well be applied to the combination of stressors with dimensions of individual differences. By appropriate analysis of the similarities and differences of effects due to experimental manipulations and individual differences it is possible to evaluate the construct validity of both. Certain individual differences seem to parallel certain stress manipulations while other stressors seems to affect different individuals in different ways. Both patterns of results are of theoretical importance: Parallel effects of personality and situational manipulation allow individual differences to be used to extend the effective range of experimental manipulations; different patterns for different people produce better theory by delineating the boundaries of effects of theoretical constructs.

Parallel effects of individual differences and situational stressors can suggest that both reflect differences on the same latent construct. By appropriate combinations of subject differences and of experimental manipulations, it is then possible to achieve a much greater effective range on the underlying latent construct than would be possible by manipulation or subject selection alone..[[4]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html" \l "fn3)

There are at least three possible reactions to the observation that what improves the performance of one individual hinders the performance of another: 1) ignore that particular manipulation because it does not have consistent effects; 2) run more subjects in the hope that error terms will be reduced; or 3) ask what are the special characteristics of the different kinds of subjects. It is this third approach that is most useful. Understanding how manipulations differ across people leads to better theories of those manipulations as well as better theories of individual differences in personality. [[5]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html" \l "fn4)

**Individual differences in motivation and performance**

Two dimensions of personality discussed by Broadbent (1958) as important sources of variation in performance were introversion-extraversion and stability-neuroticism. Extraversion was associated with decrements in performance over time and neuroticism was associated with greater decrements following stress. Although it is tempting to propose a single model to account for these effects, what has become clear is that the effects of personality upon performance require multiple levels of explanation. The broad dimensions of personality that are consistently identified from investigator to investigator and shown to be important in different cultures and different times affect behavior in many different ways.

Before reviewing specific effects of personality, it is necessary to consider what are the appropriate dimensions to discuss. Personality researchers can be grouped into those who who study the effect of a single dimension versus those who develop taxonomic models of multiple dimensions. The first approach results in alphabetic organizations of personality traits (ranging from Type A behavior, through Machievelianism to Sensation Seeking) with numerous studies of convergent validity but few studies of discriminant validity. Within the second, multivariate-taxonomic tradition are those most concerned with description and those interested in causal (usually biological) theories. The descriptive taxonomists have agreed that a set of five dimensions can be identified consistently across methods. These "big five" dimensions of self report and peer description have been labeled Surgency, Agreeableness, Emotional Stability, Conscientiousness, and Culture, (Digman, 1990, Fiske, 1949, Goldberg, 1982; McCrae and Costa, 1987; Norman, 1963; and Wiggins, 1979). For the more biologically minded, the theories of Hans Eysenck (1952, 1967, 1981, 1991), Jeffrey Gray (1972, 1981, 1982, 1987), or Jan Strelau (1983, 1985) are appealing descriptions of three fundamental dimensions (Eysenck's Extraversion, Neuroticism, and Psychoticism; Gray's Impulsivity, Anxiety, and Aggression; Strelau's strength of the excitory and inhibitory processes, and balance between these process) that fit within the five factor model [[6]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html#fn5). Whether one prefers the three dimensional biological models or the five dimensional semantic descriptions, it is clear that all of these dimensions have substantial genetic loadings and that they are moderately consistent from childhood throughout the life span.[[7]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html#fn6)

Perhaps because of a greater concern for causal theory among the biologically oriented taxonomists, there has been more research relating introversion-extraversion and stability-neuroticism to performance than there has been for the other dimensions of the "big five". Both of these dimensions may be associated with individual differences in motivational state. Although staying within the two-space defined by Introversion-Extraversion and Neuroticism-Stability, some of the more recent work has examined impulsivity, a component of I/E and anxiety, a component of neuroticism.

**Motivational states: Affective valence and intensity**

A common assumption when studying human performance is that subjects are alert and optimally motivated. It is also assumed that the experimenter's task at hand is by far the most important thing the subject has to do at that time. Thus, although individual differences in cognitive ability are assumed to exist, differences in motivation are ignored. For compliant college students participating in one of only a few psychology experiments, this assumption might well be true. It is probably less true for psychiatric patients, oil platform workers at the end of their shift, or deep sea divers under several hundred feet of water. Indeed, for almost any subject population of interest it is difficult to believe that the specific experimental task used has an equally powerful motivation effect upon all subjects. In fact, it is possible, even with college students, to show that variations in motivational state are important sources of between subject variation in performance.

