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Personality and Motivation: Sources of Inefficiency in Cognitive Performance

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Impulsivity and anxiety are two dimensions of personality which have strong effects upon the efficiency of cognitive performance. The effects of these two variables depend upon characteristics of the task as well as upon four types of tradeoffs between psychological resources. Tasks may be characterized in terms of their relative requirements for sustained information transfer (SIT), short-term memory (STM), and long-term memory (LTM). Resource tradeoffs may be automatic, strategic, directional, or stylistic. Impulsivity effects on performance involve an automatic arousal-induced tradeoff between SIT and STM, strategic tradeoffs of speed for accuracy, and stylistic differences in persistence. Anxiety effects involve strategic, directional, and stylistic tradeoffs. © 1987 Academic Press, Inc.

Although it practically has become dogma among social psychologists to dismiss the importance of stable dimensions of individual differences, there is a long and fruitful tradition in multivariate personality research concerned with the identification and measurement of dimensions of personality. Within this tradition two different approaches have been taken: that of developing descriptive taxonomies and that of developing causal theories of individual differences. In this article I first briefly review the conclusions derived from these two approaches, and then suggest how both approaches can be helped by considering evidence derived from task analyses of cognitive performance. I conclude by considering how behavior on intellectually challenging tasks should be analyzed in terms of a taxonomy of tradeoffs between various psychological resources. The common theme for the entire discussion is that a careful examination of characteristics of people, situations, and tasks allows for

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understanding the seeming inconsistency between stable personality dimensions and the extremely variable behavior of individuals.

DIMENSIONAL ANALYSES OF PERSONALITY

Descriptive taxonomies. Perhaps the earliest example of taxonomic description was that of Aristotle, who considered how various mixtures of fear and confidence could lead to rash, cowardly, or brave behavior. Later descriptive work included searching the natural language for adjectives describing stable individual differences (Allport & Odbert, 1936), semiempirical-semiintuitive collapsing of this "personality sphere" into a manageable number of cluster/dimensions (Cattell, 1957), and numerous replications and extensions of this exploration of the dimensions of verbal description (Goldberg, 1982; Norman, 1963, 1969; Wiggins 1973).

A consistent conclusion from the more recent descriptive taxonomic work is that somewhere between five and seven dimensions provide an adequate taxonomic description of the ways in which people are rated by their peers. The five dimensions of peer ratings identified by Fiske (1949), Tupes and Christal (1961), and Norman (1963) have appeared in a somewhat different form in recent personality inventories (e.g., Costa & McCrae, 1985) and even in a computer game said to help one discover one's true nature (Mindprober). The five dimensions are surgency (extraversion), agreeableness, conscientiousness, emotional stability, and culture or openness. Although the agreement among these descriptive studies with respect to *what* are the appropriate dimensions is impressive (e.g., Digman & Takemoto-chock, 1981), there is a lack of any theoretical explanation for the *how* or *why* of these dimensions.[1]

Causal taxonomies. In contrast to descriptive taxonomies, causal taxonomies are concerned with answering the how and why of behavior. An early example was that of Hippocrates, who attempted to explain differences between four temperamental types in terms of excesses of the humors. In the beginning of this century Heymans developed a theoretical basis for a dimensional model of personality. Most importantly for the current discussion, during the past four decades Hans Eysenck has been the strongest proponent of a causal theory of individual differences.

Eysenck's theory spans a broad domain from the genetic and biological bases of personality to the behavioral and social consequences of these individual differences (H. J. Eysenck, 1967, 1981). Starting with the descriptions of Hippocrates and Galen, testing and modifying the ideas of Heymans and Wundt, Eysenck has developed an impressive and con-

[1] At the very least, descriptive taxonomies give a more compelling arrangement than the alphabetical ordering of personality traits found in some texts (e.g., London & Exner, 1978).

sistent theoretical description of the causal basis for individual differences in introversion-extraversion (IE) and stability-neuroticism (SN).[2] His more recent work has been concerned with dimensions of psychoticism and the biological basis of intelligence. While many of us who are concerned with causal theories of personality have found fault with one part or another of his model, we recognize and appreciate the overall scope and breadth of his theoretical contributions.

