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Personality, Motivation, and Cognitive Performance

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A classic problem in the study of behavior is the relationship between what we know and what we do (see Woodworth & Schlosberg, 1954). Perhaps the most important aspect of the study of motivation is this distinction between competence (knowing) and performance (doing). This is particularly the case when studying individual differences in learning and motivation. Indeed, folk wisdom attributes poor performance on the part of some students not to an inability to learn, but rather to a lack of effort or motivation. Many are the poor students told by a teacher that if only they would try harder they would do better. However, as is true of much of contradictory folk wisdom, we are also told that people can get too motivated or too excited to do well. Many students, after a particularly bad performance on an exam will explain to their professor that they knew the material but while taking the test their mind just went blank because of test anxiety.

For psychologists, the competence–performance distinction was well shown in Blodgett's (1929) prototypic demonstration that learning could occur for hungry rats even when not rewarded, but that this learning was masked by a lack of an incentive to perform when food was not available in the goal box. When food was available, rats who had previously shown no evidence of learning were suddenly able to solve mazes with the same alacrity shown by their previously rewarded companions. Tolman and Honzik (1930) extended this study with the demonstration that the performance of previously rewarded rats will revert to the unrewarded level when reward is removed just as previously unrewarded rats will perform as well (or even better) than previously rewarded rats when reward is introduced. The Blodgett (1929) and Tolman and Honzik (1930) studies are important to motivational theorists because they made clear that performance was a function of prior learning as well as the motivational conditions present at the time of performance.

Even earlier evidence showing a relationship between situational manipulations affecting motivation and subsequent learning was reported by Yerkes and Dodson (1908). They showed that increasing levels of foot shock facilitated learning in an easy visual discrimination task but had a curvilinear (inverted U) effect for moderate and difficult discrimination tasks. Maximal performance was associated with moderate levels of foot shock and the peak of the function was at lower levels of foot shock for more complex tasks. Although Yerkes and Dodson interpreted this as an effect on learning, their study is frequently cited as an example of complex motivational effects upon performance.

It is this belief that a failure in performance for an otherwise competent individual reflects a *lack* or an *excess* of motivation that I address in this chapter. Presumably noncognitive individual differences in personality systematically affect learning and performance as a function of motivational state. Some of these effects are upon the development of competence in that they affect rates of learning and retention; other effects are on performance in that they affect how well previously learned material can be manipulated and processed. Furthermore, although certain motivational manipulations can facilitate learning for some individuals, these same manipulations can actually hurt both the learning and the performance of others.

Before starting, I review some basic theoretical concepts from current research in personality. I then discuss some recent research that shows how differences in personality interact with situational and task manipulations to have strong effects upon learning. These effects are upon the learning and retrieval of material that is to be retained for periods ranging from a few seconds to one week. These same personality differences interact with similar manipulations to affect complex performance tasks. Some of these tasks are quite similar to those used to assess verbal and abstract reasoning ability in standardized ability tests. Others are more similar to the simple memory, attention, and abstract reasoning problems so popular among experimental psychologists. I conclude with a plea for the detailed analyses of personality, situational, and task variables that are required if we are to understand how individual differences relate to learning and motivation.

PERSONALITY TYPOLOGIES; EYSENCK'S AND GRAY'S BIOLOGICAL PERSPECTIVES

Although most American researchers are familiar with the trait theoretic approach of Raymond Cattell (1947, 1957, 1973) and some of the typological work associated with the adequate taxonomy project (e.g., Allport & Odbert, 1936; Cattell, 1957; Digman & Takemoto-Chock, 1981; Goldberg, 1982; McCrae & Costa, 1987; Norman, 1963, 1969; Tupes & Christal, 1961; Wiggins, 1979), many are less familiar with the biological taxonomy developed in Europe by Hans Eysenck (H. J. Eysenck, 1947, 1952, 1967, 1981, 1987; H. J. Eysenck & M. W. Eysenck, 1985) and his associates (Gray, 1972, 1981, 1982, 1987; Strelau, 1983, 1985). It is, however, this biologically based theory of Eysenck that is most relevant to the understanding of efficient and inefficient cognitive performance.

Over the past 40 years, Hans Eysenck has studied four dimensions of individual differences: introversion–extraversion, neuroticism–stability, psychoticism, and intelligence. In this time, he has developed a broad and compelling theoretical explanation of how differences in a genetic-biological substrate can lead to differences in sensitivity to the environment, to conditioning, to the development of conscience, and to most aspects of human behavior. Although his theories are extremely wide ranging and often controversial, he is perhaps best known for his extensive analysis of the biological basis of introversion–extraversion and its behavioral correlates.

In brief, Eysenck hypothesizes that introverts are more cortically aroused than are extraverts and that these differences in arousal are reflected in a greater conditionability in introverts than in extraverts.[1] This greater ease of conditioning is thought to lead to the development of a stronger conscience on the part of introverts and thus to their subsequently more moral behavior. With the twin assumptions that extraverts are less aroused than introverts and that intermediate levels of arousal are most preferred, Eysenck explains extraverts' greater stimulation-seeking behavior, higher rate of sexual activity, and tendency to engage in dangerous or illegal activities as an attempt to compensate for lower internal levels of arousal with higher external levels.

Arousal is taken here as a theoretical construct asociated with the state of being alert, wide awake, and energized. Arousal is seen as a nonspecific energization in response to stimulation (Duffy, 1972). It is increased by changes in the environment or by the processing demands placed upon the subject. It can also be thought of as the inverse probability of falling asleep (Corcoran, 1965, 1972). Arousal is meant to summarize the common behavioral effects of stimulant drugs, time on task, diurnal variations in alertness, and moderate exercise. Indices of arousal include EEG amplitude and frequency, heart rate (HR), pupillary dilation, skin conductance (SC), body temperature, and self-report. It should be realized, however, that these separate indices also reflect activity in specific systems and have unique as well as common sources of variance. In addition each of these indices has different temporal parameters, with different delays and sampling rates, so that these different indices reflect arousal averaged over different lengths of time and with different delays (e.g., EEG activation will

[1]At least under appropriate conditions (H. J. Eysenck & Levey, 1972). It is also likely that impulsivity rather than extraversion is the important dimension in conditioning (Frcka & Martin, 1987).

occur within milliseconds of a stimulus onset, SC changes after several seconds, self-reports of activity and energy reflect arousal sampled over a longer period than either EEG or SC, and body temperature seems to indicate average activity over a period of minutes to hours). Finally, it is important to note that although these indices tend to covary within individuals, they do not necessarily covary between individuals; some individuals will respond to stimuli with greater changes in HR than in SC, whereas others will have large increases in SC but only small increases in HR. Within subjects, changes in SC and HR can correlate positively even though there is zero or a negative correlation between subjects.