Motivational states can be categorized in several different ways. Conventionally, it has been useful to distinguish between the *affective direction* and the *energetic intensity* of motivation (Humphreys and Revelle, 1984). More recent work on affective states, however, has suggested that direction may subdivided into positive and negative components (Watson and Tellegen, 1985) and that intensity should be considered in terms of energetic and tense arousal (Thayer, 1989). How these four constructs interrelate is far from clear. Table 1 presents sample adjectives associated with each construct.

Table 1: Adjectives associated with the measurement of affect and arousal

Thayer's dimensions of arousal Watson and Tellegen dimensions of affect

Energetic Arousal Tense Arousal Positive Affect Negative Affect

energetic fearful alert nervous

full-of-pep jittery active jittery

active tense excited afraid

wakeful clutched-up enthusiastic scared

lively intense attentive guilty

vigorous (not) quiescent interested hostile

wide-awake (not) quiet inspired distressed

(not) sleepy (not) placid determined ashamed

(not) drowsy (not) still proud upset

(not) tired (not) at-rest strong irritable

(not) calm

An alternative four dimensional model of affect and arousal

High Energetic Low Energy/Tension High Depression High Tension

alert drowsy unhappy nervous

full-of-pep dull gloomy jittery

active placid blue afraid

wakeful quiet sad tense

lively serene depressed scared

aroused sleepy angry guilty

excited calm irritable surprised

**Affective States**

Thayer (1967, 1978, 1989) has discussed four uni-polar dimensions that he groups into two higher order constructs of energetic and tense arousal. He associates energetic arousal with approach behavior and tense arousal with avoidance behavior. Energetic arousal is increased by mild exercise and varies diurnally. Thayer (1989) adopts Gray's hypothesis that approach motivation reflects a sensitivity to cues for reward and that avoidance behavior reflects a sensitivity to cues for punishment. (See also Fowles, 1980).

Matthews, Jones & Chamberlain (1989) report three mood dimensions that are sensitive to external stressors: energetic arousal, tense arousal, and hedonic tone (positive versus negative). They show that energetic arousal is decreased by the administration of Chlorpromazine, Diazepam or sleep deprivation. Tense arousal is increased by pain, or watching TV violence, but is reduced by muscle relaxation.

Watson and Tellegen (1985) have shown that positive and negative affect are independent of each other and can be used in combination to describe many psychopathological conditions. Clark and Watson (1991) recently proposed that differences in positive affect and somatic arousal account for the important distinction between two affective conditions represented by high negative affect, anxiety and depression. They suggest that while depression and anxiety share high negative affect, anxiety also reflects high somatic arousal, and depression represents lack of positive affect.

**Energetic arousal**

Energetic arousal is a non-directional component of motivation in all of these models of affect. It is also a construct that has been found to be of great heuristic importance in theories of motivation and cognition ever since Broadbent (1958). More importantly, in that individuals seem to differ systematically in their level of energetic arousal, it is a way to link theories of individual differences to theories of behavior.

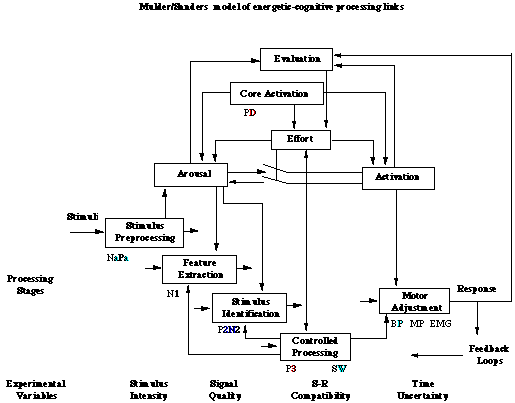
Even though Corcoran's (1965) definition of arousal as the "inverse probability of falling asleep" is immediately understandable, it is clear that the use of arousal as a construct is problematic. Indeed, some prefer to avoid discussing arousal and use a broader term, energetics, that subsumes many different constructs of motivational intensity and the effects of many environmental stressors (Hockey, Gaillard & Coles, 1986).