The place of impulsivity in Eysenck's theoretical framework has always been a question. In the initial measurement of extraversion using the Maudsley Personality Inventory and the Eysenck Personality Inventory (EPI: H. J. Eysenck & S. B. G. Eysenck, 1964), the IE scale included two components: sociability and impulsivity. The items measuring impulsivity were not particularly internally consistent and had only low to moderate relationships with the sociability items. With the expansion of Eysenck's theory to include psychoticism (P), the place of impulsivity in the theory became even more confused (e.g., Frcka & Martin, 1987). The introduction of the Eysenck Personality Questionnare (EPQ: H. J. Eysenck & S. B. G. Eysenck, 1976) led to a de facto change in the definition of extraversion, with the impulsivity component either disappearing or being absorbed by the psychoticism scale (Rocklin & Revelle, 1981).

J. A. Gray (1972, 1981), working within the Eysenckian framework (and challenging some of the assumptions), has suggested that it is more useful to consider the dimensions of impulsivity and anxiety as causal dimensions rather than those of IE and SN. To Gray, impulsivity and anxiety are primary, and extraversion is a mixture of impulsivity and stability; to Eysenck, extraversion, psychoticism, and neuroticism are primary, and impulsivity is a mixture of all three.

My own work has been concerned with applying and testing these two theoretical descriptions in the domain of efficient cognitive performance. One of the principal concepts in Eysenck's theory is that introverts are more aroused than are extraverts. This assumption, in combination with the assumption that arousal is curvilinearly related to efficient performance (e.g., Broadhurst, 1959; Hebb, 1957; Yerkes & Dodson, 1908) leads to the prediction that the complex cognitive performance of introverts and extraverts should respond in diametrically opposite ways when their arousal is increased. Although my initial results supported this prediction when arousal was manipulated by time stress and by caffeine (Revelle, Amaral, & Turriff, 1976), later results showed that the important personality

[2] It is impossible to do justice to the scope of Eysenck's theory in any single paper. Perhaps the single best description of this work may be found in the volume by H. J. and M. W. Eysenck (1985).

dimension was impulsivity rather than IE (Revelle, Humphreys, Simon, & Gilliland, 1980). Furthermore, these later results interacted with time of day and cast into question the concept of stable differences in arousal level but rather suggested that one difference between high and low impulsives was a phase difference in their diurnal arousal rhythm.[3]

Our work, in combination with others who have examined the impulsivity-extraversion distinction (e.g., Campbell, 1983; H. J. Eysenck & Levey, 1972; Frcka & Martin, 1987; Loo, 1980; O'Gorman & Lloyd, 1987) suggests that it is impulsivity rather than extraversion which is related to individual differences in arousal.[4] However, to relate our findings to Eysenck's theory requires many inferential steps (caffeine increases arousal, arousal is curvilinearly related to performance, improvements of performance with arousal imply initially low arousal, decrements of performance with arousal imply initially high arousal), and there is not definite proof that introverts are not more aroused than extraverts throughout the day, or that high impulsives are initially less aroused than low impulsives but become more aroused in the evening.

The direct way to test the arousal hypothesis is, of course, through physiological measurement. Thus one can take electrocortical (e.g., Gale, 1986; O'Gorman & Lloyd, 1987) or psychophysical sensitivity measures (e.g., Shigehisa & Symons, 1979). However, for those of us interested in how personality affects cognitive performance these direct measures are less appealing. No matter how many EEG studies show less impulsives to have higher alpha frequencies than do more impulsive subjects, it is not until we are able to show that these differences make a behavioral difference that we are satisfied.