Although there are serious problems with H. J. Eysenck's hypothesis that introverts seek less stimulation *because* they are more aroused, there is a modest amount of evidence to suggest that, in fact, introverts are more aroused more of the time than are extraverts (Davis & Cowles, 1988; Gale, 1986). Furthermore, introverts seem to prefer lower levels of sensory stimulation than do extraverts (Elliot, 1971; Ludvigh & Happ, 1974), and these differences change in response to stimulant and depressant drugs (Bartol, 1975). Simply put, extraverts given a stimulant drug are like introverts, or alternatively, introverts given alcohol or a barbiturate are like extraverts (Bartol, 1975; Gupta, 1974).

One difficulty in explaining stimulation-seeking behavior as a consequence of these arousal differences is that arousal has a pronounced diurnal rhythm (Blake, 1967a, 1967b). That is, most people are more aroused in the afternoon and evening, when they seem to be seeking stimulation, than they are in the morning, when most people tend to avoid going to lively parties. According to naive arousal models, extraverts should prefer sex origies early in the morning (in order to achieve a higher level of arousal) and prefer to study in the evening (in order to reduce an already high level of arousal). Although I know of no data directly testing this hypothesis, it does not seem intuitively compelling.

An important modification of H. J. Eysenck's theory has been proposed by Jeffrey Gray (1972, 1981), who suggested that the appropriate basis of analysis of the two-dimensional space made up of introversion–extraversion and neuroticism–stability are the dimensions of anxiety and impulsivity. It had long been known that the dimension of extraversion could be decomposed into the subscales of impulsivity and sociability (Carrigan, 1960; H. J. Eysenck, 1977b; Guilford, 1975, 1977). Similarly, anxiety is a major component of most concepts of neuroticism. Integrating this psychometric work with behavioral responses to antianxiety drugs, Gray (1972, 1981, 1982) suggested that anxiety reflects a sensitivity to cues for punishment and impulsivity reflects sensitivity to cues for rewards. Gray suggested that anxiety plus impulsivity can be equated with Eysenck's dimension of neuroticism (i.e., neurotics are highly sensitive to both cues for reward and for punishment). Furthermore, Gray proposed that introversion–extraversion reflects the balance between sensitivity to cues for reward (impulsivity) and cues for punishment (anxiety). To the extent that one is more sensitive to cues for reward than for cues to punishment, one is more extraverted.

To the extent that one is more sensitive to cues for punishment than to cues for reward, one is more introverted. Thus, Gray equates extraversion with impulsivity minus anxiety.

Although Gray's theory is flawed on psychometric grounds (neither anxiety nor impulsivity is a 45 degree rotation away from neuroticism and extraversion; Rocklin & Revelle, 1981), the concept of differential sensitivity to cues for rewards and punishments is very important to understanding individual differences in rates of learning. Furthermore, by emphasizing the role of *impulsivity* rather than extraversion, Gray has made an important modification to Eysenck's theory. As my colleagues and I have argued extensively (Revelle, Humphreys, Simon, & Gilliland, 1980; Revelle, Anderson, & Humphreys, 1987), it seems as if the dimension of impulsivity is more related to arousal than is sociability or the higher-order dimension of extraversion. (See also Campbell, 1983, and Revelle, 1987, as well as the counterargument by H. J. Eysenck, 1987.)

Even though I review the evidence for this point much more thoroughly in the subsequent sections, let me say now that it seems as if high impulsives are much less aroused in the morning than are low impulsives, equally aroused by midday, and somewhat more aroused by evening.[2] Furthermore, it seems as if high impulsives are more sensitive to cues for reward than are low impulsives and that highly anxious individuals are more sensitive to cues for punishment than are less anxious individuals.

PERSONALITY, MOTIVATION, AND LEARNING

When studying any difference in learning or performance, it is important to be sensitive to the possibility of other, extraneous differences. This is particularly important when one proposes to study noncognitive differences on cognitive tasks. To show that one group learns more rapidly than another is not very compelling evidence for a motivational difference, because the difference could just as easily be one of ability. For this reason, we have followed the path of searching for manipulations that have disordinal interactions with our personality variables in order to show that any presumed ability difference cannot account for our effects.

That is, we try to show that a particular manipulation (say, caffeine) will facilitate the performance of one group (say, high impulsives) while it hinders the performance of another (say, low impulsives). That these are not ability effects is shown by the rough equality of the mean performance of high and low

[2]The evidence for the morning differences in arousal between high and low impulsives is consistent with much of the Eysenckian literature. The evidence for the reversal in the evening is more tenuous and requires assumptions about the relationships between arousal and performance. Some of these assumptions are discussed later.

impulsives when averaged across conditions. Furthermore, as the results are disordinal (crossover) interactions, it is impossible to dismiss them as being due to mere scaling artifacts (Maxwell & Delaney, 1985; Revelle & Anderson, in press). Finally, in order to show that the effects are lawfully related to different aspects of cognitive processing, we try to include measures presumed to differ along relevant dimensions of cognitive requirements.

In our prototypic study, we cross one or two personality variables with one or two situational variables and with one or two task variables. To exclude as many competing hypotheses as possible, we frequently design studies that predict two- to four-way interactions. Typically, our studies are designed such that different patterns of interactions or main effects will be predicted by different motivational theories (e.g., Anderson, 1981; Leon & Revelle, 1985; Zinbarg & Revelle, in press). Although I have said why we chose to conduct studies predicting high level interactions, I should also suggest why one should not. Perhaps the most compelling reason *not* to search for such interactions is that they are extremely hard to communicate to others. Without presenting several two- and three-panel graphs, some of our results are quite hard to understand.[3] To ease the difficulty of communication, we typically have taken an effect found in another aspect of the arousal, cognition, or performance literature and done a conceptual replication and extension by including an additional personality, motivational, or task variable. Thus, we explore how individual differences and situational manipulations affect the boundary conditions of more classic cognitive effects. Equally important, we examine how situational or cognitive variables allow for theoretical refinements of our models of personality. Finally, in order to make sure that our results are robust, we have preferred to conceptually replicte our own studies several times in order to look for the consistent patterns across studies.