Most simply, arousal is a hypothetical construct used to organize the common behavioral effects of exercise, stimulant drugs, sleep deprivation (negatively), time of day, time on task and impulsivity (Anderson, 1990). Each of these separate variables has both a common and specific effect on behavior. Caffeine and amphetamine both make one more alert and able to respond more rapidly and for longer periods of time. Caffeine differs from amphetamine in the locus of its action (post-synaptically versus synaptically) as well as in some peripheral effects (e.g. caffeine induces hand tremor). It is not difficult to demonstrate that different manipulations of arousal have somewhat different effects on the patterning of responses. As an example of a behavioral dissociation, simple reaction time is facilitated by caffeine but is also faster for high impulsives (thought to be less aroused than low impulsives). High impulsives differ from low impulsives in terms of their speed accuracy tradeoff (Dickman and Meyer, 1988) as well as in terms of arousal level.

Sanders (1983) discussed the multiple approaches to the study of stress. One can manipulate the antecedent conditions or examine the physiological consequences. Similarly, there are at least three ways to study the relationship of arousal to performance: 1) by varying the situational demands thought to lead to arousal; 2) by correlating psychophysiological measures to performance; and 3) by correlating self report measures of arousal with performance.

The first approach, manipulations of arousal by the use of stressors such as stimulant drugs, noise, time on task, or time of day, is more commonly used by experimental psychologists. Broadbent's 1971 review suggested that there were common effects for some of these manipulations, but also showed that at least two levels of control processes needed to be invoked to understand all of the effects. A lower level of control associated with executing well learned responses was thought to be sensitive to noise or sleep deprivation and an upper level control process responsible for monitoring the state of the lower level process was thought to be sensitive to alcohol, extraversion, and time on task.

Hockey (1986) has proposed that each manipulation produces its own idiosyncratic state, and that it is a mistake to look for a holy Grail of unified arousal. Several energetics theorists (Gopher, 1986; Mulder, 1986; Sanders, 1983, 1986) have made use of Pribram and McGuinness' (1975) distinction between (phasic) arousal as affecting input processes, (tonic) activation as affecting motor outputs, and effort as an integrative resource allocation mechanism (Figure 2).



2) Levels of control associated with reaction time. Different stages of information processing are affected by different control processes. Modified from Mulder's (1986) revision of Sanders' (1983) model of reaction time.

After reviewing the parallels and differences between physiological measures and psychological manipulations, Broadbent (1971) concluded that "We have therefore no satisfactory physiological reference for the general state which we are discussing, and which we have revealed purely from behavioral studies. In some ways it might have been better therefore to avoid using the term 'arousal' for this behaviorally defined concept, but this would probably do too much violence to the common usage in the literature. The reader should remember however that we are working solely on a psychological level, and that the existence of a physiological concept of arousal is merely an interesting parallel, with no direct contact at present." (p 413). Later he added that "in complicating the theory of arousal we shall need to know more about the functions involved in various tasks; behavioral studies and the physiological attack upon the brain must go hand in hand." (p 447).

The second approach, that of psychophysiological correlates, has proven to be the most difficult. Partly this is due to confusing a within subject concept with between subjects measurement (Venables, 1984). It is also partly due to variations in the time course of different physiological measures. Just as broad motivational constructs affect behavior at different time courses, so do narrow constructs of motivational intensity, (e.g., arousal) have different temporal parameters. EEG measures of arousal have latencies measured in milliseconds while autonomic measures such as Skin Conductance have latencies measured in seconds, and body temperature reflects average levels of metabolic demands during the previous several hours. The disassociations and specific patterning of responses associated with reactions of the hand, the heart and the head (Lacey, 1967) make physiologists particularly cautious whenever they discuss a construct such as generalized arousal.

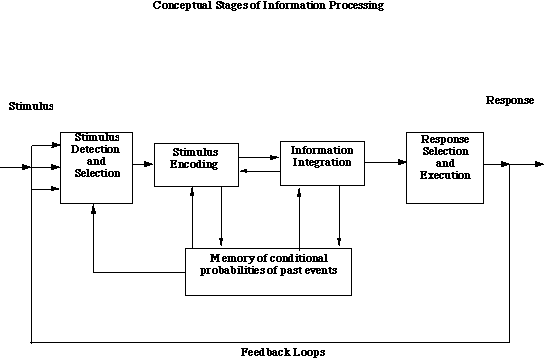
The third approach is to use self reports of arousal. Thayer (1989) has argued that subjective estimates of energetic arousal are the most likely to be associated with performance. He has also reported that self ratings correlate more with psychophysiological measures than the measures do themselves. This is what would expect if each psychophysiological measure had specific as well as general effects, and if subjective awareness of arousal reflected the general effects.