COMPONENTIAL ANALYSES OF PERFORMANCE

In the search for a coherent explanation of these results it has been necessary to develop a componential analysis of the performance tasks we have used (Humphreys & Revelle, 1984; Revelle, 1986; Revelle, Anderson, and Humphreys, 1987). This is in contrast to our (and others) earlier work (e.g., Revelle, 1973; Revelle et al., 1976, 1980), where tasks were chosen on the basis of convenience rather than to examine how personality affected specific components of information processing. The approach taken is to classify tasks in terms of the demands they place upon cognitive resources. Although many such organizations are possible,

[3] This interpretation was based upon the earlier findings that introverts differed from extraverts in the phase of their diurnal body temperature rhythm (Blake, 1967, 1971) is in agreement with the report by M. W. Eysenck and Folkard (1980) of diurnal differences relating to impulsivity rather than extraversion.

[4] See, however, Larsen (1985) and Matthews (1985) for evidence contradicting this generalization.

fill out personality inventories (e.g., the EPI) while waiting approximately 30 min for the caffeine to take effect, and then take some performance task. Subjects and experimenters are blind to condition and the subjects have been asked to abstain from caffeine for the 6 h prior to the experiment. Following our recognition that time of day interacts with impulsivity (Revelle et al., 1980), we have conducted all of our recent experiments in the morning. This has been done in order to clarify the arousal performance relationship before exploring the time of day–personality relationship.

The results from these studies have shown a consistent pattern of relationship between impulsivity, caffeine dosage, and task complexity. On a simple recognition task requiring sustained alertness to process the stimuli, the error rate of high impulsives is greater than that of low impulsives, and the performance of both groups is facilitated by caffeine (Bowyer, Humphreys, & Revelle, 1983). On a proofreading task requiring contextual processing (e.g., subject-verb agreement), the performance of high impulsives is improved and that of the low impulsives is hindered by the administration of caffeine (Anderson & Revelle, 1982). With doses ranging from 0 to 4 mg/kg body weight, the performance on complex verbal problems similar to the Graduate Record Examination is a monotonically increasing function of caffeine for high impulsives and is a curvilinear (inverted *U*) function for low impulsives (Anderson, 1986; Gilliland, 1976). Finally, on complex verbal and spatial tasks the performance of low impulsives is hindered while that of high impulsives is facilitated by caffeine in the morning, while this relationship reverses in the evening (Revelle et al., 1980).

The results for the studies involving anxiety show a different pattern of results. First, it should be noted that neither anxiety nor neuroticism had significant effects in the studies discussed earlier. Anxiety did interact with caffeine and task characteristics in one study (Craig, Humphreys, Rocklin, & Revelle, 1979), but with a pattern inconsistent with an overarousal interpretation. High anxiety hindered performance on simple and complex geometric analogies (Leon & Revelle, 1985), but did not interact with memory load the way impulsivity and caffeine do (Benzuly, 1985). Rather, the results suggested that the high anxious allocate fewer resources to the experimenter-defined task. These results supported predictions derived from Sarason (1975) and Wine (1971), but contradicted predictions derived from drive theory (Hull, 1952; Spence & Spence, 1966), cue utilization theory (Anderson, 1981; Easterbrook, 1959), and working memory theory (Eysenck, 1979).

Four levels of resource tradeoffs. In many of the caffeine studies there were additional personality effects which did not interact with caffeine.

Types of Resource Tradeoffs	Mechanism/ Measure	Impulsivity	Anxiety
Level I: Automatic SIT/STM	Arousal: facilitates SIT impairs STM (Humphreys & Revelle, 1984)	Caffeine on complex tasks: facilitates high Imps hinders low Imps (Revelle, Anderson & Humphreys, 1986)	
Level II: Strategic Speed/Accuracy	Sensitivity to reward Sensitivity to punishment (Gray, 1981; Nichols & Newman, 1986)	High Imps fast Lows Imps accurate (Revelle, 1986)	Low Anx fast High Anx accurate (Geen & Kaiser, 1985; Sabates, 1986)
Level III: Directional Effort	Allocation of effort to on task or off task thoughts (Humphreys & Revelle, 1984)		Low Anx on task High Anx off task (Leon & Revelle, 1985)
Level IV: Temporal/ Stylistic Choice, Frequency	Latency to initiate task Persistence on task (Atkinson & Birch, 1978)	Low Imps slow to initiate but persistent High Imps fast but not persistent (Eysenck & Eysenck, 1985)	Low Anx choose challenging tasks High Anx avoid possibility of failure (Atkinson, 1974)

FIG. 2. Four levels of resource tradeoffs. For each level, the resources which are traded off as well as possible mechanisms are listed. References are given to examples of each tradeoff.