Perhaps to compensate for our complex data, we have also searched for theoretical explanations that are particularly simple. Thus, to account for a variety of motivational manipulations we have argued that only two basic concepts are needed: effort and arousal. To organize a wide range of performance tasks, we have suggested that only three cognitive constructs need to be considered: the amount of resources needed for Sustained Information Transfer, Short-Term and Long-Term Memory. Finally, to describe the process of learning, I consider only three separate stages: the initial acquisition and encoding of the stimuli, the organization and storage of the information, and the subsequent retrieval of the to-be-remembered material. In all of our theorizing we have recognized that these assumptions are oversimplifications and that careful research can and does indicate many specific sources of variance in each task and each experimental manipulation. However, we believe that as a way of organizing large bodies of data, a limited set of constructs is a useful and appropriate first approximation.

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[3]One colleague at a doctoral oral examination asked, perhaps seriously, whether psychology is really ready for three-way interactions. The answer was a strong yes!

In the following section, I review evidence that impulsivity and stimulant drugs affect the acquisition of new information by modifying the rate at which information is detected and transformed; that impulsivity and anxiety affect the encoding of information by modifying the salience of positively and negatively valenced information; and that impulsivity and time of day affect the storage of information in different ways for short and extended periods of time. I also report a lack of evidence supporting state-specific effects on recall.

Personality and the Acquisition of Information

The first stage in most models of learning requires detection and encoding of the to-be-learned material (see Broadbent, 1984, for a particularly appealing organization of the cognitive processes involved in learning and performance). There have been many studies showing how various cognitive factors affect this stage of processing. For example, expectations can affect the allocation of attention to various parts of the perceptual field (Posner, 1978), and familiarity with the material to be learned allows for more efficient chunking of complex displays. Characteristics of the stimuli can also affect the perceptual process. With extensive practice, it is possible to detect stimulus features that do not vary across trials much more rapidly and accurately than those stimuli that have features varying from trial to trial (Shiffrin & Schneider, 1977). More relevant for our concerns in this chapter, however, are those studies that have demonstrated how differences in personality can affect even this earliest stage of learning.

Impulsivity and Sustained Information Transfer

The first requirement in learning is to detect and encode the material to be learned. Although obvious, it is important to remember that a subject who is too bored, sleepy, or otherwise inattentive is less likely to learn new material than is one who is paying attention to the learning task. Although we have mainly examined other, later processes in learning, Paul Bowyer, Michael Humphreys, and I have pointed out that individual differences in impulsivity also reflect the ability to stay alert while learning new material (Bowyer, Humphreys, & Revelle, 1983).

Humphreys and I have described certain tasks that we believe require resources for Sustained Information Transfer (SIT; Humphreys & Revelle, 1984; Humphreys, Revelle, Simon, & Gilliland, 1980). Information transfer (IT) tasks are ones in which a subject must rapidly make an arbitrary response to a simple stimulus input. Typical experimental examples include simple and choice reaction time, letter scanning, and simple arithmetic problems. An additional set of IT tasks are those requiring sustained performance over periods lasting minutes to hours. Excellent applied examples of tasks requiring SIT resources are vigilance tasks such as driving a truck or a train for long periods of time, operating a sonar detector trying to locate submarines, or monitoring vital signs during an extended medical operation. A shared characteristic of these tasks is that they require detection and response to low probability stimuli that occur at irregular intervals. Even with skilled subjects, performance on vigilance tasks rapidly deteriorates as a function of time but is sustained by manipulations that increase alertness or arousal (Gale, 1977; Mackie, 1977).[4]

Extraverts and high impulsive subjects exhibit strong vigilance decrements (Bakan, Belton, & Toth, 1963; Thackray, Jones, & Touchstone, 1974). In fact, it was the similarity of the characteristic decline of performance during vigilance tasks for extraverts and sleepy or tired subjects that led Claridge (1967), Corcoran (1965), and H. J. Eysenck (1967) to first suggest that perhaps extraverts were less aroused than introverts.

A similar decline in performance over trials had been found in verbal learning by Underwood (1978), who suggested that decay of attention might be involved in the performance decrement over trials. Underwood had presented subjects with four lists of words and examined the decline in accuracy across these four lists. We conceptually replicated the Underwood study with the addition of a personality variable (impulsivity) and an arousal manipulation (caffeine). Across trial blocks of 24, 80, 80, and 24 words (replicating Underwood), we found that for high impulsives the number of correct forced-choice recognitions for the last 20 words in each block deteriorated from .97 to .84, whereas for the low impulsives recognition went from .92 to .88. With the addition of 4 mg of caffeine per kilogram body weight, however, the performance of the high impulsives showed markedly less deterioration (from .96 to .91; see Fig. 11.1; Bowyer, Humphreys, & Revelle, 1983).

Our results show a remarkable similarity to those of a more standard vigilance task. The obvious message from this study is that subjects who are unable to sustain the resources necessary for information transfer are also less likely to detect and encode material in a learning task. Our least aroused subjects (high impulsives without caffeine) increased their error rates on this simple recognition memory task by a factor of 5 in the space of only a few minutes. The administration of caffeine reduced this decrement by a factor of two.

Impulsivity, Anxiety, and Cue Valence

Once a stimulus is detected, it needs to be encoded. Individual differences enter at this stage by interacting with the valence of the stimulus. In a set of four studies, Richard Zinbarg and I have shown that impulsivity and anxiety interact with cue valence (reward or punishment) to affect learning a simple discrimination task. Our task involved learning to press (*Go*) or not to press (*No-Go*) the button on the mouse of a microcomputer. On each trial, a pair of letters made up

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[4]There are, of course, many other determinants of the vigilance decrement. Interested readers should consult the volumes by Mackie (1977) and by Davies and Parasuraman (1982) for discussions of how presentation rate, signal-to-noise ratio, and type of processing demands affect the vigilance decrement.

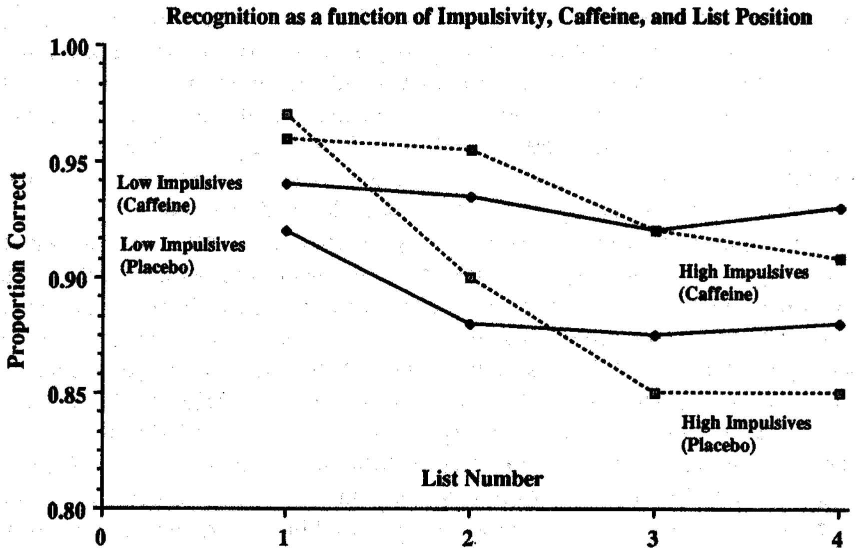

FIG. 11.1. Accuracy in forced-choice recognition as a function of time on task (trial blocks), impulsivity, and caffeine (adapted from Bowyer et al., 1983).