Matthews (1989) and his colleagues (Matthews, et al., 1989) have done some of the most extensive work examining the relationship between self reported mood and performance. They have found consistent, although complicated, relationships between self reports of energetic arousal and performance on a variety of simple and complex detection tasks. In addition, they have found that state measures of self reported arousal interact with trait measures of individual differences in introversion-extraversion to affect performance on these tasks.

The use of the term arousal to encompass phenomena ranging across many orders of temporal magnitude from the milliseconds of the early stages of the evoked potential (Mulder, 1986) to the effects of 10 minute brisk walks (Thayer, 1989) to the tendency to seek out stimulation throughout a lifetime (Zuckerman, 1991) is thought by many to be a mistake. I disagree. I believe that the concept that changes in resource availability are associated with changes in arousal allows one to integrate the effect on cognitive performance of stable personality traits with those of variety of environmental manipulations. This model has great heuristic value, for it allows an integration of seemingly unrelated phenomena. Such broad lumping together of disparate effects does indeed mask differences, however. Each task and each measure has its own unique variance as well as common variance. What is important is to try to distinguish the unique from the shared variance. But this is the fundamental challenge of any theory.

**Personality, motivation, and performance**

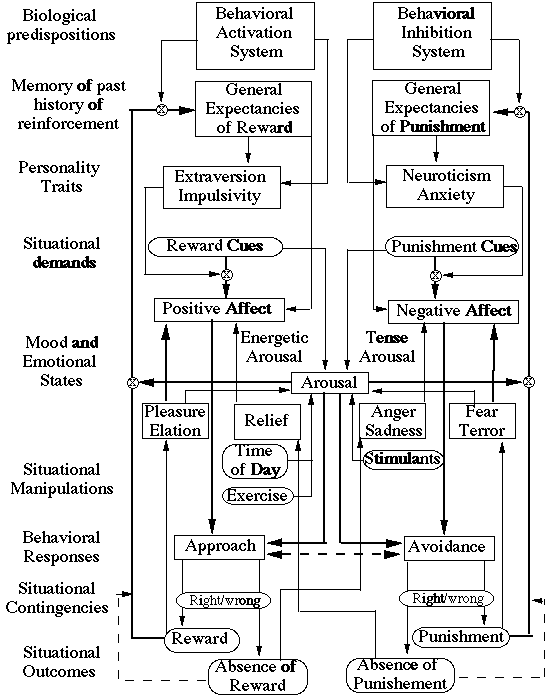
Over the past 17 years, my colleagues and I have examined how personality traits combine with situational manipulations to produce motivational states that in turn affect cognitive performance. For organizational purposes, these effects can be conceived as affecting information processing at several different, possibly overlapping, stages (Figure 3).[[8]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html#fn7) The conceptual stage model I present is obviously derived from Broadbent's filter model (1958) and the latter distinctions between filtering and pigeonholing (1971), and even more from his Maltese cross model of memory and attention (1984) as well as Sanders' (1983) stage model of reaction time. I show it merely to distinguish between the types of demands placed upon the subject. Stimuli must first be detected, then encoded, before this new information is able to be stored in memory. Based upon the incoming stimuli, further information needs to be retrieved from memory, information needs to integrated, and some response needs to be executed. This is a continuous loop, in that as a consequence of each response, environmental feedback occurs that partly determine the next stimulus that is to be detected. Storage and retrieval processes are shown as arrows between the encoding, integrating, and memory systems.



3) A conceptual organization of the stages of processing that are affected by individual differences in motivation. Environmental inputs are first detected, then encoded, stored, and integrated with prior expectancies before responses are selected and executed. Behavioral acts, through feedback, lead to new environmental input. Storage and retrieval processes are represented as arrows to and from the memory system.

Motivation affects each of these stages. In terms of tasks we have examined, we believe that vigilance-like tasks relate to the detection and response stages and are affected by variations in arousal; individual differences in the learning of affectively valenced material occur at the encoding stage and are related to differential sensitivities to rewards and punishments; memory storage and retrieval and the effect of retention interval are affected by variations in arousal: arousal facilitates storage but hinders retrieval; and the information integration stage is curvilinearly related to arousal because it reflects two components--a beneficial effect due to the speed of input and a detrimental effect due to unavailability of recent events.