These results suggested to us that other, nonarousal-related, explanations needed to be considered as well. This has led us (Revelle, 1986; Revelle & Anderson, 1986) to analyze personality-performance relationships in terms of four different levels of resource tradeoffs. The first of these is the arousal-induced tradeoff between SIT and STM, the second is a strategic tradeoff between speed and accuracy, the third is a directional tradeoff between on-task and off-task allocations of effort, and the fourth is a stylistic tradeoff (Fig. 2). We have previously discussed arousal and effort as two components of motivation (Humphreys & Revelle, 1984). By analyzing them in terms of resource tradeoffs it is possible to develop a better understanding of the costs and benefits associated with motivation.

The first of these tradeoffs (between SIT and STM) we view as an automatic function of changes in arousal. That is, arousal facilitates SIT but at a cost of reducing resources available for STM. It is as if the processing system is prepared for rapid reactions to stimuli at the cost of reducing the ability to do complex processing of the stimuli. A plausible mechanism to explain this effect involves increasing the speed of some internal clock (i.e., reducing the length of the psychological moment) or speeding up the flow of information through the system. As stimuli are processed more rapidly, faster responses are possible for external stimuli, but STM tasks are hindered by the increased interference associated with a higher rate of information flow.[8]

As evidence for this tradeoff, Anderson (1986) demonstrated that task complexity moderates the effects of impulsivity and caffeine. We believe that this is probably due to the differences in memory load between the letter cancellation task and the verbal analogies task. This assumption is compatible with the effects found in the Bowyer et al. (1983), Anderson and Revelle (1982), and Revelle et al. (1980) studies. Anderson, Revelle, and Lynch (1985) found that caffeine decreased the intercept (improved SIT resources) but increased the slope (hindered STM resources) in a memory-scanning task. A more direct test of the memory load assumption was done by Benzuly (1985) who found that performance on geometric analogies with a low memory load is facilitated but performance on geometric analogies with a high memory load is hindered by caffeine. Memory load for these analogies was manipulated by varying the number of transformations from the A to B term; SIT load was varied by changing the number of elements in each term (see Mulholland, et al., 1980).

A different type of tradeoff is the strategic tradeoff between speed and accuracy. In even the most basic reaction time task, faster performance can be achieved if there is an increased tolerance for errors. A typical reaction time finding is that RT is linear with log odds (i.e., the logarithm of the probability of correct responses divided by the probability of incorrect responses). Many tests are scored for the total number correct which is, of course, the product of the number of problems attempted and accuracy on those attempted problems. If accuracy is a negatively accelerated but increasing function of time spent on a problem and the number of problems attempted is a decreasing function of the total time spent per item, then the number of problems correct will be a complex function of task difficulty and error rate.

Finding the optimal level of the speed for accuracy tradeoff in terms of total number of problems correct becomes quite difficult, for it depends upon one's ability and the difficulty of the items. If there are individual differences in the tolerance of errors, then even subjects with similar levels of ability will work at different rates and differ in their total number correct. Manipulations which increase accuracy may lead to either increases or decreases in total problems correct, depending upon the subject's ability, the item difficulty, and the initial bias toward speed or accuracy.