of one discriminative and one distractor cue was presented on the screen of a Macintosh. These letters were drawn from a set of 16 letters, 8 of which were distractors and 8 of which were cues for pressing or not pressing the mouse button. Of the discriminative letters, two were asociated with reward for pressing the button (*Active Approach* or *Ap*), two were associated with reward being presented for not pressing the button (*Omission* or *Om*), two were cues for punishment following not pressing (*Active Avoidance* or *AA*), and two were cues for punishment following pressing (*Passive Avoidance* or *PA*). In his frustration = punishment and lack of punishment = reward hypothesis, Jeffrey Gray has suggested that high impulsives are more sensitive to those cues that signal reward (Ap) or lack of punishment (AA) than are low impulsives, whereas high anxious subjects are more sensitive to the cues that signal punishment (PA) or lack of reward (Om). Thus, in our experiment, half of the cues were signals to respond for rewards or to avoid punishments (Ap and AA), while the other half were cues for not responding in order to get a reward or to avoid being punished (Om and PA).

In each of four studies, we found a triple interaction of impulsivity, anxiety, and cue type (Zinbarg & Revelle, in press).[5] For trials where making a response led to a reward or avoided punishment (Ap and AA), anxiety inhibited learning

[5]In two of the four studies, this effect was significant. The other two studies (with smaller *N*s) showed the same interaction, but the effects were not significant.

among the high impulsives. However, for trials where not making a response led to a reward or avoided punishment (Om and Pa), high anxiety facilitated learning for the low impulsives. That is, the high impulsive subjects were best able to learn to make a response, unless they were also highly anxious. The highly anxious subjects were best able to learn to not make a response, if they were also less impulsive (Fig. 11.2). Impulsivity and anxiety seemed to have had mutually inhibitory effects on the encoding of the to-be-learned material.

The implication of these four studies is that individual differences in personality interact with the valence of the stimulus material to affect learning. The particular pattern of results could not be explained by Spence's theory of anxiety and conditioning (Spence & Spence, 1966), by Eysenck's theory of extraversion and conditioning (H. J. Eysenck, 1965, 1977a), by Gray's hypotheses concerning conditioning in terms of extraversion or in terms of impulsivity (Gray, 1972, 1981, 1982), or by Newman's theory of extraversion and conditioning (Newman, Widom, & Nathan, 1985; Patterson, Kosson, & Newman, 1987). We have suggested that it is necessary to consider how impulsivity and anxiety interact in forming expectations of the to-be-learned material in order to explain our results (Zinbarg & Revelle, in press). It seems that high impulsives are more likely to form expectations that an action will lead to a reward than are low impulsives, and that the highly anxious are more likely to expect that an action will lead to punishment than are the less anxious. In addition, a bias toward expecting rewards can be thought of as inhibiting the development of an expectation about punishment.

Personality and the Storage of Information

Once stimuli are acquired and encoded, it is then necessary to store them for later retrieval. Although much of experimental psychology has been devoted to determining the environmental and situational conditions that facilitate learning, there has been less concern with the personality and motivational effects on storage. One interesting effect that we can now interpret in terms of arousal theory is the effect of time of day at study on subsequent recall. Ebbinghaus (1883/1964) found systematic effects of time of day on the ease of learning nonsense syllables in a well-practiced subject (himself). Learning was an inverted-U function of the time of day. In a later series of studies of the effect of time of day on learning, Gates (1916) recommended that serious academic material should be offered in the morning, as "learning" was greater then than later in the day. These studies did not, however, examine individual differences, but rather set the stage for later studies.

Arousal Theory and Short-Term versus Long-Term Retention

More recent research on the effect of time of day and learning has been interpreted in terms of diurnal rhythms in arousal (Blake, 1967a, 1967b; Folkard,

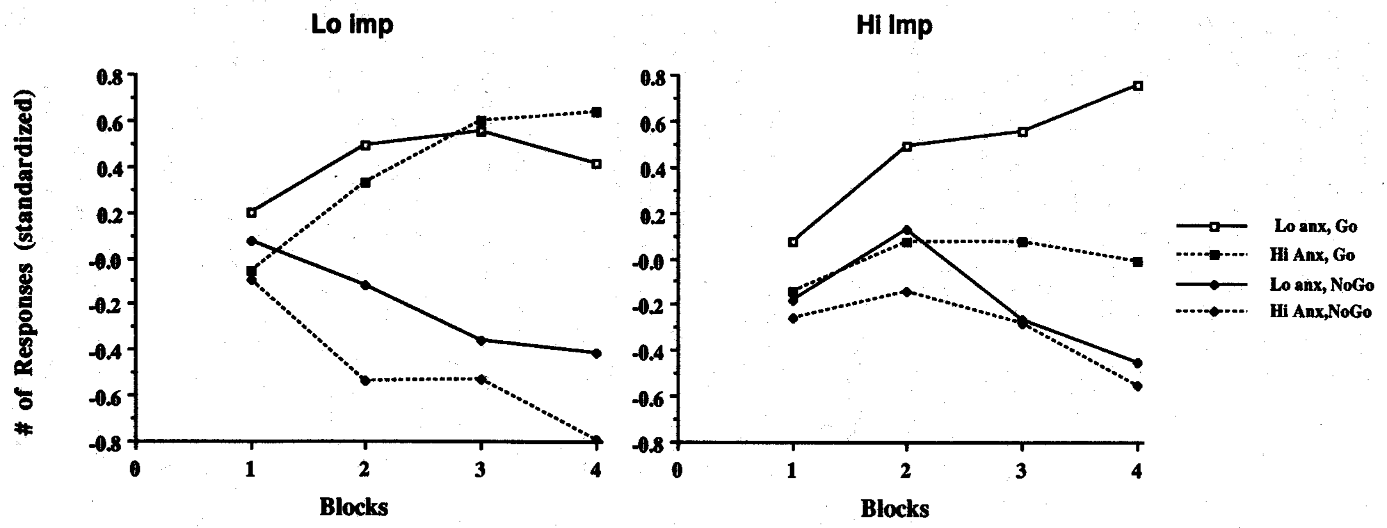

FIG. 11.2. Standardized response rate as a function of impulsivity, anxiety, and cue type (*Go* versus *No-Go*) (adapted from Zinbarg & Revelle, in press).