On a larger time scale, as the information processing loop continues to be executed, resources vary in their availability and in their allocation. Knowledge structures in memory change, affective reactions to the outcomes bias expectancies of future reinforcement and strategic decision processes are used. The encoding of environmental demands reflect differences in biological sensitivities to cues for rewards and punishment (Gray, 1981) as well as the prior contents of memory. Emotional reactions to feedback reflect the interaction of expectancies and outcomes. Positive affective states result from reward following expectancies of reward or non-punishment following expectancies of punishment. Negative affective states result from punishment following expectancies of reward and from punishment following expectancies of punishment (Rolls,1990). Positive affect facilitates approach behavior, negative affect facilitates avoidance behavior. Approach and avoidance tendencies are mutually inhibitory. Increased arousal facilitates the detection and storage of information as well as the execution of the dominant response tendency. This leads to a much more complex model (Figure 4), but one that is probably necessary if the interdependent effects of cognitive and affective processes are to be understood. This model is an attempt to sketch out the systems that are involved in actively processing valenced information in an ongoing system responding to environmental demands and environmental reinforcements[[9]](https://personality-project.org/revelle/publications/broadbent/broad_fn.html" \l "fn8).



4) Affective and cognitive reactions as part of an ongoing behavioral system. The encoding of environmental demands reflect differences in biological sensitivities to cues for rewards and punishment (Gray, 1981) as well as the prior contents of memory. Reactions to feedback reflect the interaction of expectancies and outcomes. Positive affective states result from reward following expectancies of reward or non-punishment following expectancies of punishment. Negative affective states result from punishment following expectancies of reward and from punishment following expectancies of punishment (Rolls,1990). Positive affect facilitates approach behavior, negative affect facilitates avoidance behavior. Approach and avoidance tendencies are mutually inhibitory. Increased arousal facilitates the detection and storage of information as well as the execution of the dominant response. Adapted from Clark and Watson (1991), Gray (1981), Larsen (1991), Rolls (1990), and Thayer (1989).

In the following section I discuss the immediate motivational effects upon performance of various combinations of individual differences in personality and situational stressors. In the final section I suggest how an adequate theory of individual differences and cognitive performance needs to examine motivational effects on the stages of processing as well as consider the larger temporal variations in affect, cognition and behavior that occur as the information processing loop continues over time.

**Personality, vigilance and continuous performance**

Differences in the ability to sustain performance across time have been noticed in dogs, sonar operators, train engineers, and faculty listening to colloquia. What is particularly interesting to those interested in coherent descriptions of personality is that several of the basic dimensions of personality are related to performance decrements across time.

After an extensive discussion demonstrating that performance decrements generalize across several types of continuous performance tasks, Broadbent (1958) presented evidence suggesting that extraverts were more likely to show such decrements than were introverts. By 1971, the evidence supporting this position was much stronger. Extravert performance deteriorates more rapidly in terms of detecting infrequent signals (Bakan, Belton & Toth, 1963; Keister and McLaughlin, 1972), in terms of variability and speed of continuous reaction time (Thackray, Jones & Touchstone, 1974), and in the ability to stay awake on long distance drives (Fagerström & Lisper, 1977).

Matthews (1989) and Matthews, Davies and Lees (1990) have shown that this decrement in performance can occur very rapidly and that self reported high arousal is associated with the ability to maintain performance. They used a rapidly paced discrimination task introduced by Neuchterlein, Parasuraman and Jiang (1983) with an inter stimulus interval (ISI) of 1 second and a priority stimulus frequency of 25% (i.e. a response was required on the average every 4 seconds) with two levels of stimulus degradation. For the degraded stimuli, performance of low aroused subjects deteriorated within 12 minutes, but did not for high aroused subjects. Neither Neuchterlein et al. nor Matthews et al. found a decrement on this task with non-degraded stimuli. Neuchterlein et al. interpret the detection of the degraded stimuli as requiring substantial "effortful" processing as compared to the non-degraded stimuli which may detected in an "automatic fashion". Matthews et al. argue that the degraded stimuli lead to the kind of resource limited attention task that Humphreys and Revelle (1984) suggest should benefit from high arousal.