Atkinson (1974) reviewed evidence suggesting that anxious subjects

[8] Another interesting feature of reducing the psychological moment is that the long-term memory for events learned under high arousal should be facilitated. This could be due to the greater subjective time (more psychological moments) spent learning the material for the highly aroused subject.

are more sensitive to failure than are less anxious subjects. Gray (1981) also has suggested that anxiety is related to a sensitivity to punishment or nonreward. Thus, we would expect that anxious subjects prefer to work slowly in order to minimize errors. Impulsive subjects, however, would be expected to work rapidly, trying to maximize the number of problems attempted with little concern for making errors. An example of the effect of anxiety on speed-accuracy tradeoffs comes from Geen and Kaiser's (1985) comparison of speed versus accuracy in a Stroop color word naming task. Geen and Kaiser found that when given instructions "to do your best," anxious subjects were slower but more accurate than were nonanxious subjects. However, the two groups did not differ when given instructions to be as accurate as possible or to be as fast as possible. Similarly, Sabates (1986) has found that anxious subjects report a preference for being slow but accurate while less anxious subjects report preferring speed over accuracy. Nichols and Newman's (1986) observation that extraverts speed up on trials following failure while introverts slow down might be another example of a strategic tradeoff.

The third or directional tradeoff affects the allocation of resources to the task at hand. Recent analyses of the effects of anxiety on performance (e.g., Leon & Revelle, 1985; Sarason, 1975; Wine, 1971) have suggested that anxious subjects spend more time worrying or engaging in off-task thoughts than do less anxious subjects. Although seemingly inefficient from the point of view of the experimenter, time spent in evaluating one's self-esteem, or thinking about what one will do when the test is over can be seen by the subject as a more appropriate use of time than actually engaging in a threatening task.

The fourth, or stylistic, tradeoff affects the total allocation of time over much broader periods. It is this sort of tradeoff which is relevant to the broad study of motivation (e.g., Atkinson, 1974). Individuals with a low level of anxiety will spend more time in challenging situations than will those with a higher level of anxiety or a higher need for affiliation. Students who spend the weekend studying for exams are using their time more efficiently from the point of view of their achievement-oriented professors; students who prefer to spend the weekend at a series of lively parties are spending their time more efficiently from the point of view of their extraverted friends.

At this same level are differences in choice and frequency of behavior (Revelle, 1986). Highly impulsive subjects are fast to initiate tasks, but tend not to be as persistent once they start as are their less impulsive colleagues. Although this lack of persistence is partly arousal related (Bowyer et al., 1983), it is also partly stylistic. People who learn that they can perform efficiently under time pressure are more likely to procrastinate until the deadline is almost upon them, while those who have discovered that they are inefficient in such situations will tend to adopt coping strategies such as starting assignments long before they are due.

SUMMARY AND CONCLUSION

In our studies of the effects of personality and motivation upon performance, my colleagues and I have found that forming a typology of tasks as well as of personality and motivational variables is quite useful. We have also found that we need to analyze performance effects at several different levels. For example, less impulsive people differ from more impulsive people in many different ways. They are more aroused and are therefore more able to sustain their performance over time but less able to do tasks requiring the retention of information for short periods of time. They are also less sensitive to rewards and are less biased toward speed than are more impulsive individuals. Less impulsive individuals are slow to initiate tasks, but once they start, they tend to persist for long periods of time. It is not clear that the differences in arousal between high and low impulsives either cause or are caused by their differential sensitivity to cues of reward or punishment. Nor is it clear that differences in arousal cause stylistic differences in personal tempo. It is clear that the arousal differences, the differential sensitivity to reward, and the stylistic differences between high and low impulsives have important effects upon behavior.

Similarly, more anxious subjects prefer to be accurate rather than fast when taking tests, tend to allocate their effort off-task rather than on-task, and prefer to spend their time doing tasks which are less challenging and less likely to result in failure. Whether this is all due to one mechanism (a greater sensitivity to punishment for the more anxious) or to many is not known. What is known, however, is that different behavioral interventions will affect different levels of tradeoffs. Thus, instructions controlling the speed-accuracy tradeoff will not affect task choice, or even the allocation of effort on-task rather than off-task.

Unless we are sensitive to the many different ways that the less impulsive differs from the more impulsive, or the less anxious differs from the more anxious, we will be caught in the trap of the (mythically) naive trait theorist who predicts constancy of behavior across situations. Behavior is complex, and until we are prepared routinely to consider effects of individual differences as they are moderated by the situation and the task, we will be unable reliably to predict it. Interesting phenomena are not to be caught in a net of only main effects but can be caught if we examine higher order interactions. However, the search for such interactions will only be fruitful if our research is theory driven and sensitive to the appropriate levels of analysis.[9]

[9] Even another level of analysis is to consider the effects of aggregating data across subjects. Anderson (1986) has shown how it is possible to find effects at the subject level which are not observable at the aggregate group level.