1975; Folkard & Monk, 1980; Folkard, Monk, Bradbury, & Rosenthal, 1977; Oakhill, 1986, 1988). Folkard et al. (1977) found that time of day interacted with retention interval (immediate vs. one-week delay) and explained their results in terms of a beneficial effect of arousal on long-term memory but a detrimental effect on short-term memory. This explanation was partly based upon the early reports of Galvanic Skin Response (GSR) arousal interacting with the length of the retention interval (Kleinsmith & Kaplan, 1963). In those earlier studies, subjects were to learn associations between digits and words. GSR arousal to each word was correlated with subsequent cued recall of the word-digit pair. High arousal to a word at study time led to poor immediate recall but better recall after 45 minutes. These results were explained in terms of Walker's consolidation hypothesis that arousal increased consolidation of the memory trace but that the trace was unavailable during the process of consolidation (Walker, 1958; Walker & Tate, 1963). Although there have been subsequent replications of this effect, the consolidation hypothesis has not received much acceptance.

Impulsivity, Time of Day, and Short-Term versus Long-Term Retention

If high and low impulsives differ in the phase of their diurnal rhythm as we have suggested (Revelle et al., 1980), then impulsivity should moderate the relationship between time of day and short- versus long-term retention. Mark Puchalski and I have recently completed a study examining this hypothesis (Puchalski, 1988; Puchalski & Revelle, in preparation). We replicated the Folkard et al. (1977) study with the addition of impulsivity as a subject variable.

Ninth grade students in a local school listened to a 12-min tape recording of a 2,000-word passage. One half of the students were then given an immediate test of their comprehension and recall of material from the story, whereas the other half were given a one-week delay interval before being asked about the story. One half of the subjects were run at 8 a.m., the other half at 2 p.m. Of the subjects tested with a week delay, one half were tested at the same time of day as the original story, the other half were tested at the other time. Finally, impulsivity and extraversion were assessed by using the Eysenck Personality Inventory (EPI; H. J. Eysenck & S. B. G. Eysenck, 1964).[6] The results are striking (Fig. 11.3).

For material learned in the morning, high impulsives were far superior to low impulsives in their immediate recall, whereas they were inferior to low impulsives in their delayed recall. These results were reversed for material learned in the afternoon. For these subjects, low impulsives were able to recall more

[6]Because we are more interested in assessing impulsivity than extraversion, we use the EPI rather than the more recent Eysenck Personality Questionnaire (EPQ; S. B. G. Eysenck & H. J. Eysenck, 1975). As we have argued elsewhere (Revelle et al., 1980; Rocklin & Revelle, 1981), extraversion as assessed by these two tests is not the same construct. We have found empirically that the impulsivity scale of the EPI is more related to arousal differences than are the scales of the EPQ.

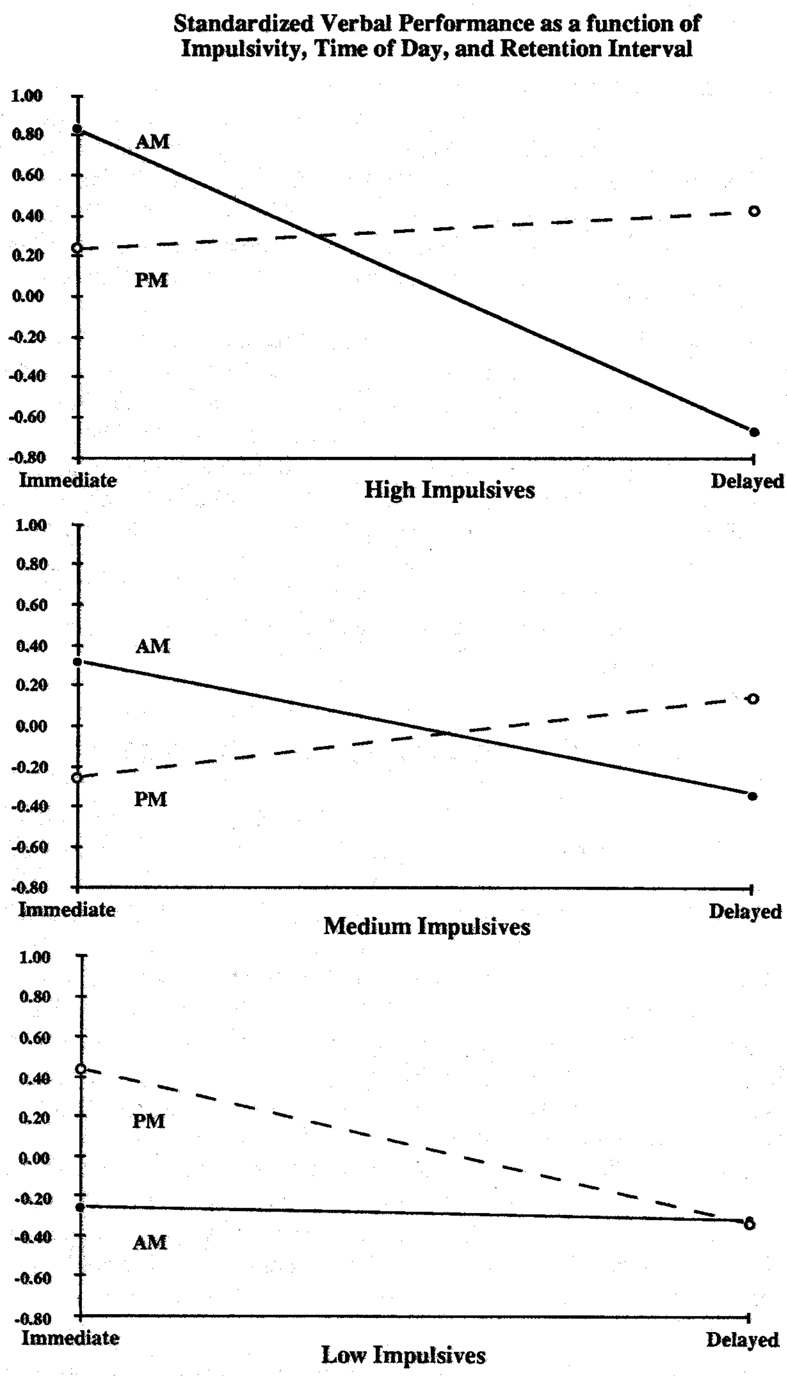

FIG. 11.3. Standardized number of problems correct on a recall-comprehension test as a function of delay (immediate vs. one week), time of day (8 am vs. 2 pm), and impulsivity (adapted from Puchalski & Revelle, in preparation).

material immediately than the high impulsives, but the high impulsives were superior after the one-week retention period. Perhaps most striking is the absolute increase from short-term to long-term recall on the part of the high impulsives in the afternoon: For material learned in the afternoon, the high impulsives remembered more about the story after a delay of one week than they did immediately after the story. There were no reliable effects of state dependence (i.e., better morning recall for material studied in the morning than in the afternoon).