Impulsivity at the adult level has frequently been claimed to be related to the impulsivity associated with hyperactivity or what has come to be called Attention Deficit Disorder (ADD) with (or without) Hyperactivity. ADD children are particularly susceptible to decrements on continuous performance tasks. Sergeant and van der Meere (1990) have reviewed the application of Sanders' model of energetic effects on reaction time to the case of individual differences associated with attention deficit disorders. Their review is an excellent example of the wealth of information that comes from combining sophisticated experimental procedures with the study of important individual differences.

Revelle, Rosenberg & Anderson (in preparation) have recently completed three studies with an even simpler task than the Neuchterlein et al. task, but one that still shows pronounced decrements within a few minutes. Because of our interest in the dynamics of behavior, we examined performance as a function of time on task. The task we used (variable fore-period reaction time with an inter stimulus interval of 1-11 seconds) lasts for just a few minutes (12-15) and is typical of the demands placed upon subjects doing many monotonous real world (or experimental) tasks. The subjects task is to respond as rapidly as possible whenever a series of X's appears on the monitor of a computer. The targets remain until the subject responds. The fastest reaction times of our subjects tend to be of the order of 220-250 msec, with most responses being less than 400 msec. We discard all trials in which the subject took more than 1000 msecs to respond, although we have observed at least one subject who was taking 7-8 seconds on some trials. That is, our task succeeds in putting some subjects to sleep. More objectively, self reports of energetic arousal decay reliably across the 12 minutes of the task.

We have done three studies with this task. The first examined the effects of impulsivity, anxiety (neuroticism) and time of day (0900 versus 1930 hours) the second added caffeine as a factor; the third was run just in the morning and examined the effects of an incentive (half of the subjects were offered $10 if they could score in the top 33% of the subjects, the other half were not told about the incentive). Dependent measures were simple reaction time, as well as the change in reaction time as a function of trials.

When the results from all three studies are compared they clearly show a difference between the effects of (caffeine induced or diurnally varying) arousal versus (monetary incentive induced) effort. Although both arousal and effort manipulations improve performance, only the arousal manipulation was able to sustain performance. The change across time clearly demonstrated the effects of arousal as well as impulsivity and neuroticism. Impulsivity was positively correlated with decay of RT in the morning but negatively in the evening, and high neurotics were unable to maintain their performance from the first to the last part of the experiment. These results bring to mind Broadbent's (1971) two levels of control. For although effort facilitated reaction time (Broadbent's lower level) arousal facilitated the long term maintenance of reaction time (Broadbent's higher level).

**Personality and non vigilance increments and decrements**

Learning valenced material. Humans as well as other animate organisms need to learn sources of reward and punishment within their environment to survive. This fundamental observation has long been ignored by many cognitive theorists concerned with memory. Although a great deal of research on human learning has been done on affectively neutral material (e.g., nonsense syllables), much of the animal learning literature has examined the effects of rewards and punishments upon learning. Jeffrey Gray (1972, 1982) has generalized from an animal model of rat learning to propose a neuropsychological basis of anxiety and to propose a revision of Hans Eysenck's theory of introversion-extraversion and neuroticism. In brief, Gray has proposed that individuals differ in their sensitivities to cues for reward and for cues for punishment. Furthermore, Gray associates the sensitivity to cues for reward with a behavioral activation system (BAS) and the sensitivity to cues for punishment with a behavioral inhibition system (BIS). He associates impulsivity with the BAS, anxiety with the BIS.

The evidence for this hypothesis is mixed. Richard Zinbarg and I have shown that when subjects learn a go-no go discrimination task to achieve rewards or to avoid punishments, impulsivity interacts with anxiety to affect rates of learning (Zinbarg and Revelle, 1989). High impulsives who are low on anxiety rapidly learn to make responses to achieve rewards but have difficulty learning to inhibit responses in order to avoid punishment. Highly anxious subjects who are also less impulsive rapidly learn to inhibit their responses in order to avoid punishment. High anxiety when combined with high impulsivity leads to poorer learning, as does low anxiety and low impulsivity. Further support for Gray's model comes from work of Fowles (1980, 1987) and Newman and his associates (Nichols and Newman, 1986; Newman, 1987). Failures to support Gray's hypothesis have been reported by Diaz, Gray & Pickering, (1991) and Pickering (1991).