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and one transformation per element), or greater STM demands (one element but three transformations per element) to problems with large STM and SIT demands (three elements and three transformations per element). Finally, the GRE analogies we used in Revelle et al. (1980) were high in SIT, STM, and LTM demands.

This organization may be thought of as a conceptual rather than empirical simple structure of tasks. It is not based upon a factor analysis of tasks, but is rather based upon an analysis of the processes involved within each task. A more detailed examination of any one of these tasks would show that there are components which are not included in this three-way typology. The emphasis in this analysis is to consider the communalities among, rather than the distinctions between, tasks.

PERSONALITY/MOTIVATIONAL EFFECTS ON PERFORMANCE

In a more extensive analysis of the effects of motivation upon performance, Michael Humphreys and I (Humphreys & Revelle, 1984) have suggested that individual differences in personality interact with situational manipulations to affect at least two components of motivation. These two, which we call effort and arousal, can best be thought of as the directional and intensity aspects of motivation. A somewhat related argument in favor of two components of motivation is in terms of the levels of control analysis of Broadbent (1971). Although similarities certainly exist between his and our motivational analysis, they are not isomorphic.

A two-dimensional motivational model. The first or directional dimension, effort, is what is commonly understood to mean trying hard or being involved in a task. Effort may be increased by instructions to try harder, by incentives, or when the task is more important. Effort may be allocated to one task rather than another through experimental instructions or changes in the relative payoff between two tasks. Although related, it is important to distinguish between on-task effort and the subjective feeling of trying hard. Effort has a facilitative effect on tasks requiring resources for SIT. That is, trying harder improves reaction time, speed of letter scanning, simple arithmetic, or letter cancellation.

The second or intensity dimension, arousal, is what is commonly understood as being alert, vigorous, peppy and full of activation. Arousal may be thought of as a conceptual dimension ranging from extreme drowsiness at the one end to extreme excitement at the other. Arousal level is the result of internal and external stimulation. High levels are associated with high levels of sensory stimulation; loud noises, bright lights, time pressure, external distractors, and complex stimuli all lead to increases in arousal. Arousal may be manipulated, physiologically indexed, or behaviorally observed (Duffy, 1972). 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. While we recognize that many feel it is naive to propose a single dimension of arousal, we feel that it is equally naive to ignore the common behavioral consequences of various stimulant drugs, lack of sleep deprivation, variations in the time of day, and individual differences in impulsivity or extraversion.

Both effort and arousal have a facilitative effect upon tasks requiring SIT resources but only arousal seems to have a debilitative effect upon tasks requiring STM resources. For tasks that require both SIT and STM resources (complex tasks such as verbal or geometric analogies) there is a curvilinear relationship between arousal and performance (Anderson, 1986; Gilliland, 1976, 1980; Gupta, 1977).[6] We have suggested that this is because the SIT component is facilitated, while the STM is hindered by increases in arousal. At low levels of arousal, STM resources are adequate and performance is limited by the resources available for SIT; increases in arousal lead to increases in SIT resources and subsequent increases in performance. At higher levels of arousal, SIT resources are adequate and performance is limited by STM resources; increases in arousal lead to further decreases in STM resources and subsequent decrements in performance (Humphreys & Revelle, 1984; Humphreys, Revelle, Simon, & Gilliland, 1980; Revelle et al., 1987).

Motivation and dimensions of personality. Two dimensions of personality closely related to the motivational constructs of arousal and effort are impulsivity and anxiety. In a number of studies my colleagues and I have shown that impulsivity and caffeine-induced arousal have complex but systematic effects upon performance. In other studies we have examined the effects of anxiety and task parameters upon performance.[7] One of the major conclusions from the entire set of studies is that the impulsivity and caffeine effects are different from those found with anxiety. Another major conclusion is that impulsivity and anxiety also relate to strategic and stylistic differences but that these effects are mediated by neither effort nor arousal.