One way to understand the magnitude of the effects of individual differences in learning is to consider the additional variance accounted for as various classes of variables are added. Relevant variables for our listening comprehension/recall task include the task variable of short- versus long-delay interval, the situational variable of morning versus afternoon, individual differences in reading ability, and finally, individual differences in impulsivity. The effect of the delay interval accounted for 4% of the variance of recall. Time of day and the interaction of time of day and delay accounted for an additional 3%. Adding reading ability accounted for an additional 11%. Finally, adding the interaction of impulsivity, time of day, and length of delay added an additional 7%, which accounted for a total amount of variance of 25%.[7]

PERSONALITY, MOTIVATION, AND PERFORMANCE

In the preceding sections I have shown how personality variables can affect the development of competence (i.e., learning). The personality dimensions of impulsivity and anxiety, in combination with situational manipulations of arousal, affect the initial detection of material, how that material is encoded, and how well that material can be stored for later retrieval. These same variables also affect performance of well-learned skills. Inspired by the personality theories of H. J. Eysenck (1967) and Gray (1972, 1982) and the performance theories of the experimental psychologists Donald Broadbent (1971), Simon Folkard (1975), and Robert Hockey (1979), my colleagues and I have been examining how personality combines with situational and task variables to affect performance on simple and complex cognitive tasks. We have been able to show a consistent pattern of effects in which the personality dimensions of impulsivity and anxiety interact with situational manipulations such as time of day, stimulant drugs, or time on task and with task variables such as the amount of resources required for Sustained Information Transfer or for Short- versus Long-Term Memory to affect performance on many types of tasks.

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[7]The model tested was in fact the full model. These stepwise multiple *R*s are reported merely to give an estimate of the relative importance of each class (task, situational, ability, personality) of variable.

Personality, Stress, and Performance

Our earliest demonstrations of the importance of considering personality variables in combination with situational manipulations were studies investigating how introversion–extraversion combined with various situational stressors or arousers[8] to affect performance. In the first of this series (Revelle, 1973), several ad hoc performance tasks were used, including anagrams, digit-symbol substitution, and maze performance. In addition to the personality variables of introversion–extraversion and neuroticism, individual differences in arousal were indexed by Skin Conductance (SC). Within each type of task, there were three levels of difficulty. Stress was manipulated by combining the presumed stressors of group size, incentive motivation, and noise using an additive design.[9] The expected finding was to show that performance fit the pattern predicted by the Yerkes–Dodson law and that these results were an interactive effect of personality and stress. Thus, a difficulty by stress by introversion interaction was predicted. Furthermore, it was predicted that the use of SC would allow for a clear ordering of the effects and therefore a SC by task difficulty effect was expected. However, as is often the case in naively ambitious dissertations, this was not to be the case: Across all six stress levels, there was no indication of an interaction between personality and stress or personality and arousal. When these situational manipulations were held constant, however, there was a reliable interaction between arousal as indexed by SC and introversion–extraversion: Performance was a monotonically decreasing function of increases in SC for introverts but a curvilinear function (an inverted U) for extraverts. That is, introverts performed best if they had low skin conductance, but extraverts performed best with moderate levels of skin conductance. The lack of interactions of personality and arousal when incentives were varied and the presence of an

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[8]Our earliest work did not distinguish between these two concepts. It was only when the pattern of results indicated that arousal and effort manipulations needed to be considered separately that a more clear-cut distinction was made.

[9]For a more complete treatment of the types of designs used in these and similar studies, see Revelle and Anderson (in press). The most common between-subjects designs used to test arousal are the factorial, the additive, and the multiple-level design. In factorial designs, two or more presumed sources of arousal are crossed in the typical N-way analysis of variance. Unfortunately, as a means of testing for inverted-U relationships, such designs make up for the simplicity of the statistical analysis with a complexity of interpretability. It is easier to use these designs to show that different variables do not affect the same underlying construct (arousal) than it is to show that they do (Craig, Humphreys, Rocklin, & Revelle, 1979; Revelle, 1973).

In the additive design, the independent variables are not fully crossed but merely added onto each other. Although this makes for a more efficient allocation of subjects to conditions that may be unambiguously ordered, additive designs suffer from a lack of explicitness in determining whether the variables all add to the same underlying construct.

Multiple-level designs allow for unambiguous ordering of conditions by varying a treatment such as drug dosage. There are few situational variables other than drug dosage that yield so easily to such a design, however.

interaction when incentives were held constant was interpreted as indicating the importance of considering effort and arousal as separate constructs rather than as one unified motivational term.

In a follow-up study (Revelle, Amaral, & Turriff, 1976), performance on items from a practice Graduate Record Examination (GRE) was an interactive function of introversion–extraversion and situational stress. Stress was manipulated by increasing time pressure and administrating caffeine. In a within-subjects additive design, subjects were given 60 GRE items under instructions to take as long as they needed (relaxed) or to do them in 10 minutes with or without caffeine (timed-placebo vs. timed-caffeine). The amount of caffeine (200 mg) was roughly equivalent to that consumed in two–three cups of coffee. The results were strikingly clear-cut: Compared to the relaxed condition, time pressure and caffeine hindered the performance of introverts by .6 standard deviations, while the same manipulations facilitated the performance of the extraverts by .45 standard deviations (Fig. 11.4).

In an early replication and extension of this study, Kirby Gilliland (1976, 1980) found that these effects were strongest for the impulsivity component of introversion–extraversion rather than for the whole scale. Using a between-subjects multiple-level design with three levels of caffeine (0, 2, and 4 mg per kilogram body weight) and comparing predrug with postdrug performance on practice GREs, Gilliland found that the performance of the high impulsives was a monotonically increasing function of caffeine, and the performance of the low impulsives was a curvilinear (inverted-U) function of caffeine.