Kathy Nugent and I extended Gray's model and examined the effect of affective manipulations on the interpretation of stimuli and resulting effects upon memory (Nugent and Revelle, 1991). We examined whether variations in affect (situationally induced by positive and negative feedback) or stable personality traits (impulsivity and neuroticism) affect the memory for neutral stimuli. The results are partly consistent with Gray's model, in that the high impulsives were more likely to remember words following reward rather than punishment, but were inconsistent in that the low impulsives remembered words better following punishment rather than reward (rather than the predicted no effect) and there was no effect of anxiety (we had predicted that more anxious subjects would have better memory for stimuli followed by punishment).

Immediate and delayed retrieval. Honey bees as well as humans need to learn affectively important information and can not afford to waste cognitive resources on trivia. James McGaugh (1990) has reviewed evidence that stimulation following a particular cue enhances the long term memory for that cue. Debra Loftus and I have reviewed 25 years of findings showing that a variety of arousal inductions and measures interact with retention interval to affect memory (Revelle and Loftus, 1990, in press). Experiments using a surprising number of manipulations and measures of arousal have shown similar results: high arousal at learning inhibits immediate retrieval of the information presented but facilitates later recall of that information. Whether this is due to different effects on different stores, or to an arousal induced decrement at retrieval, or to some other explanation remains uncertain. What is certain, however, is that a consideration of individual differences is important. Puchalski (1988) replicated earlier work by Folkard, Monk, Bradbury & Rosenthal (1977) on the effects of time of day on immediate versus delayed retention and found that the pattern reverses for high and low impulsives. Immediate memory of high impulsives was superior in the morning to the afternoon, although recall after one week was superior for information learned in the afternoon rather than the morning. This was essentially Folkard's finding. However, for low impulsives, immediate memory was better in the afternoon than in the morning and delayed recall was equal for information learned at both times of day. Loftus (1990) found that impulsivity and self reported arousal interacted with retention interval to affect the probability of recall. Some of the confusion relating the effects of mood to memory is likely due to ignoring these relationships between individual differences in arousal and the effect of retention interval.

Complex tasks When information needs to be integrated and complex decisions need to be made, there seems to be an optimal level of arousal. Performance on complex reasoning tasks similar to the Graduate Record Exam is an interactive effect of impulsivity, caffeine, and time of day. Specifically, the performance of individuals thought to be less aroused (e.g. high impulsives in the morning, low impulsives in the evening) is facilitated by increases in arousal (e.g. caffeine) while that of individuals thought to be more aroused (e.g. low impulsives in the morning, high impulsives in the evening) is actually hindered (Revelle, Humphreys, Simon, and Gilliland, 1980). This result is large and is replicable. Matthews (1985) has found a similar pattern of results for extraversion and self reported arousal. Although Revelle et al., (1980) suggested that their pattern of results was consistent with an inverted U relationship between arousal and performance they did not have an unambiguous means of ordering the conditions in the between subjects design they used. Gilliland (1980), in a between groups design with three levels of caffeine did find a curvilinear (inverted U) relationship between caffeine dose and GRE performance for low impulsives and a monotonically increasing function for the high impulsives. Stronger evidence has been reported by Anderson (1990) who, in a within subjects design with multiple levels of caffeine, found a reliable number of subjects showing an inverted U relationship between GRE performance and caffeine.

**Theoretical organization of results**

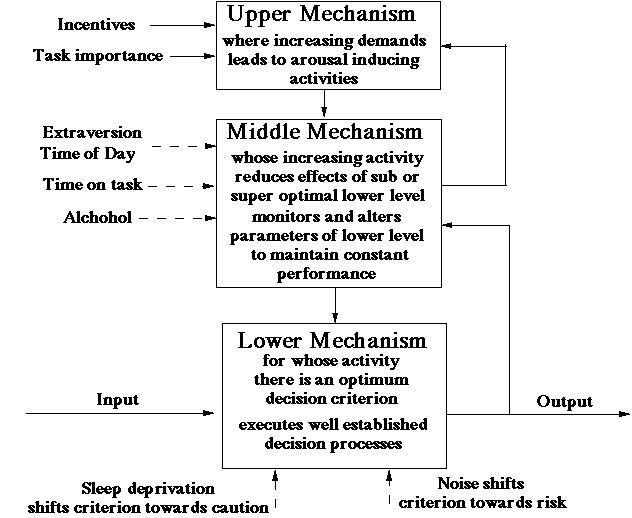
One way to organize the results I have presented was adapted by Mike Humphreys and me from work done by Broadbent (1971), Simon Folkard (1975), Robert Hockey (1979) and others. In brief, Humphreys and I suggested that increases in both effort and arousal facilitate the ability to sustain rapid rates of information transfer but that arousal also inhibits some aspect of short term or working memory (Humphreys and Revelle, 1984). More recently we have proposed that although arousal inhibits immediate availability, it facilitates longer term availability in memory. Furthermore, we suggested that impulsivity interacts with time of day and time on task to affect arousal, and that achievement motivation and anxiety interact with rewards and punishments to affect on task effort.