In all of our caffeine experiments the basic paradigm has been the same: subjects are given 0–4 mg of caffeine per kilogram of body weight,

[6] Anderson (1986) has shown curvilinearity for low-impulsive subjects using a within-subjects design across five levels of caffeine. Gilliland (1976) found evidence for curvilinearity for low impulsives using a between-subjects design across three levels of caffeine. Gupta (1977) showed curvilinearity for extraverts in a between-subjects design using four levels of amphetamine. He also found that the performance of introverts declined across all levels.

[7] We have also suggested that achievement motivation is positively related to effort and have considered this relationship in some detail in other papers (Humphreys & Revelle, 1984; Revelle, 1986).

we have found that by arranging tasks in terms of three separate components we are able to summarize earlier findings relating motivation and performance.[5] This synthesis owes much to the prior work of Broadbent (1971), Folkard (1975), Hamilton, Hockey, and Rejman (1977), and Hockey (1979).

Sustained information transfer (SIT). The first dimension along which tasks can be ordered measures the extent to which subjects are required to process a stimulus, associate an arbitrary response to the stimulus, and execute a response. We have characterized this dimension as measuring information transfer. Examples of low-IT requirements include simple and choice reaction time, simple arithmetic, letter search, and letter cancellation. In these tasks there is no appreciable retention of information required nor is there an appreciable amount of distraction. Tasks which in addition require subjects to sustain their readiness to respond and which include a temporal or spatial uncertainty in the location of the stimulus we have referred to as sustained information transfer tasks. These include standard vigilance tasks, simple letter search tasks, as well as proofreading for noncontextual (e.g., spelling) errors.

Short-term memory (STM). A second dimension measures the amount of information which must be retained for short periods of time. Tasks with high memory load include traditional experimental measures of STM (e.g., recognition or recall tasks), derived measures such as the speed of memory scanning in a Sternberg paradigm, or simple tasks in which a memory load has been added. Example of the latter include a letter search task in which one is to identify strings of 20 letters that include a memory set of 6 letters (Anderson & Revelle, 1983; Folkard, Knauth, Monk, & Rutenfranz, 1976) or geometric analogies with several transformations from the A to B and C to D terms (Mulholland, Pellegrino, & Glaser, 1980).

Long-term memory (LTM). A third dimension along which tasks may vary is the amount of retrieval of previously learned material which is necessary. High-LTM load would include tasks measuring vocabulary or previously acquired information. Thus a proofreading task would have a higher LTM load than would a letter search task, which would in turn have more LTM load than a simple reaction time task.

A typology of tasks. These three dimensions of information processing can be combined to allow for a classification of many different tasks (Fig. 1). Seventeen different measures used in recent studies in my lab have been organized in terms of their SIT, STM, and LTM requirements. Although the absolute location in this three-space typology is somewhat

[5] For a more thorough treatment of these three components of information processing see Humphreys and Revelle, 1984, and Revelle et al., 1987.