Working independently, Gupta (1977) used a between-subjects, multiple-level design to examine the interaction of amphetamine dosage and introversion–extraversion on an IQ test. Dosages of 0, 5, 10, and 15 mg were given to extreme introverts and extraverts.[10] For the introverts, performance deteriorated across all levels of amphetamine. For the extraverts, on the other hand, performance first increased (from 0 to 5 to 10 mg) and then decreased (at 15 mg). Thus, there was a negative monotonic function of amphetamine dosage for introverted subjects, but a curvilinear function for extraverted subjects.

In a further series of five experiments extending the Revelle et al. (1976) and Gilliland (1976) experiments, we found that the personality dimension that most reliably interacted with caffeine was not introversion–extraversion, but rather one of its components, impulsivity (Revelle et al., 1980). Including the Gilliland (1976) experiment, each of the five studies conducted in the morning showed the same effect: The performance of high impulsives was facilitated by caffeine, and the performance of low impulsives was impaired by caffeine. The median improvement was .55 standard deviations for the high impulsives, and the median decrement was .22 standard deviations for the low impulsives. In addition, we

[10]By using this extreme-groups design, Gupta was unable to distinguish between the impulsivity and sociability components of introversion–extraversion. This is an excellent demonstration of the advantages and disadvantages of using extreme groups: The statistical power is increased, but the possibility of reanalysis of the personality scale is lost.

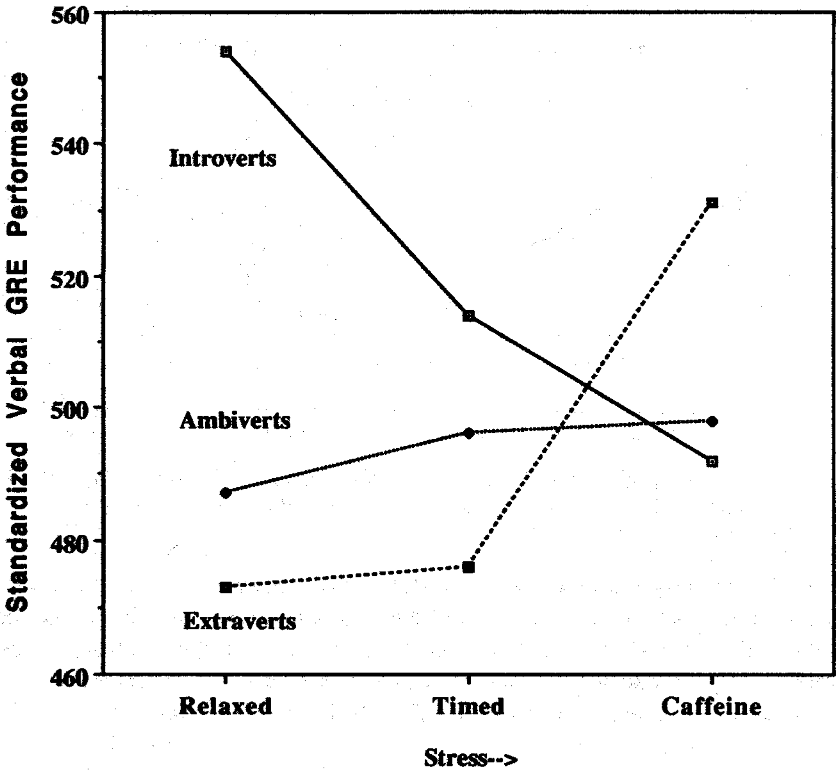

FIG. 11.4. Standardized performance on a practice Graduate Record Exam as a function of stress (relaxed, time pressure, time pressure + caffeine) and introversion–extraversion (adapted from Revelle, Amaral, & Turriff, 1976).

discovered that this interaction was reversed in those studies conducted in the evening. In three of four studies conducted in the evening, the performance of the low impulsives was improved with caffeine, whereas in all four studies the performance of the high impulsives was impaired. The median improvement for the low impulsives was .27 standard deviations, and the median decrease was .15 standard deviations for the high impulsives (Fig. 11.5). In addition to these interactions with time of day, there were interactions with day of study (Day 1 vs. Day 2) that are difficult to understand or to explain.[11]

[11]However, consider the discussion by Gale (1977) and Davis and Cowles (1988) about the effects of multiple days upon arousal. It is possible that the interactions of days with time of day and impulsivity might be due to a differential adaptation to the laboratory (Davis & Cowles, 1988) for high and low impulsives. In a new situation (i.e., a caffeine study), high impulsives are fairly alert in the evening of the first day, while the low impulsives are tired from being aroused all day. By the second or third day, however, this initial excitement has passed for the high impulsives, and they become less aroused than the low impulsives.

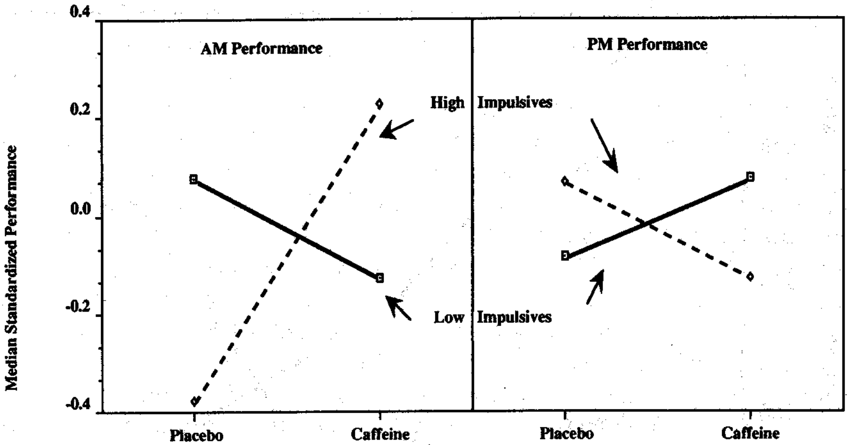

FIG. 11.5. Standardized performance on seven ability measures as a function of impulsivity, caffeine, impulsivity, and time of day (adapted from Revelle et al., 1980).

We have interpreted these time of day results as showing that impulsivity relates not to absolute arousal level but rather to the phase of the diurnal arousal rhythm. The arousal level of high impulsives seems to lag behind that of low impulsives by several hours. Similar diurnal differences have been reported for introversion–extraversion (Blake, 1967b, 1971) and for impulsivity (M. W. Eysenck & Folkard, 1980).