I like to explain the arousal effects on the rate of information transfer as well as on memory by analogy to increasing the internal "tick rate" of a computer. A faster clock speed will lead to more samples of the environment taken per unit time, which will in turn lead to faster reaction times. However, increasing the tick rate (taking more samples of the environment) also will function to change the background context more rapidly. This will lead to greater difficulties in immediate recall, but will facilitate delayed recall.

**Motivation as a control process.**

What complicates the relationship between stable measures of personality and performance across situations has been summarized by Rabbit "the human cognitive system is designed for flexibility, and can carry out any particular task in many different ways" (Rabbit, 1986, p 155). Indeed, not only do different people do the same task in different ways, the same people do the same task in different ways. Motivation can be seen as a control process, altering the parameters of the cognitive system so as to execute responses most efficiently. Individual differences reflect higher order rates of change in these parameter settings (see also Sanders, 1983,1986).

Consider the results from our three reaction time studies. All subjects could do the task most of the time. Increased incentive or caffeine induced arousal improved performance. As the task continued, although the fastest responses remained about the same, some responses were much slower, reflecting an occasional lapse of attention. High impulsives in the morning and high neurotics throughout the day were particularly sensitive to this loss of attention. Incentives were unable to inhibit the decay across time, but caffeine was able to inhibit the decay. We interpret this result as suggesting that while effort can improve immediate performance, effort alone is unable to sustain performance. That is, in a constrained situation, one is unable to will oneself awake. But at a higher level, effort can increase alertness. As anyone knows who has struggled to overcome jetlag, drive long distances, or write an overdue paper by staying up all night, given the proper incentives one chooses activities that lead to alertness (e.g., stands up, takes brisk walks, or consumes large doses of caffeine). Thus, we are forced to add a higher level control process (Figure 5) to the two proposed by Broadbent (1971) or the hierarchy of resource pools proposed by Mulder (1986) and Sanders (1983, 1986).



5) Broadbent's two levels revisited. Higher order controls adjust the level of arousal. Although effort can not directly overcome the effect of inappropriate arousal without the ability to engage in behaviors that modify arousal, a higher order control process can recognize inappropriate arousal levels and strategically seek out or avoid arousal inducing behavior. Adapted from Broadbent, 1971

**Theories of individual differences**

In 1958 Broadbent organized his discussion of individual differences around the personality and learning theories of Hans Eysenck and Kenneth Spence. Extraverts were thought at the time by Eysenck to have stronger reactive inhibition processes, and anxious individuals were thought to have higher levels of Hullian drive. Although the dimensions of introversion-extraversion and stability-neuroticism have remained important, a great deal has changed in the past 33 years in terms of our theoretical understanding of these dimensions. A particularly compelling model may be derived by integrating the neurobiology model of Jeffrey Gray (1972, 1982, 1987) with the multiple dimensional models of affect of Watson and Tellegen (1985) and Thayer (1989) (Figure 4). An adequate model needs to integrate differences in affective reactions to feedback with differences in rates of learning and differences in performance. Such a model will certainly include the dimensions of impulsivity-extraversion-surgency and anxiety-emotionality as well as the behavioral differences observed under different stress manipulations on different types of tasks. It will also include multiple levels of control processes and will need to account for individual differences in reactions to many different kinds of stressors. Although such a model will be more complex than the ones proposed by Broadbent (1958, 1971), an adequate model will owe a great deal to the pioneering work of Donald Broadbent. It has been his willingness to consider individual differences in models of cognitive performance that has layed the foundation upon which future theories may be built.

**Personality, motivation, and performance-References**

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