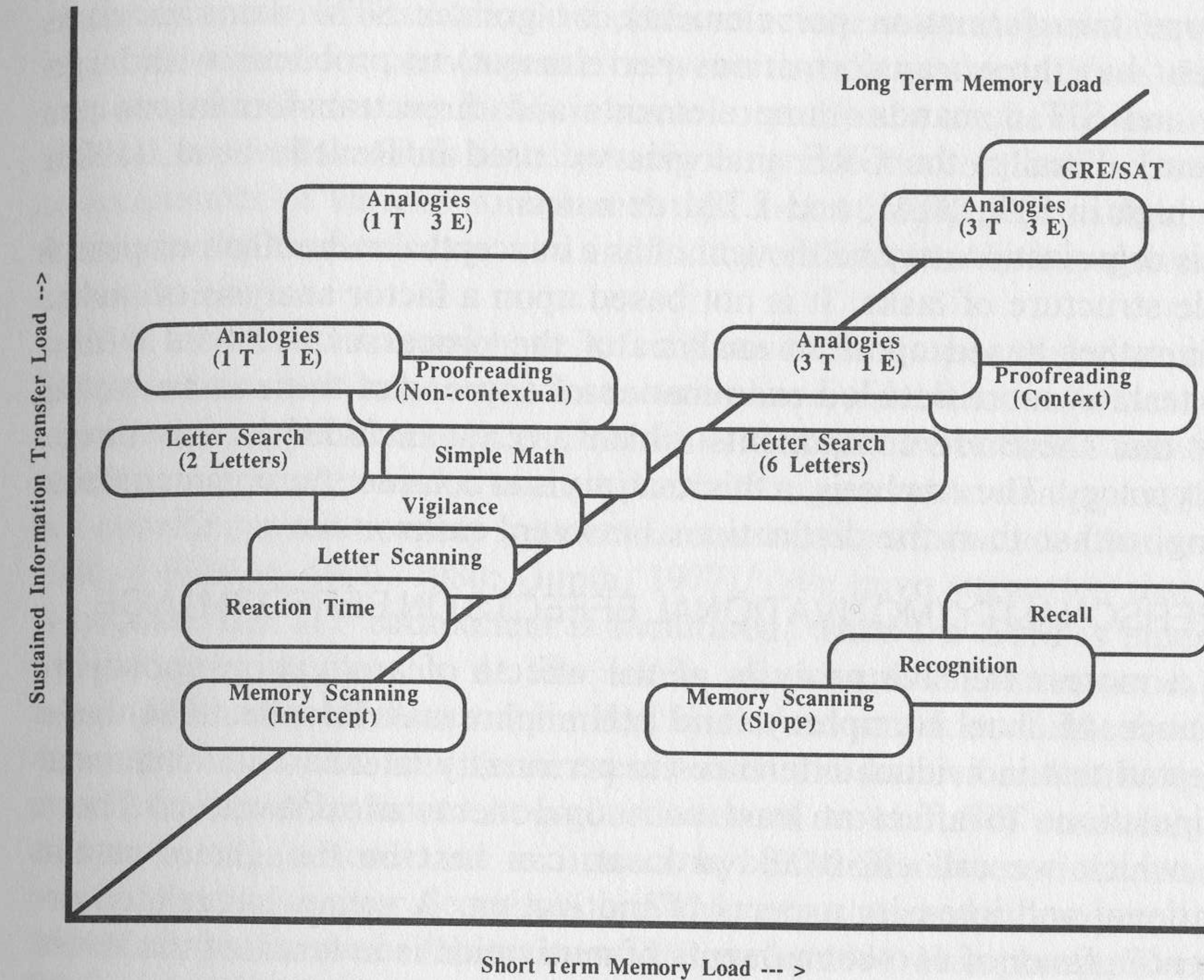

FIG. 1. A conceptual organization of cognitive performance tasks along three dimensions of information processing (short-term memory, sustained information transfer, and long-term memory). Tasks further to the right require more short-term memory resources than do those to the left. Tasks further up require more sustained information transfer resources than those nearer the bottom. Tasks shown behind other tasks are thought to require more long-term memory resources than those drawn closer to the front of the figure. In general, performance on tasks to the left of the center are facilitated by caffeine or other arousal manipulations, while performance on those tasks to the right of the figure is either hindered or shows an interactive effect of caffeine and impulsivity. For the analogies, T stands for transformations and E for elements (see Onken & Revelle, 1984). (Adapted from Revelle, 1986, and Revelle, Anderson, & Humphreys, 1987. Reproduced by permission.)

arbitrary, the relative location is not. Thus, the intercept in a memory-scanning task has less STM load than does the slope taken from the same measure. The SIT load in this task is less than that in a recognition or recall task, where a subject is required to detect the stimulus as well as retrieve it later. Searching for two letters has less STM load than searching for six letters, just as proofreading for noncontextual errors has less STM load than proofreading for contextual errors. Proofreading, however, has more LTM load than a letter search. Geometric analogies can range from those with few SIT or STM demands (one element and one transformation, to those with greater SIT demands (three elements

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