Although having only two levels of situationally induced arousal (placebo vs. caffeine), we interpreted our data as providing evidence for the inverted-U effect (e.g., Hebb, 1955; Yerkes & Dodson, 1908). For the studies in the morning, we assumed that high impulsives were less aroused than were low impulsives and that increases in performance with caffeine were due to increases in arousal. The decrease in performance on the part of the low impulsives we explained in terms of an initially higher level of arousal and a subsequent overarousal leading to inefficient performance. In the evening, the explanation was reversed: High impulsives were now seen as optimally aroused without caffeine and overaroused with caffeine; low impulsives were underaroused and improved their performance when given caffeine (Revelle et al., 1980). Unfortunately, these studies provided no evidence for curvilinearity per se. Gilliland (1976, 1980) and Gupta (1977) had shown curvilinearity, but using between groups designs that do not provide unequivocal evidence for inverted Us. It is possible that some subjects get better as arousal increases and others get worse; curvilinearity at the aggregate level could merely reflect changing proportions of these two types of subjects.

In an elegant demonstration of the importance of examining data at the aggregated, group level as well as the unaggregated, subject level, Kristen Anderson (1988) has found that GRE performance is in fact a inverted-U function of increasing dosages of caffeine for low impulsive subjects, but is a monotonically increasing function for high impulsives. In a within-subjects multiple-level study using five levels of caffeine (0, 1, 2, 3, and 4 mg per kilogram body weight) and two performance tasks, caffeine facilitated the performance of both high and low impulsives on a letter-scanning task but had an inverted-U relationship for the performance of low impulsive subjects on a GRE task. For the high impulsives, GRE performance monotonically increased with increasing dosages of caffeine. That these curvilinear relationships were not an artifact of aggregation was shown when the data were examined at the individual level: A reliable number of subjects showed the pattern predicted by the Yerkes–Dodson law (Anderson, 1988). These data supply convincing evidence that the Yerkes–Dodson effect is not some statistical artifact but is rather a powerful phenomenon that needs to be explained.

Personality, Motivation, and Task Components

All of these studies indicated the importance of considering individual differences and situational manipulations when examining efficient performance, but they did nothing for explaining the effect. The statement that performance is a curvilinear function of arousal is a description, not an explanation. In an effort to go beyond merely describing our results, we have proposed a model that organizes a variety of personality and situational manipulations along two dimensions of motivation: effort and arousal. In addition, we explain the curvilinear relationship between arousal and performance in terms of two monotonic relationships, one increasing and one decreasing (Fig. 11.6; Humphreys & Revelle, 1984).

Personality and Motivation

It is possible to categorize several different dimensions of personality as well as the effect of a variety of situational manipulations in terms of two motivational constructs: on-task effort and arousal. In everyday terms, effort can be associated with trying harder, arousal can be associated with alertness. In somewhat more formal terms, effort is an indication of the direction of action and arousal is an indication of the intensity of action.

The dimension of impulsivity, as well as situational manipulations such as time of day, stimulant drugs, or time on task, are related to arousal level. High impulsives are less aroused than low impulsives in the morning, equally aroused in the early afternoon, and more aroused in the evening. Stimulant drugs increase arousal, as do moderate increases in noise or light.[12]

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[12]Noise has contradictory effects, partly because moderate levels of white noise can mask other distracting stimuli. It is also likely that prolonged exposure to high levels of noise leads to fatigue. See Broadbent (1978) and Poulton (1978, 1979) for a more thorough treatment of the issues involved with noise.

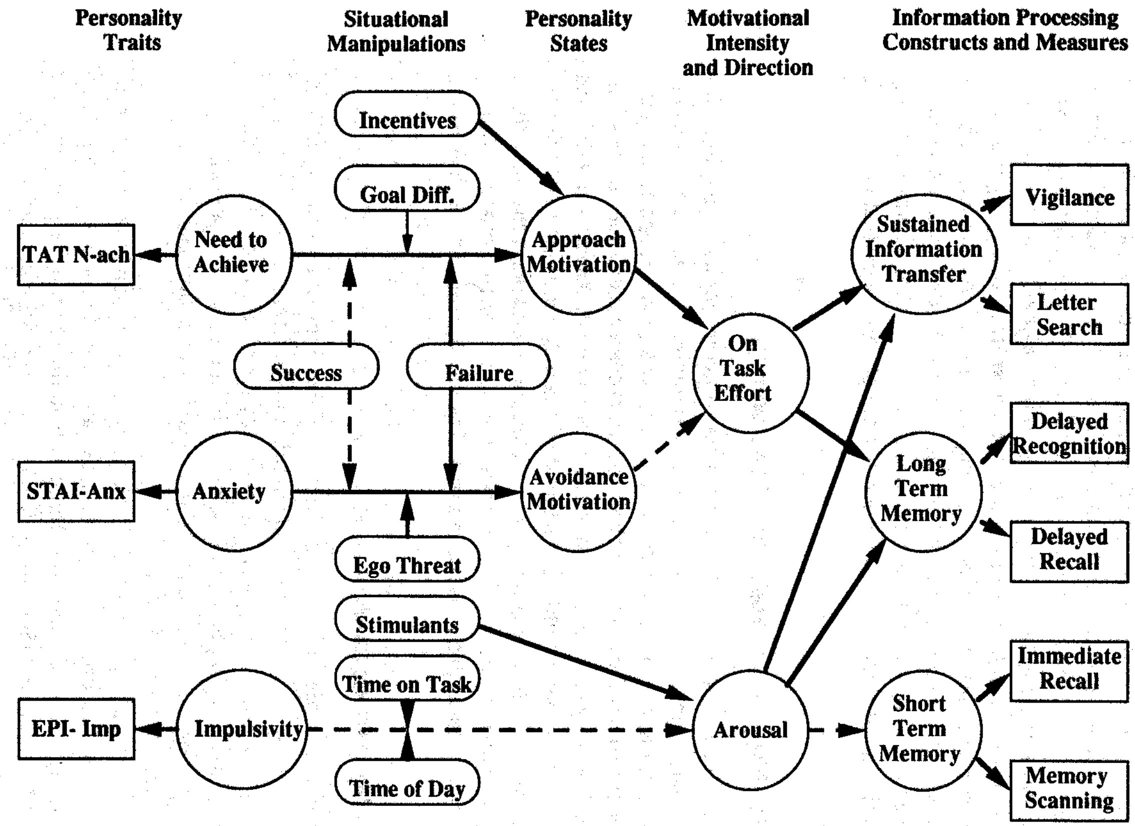

FIG. 11.6. A conceptual organization of personality traits, situational manipulations, motivational states, components of information processing, and performance tasks. Solid lines indicate positive effects; dashed lines, negative effects. Boxes represent observable measures, ovals represent experimental manipulations, circles represent unobservable latent constructs. Error variances for observable measures are not shown. (Adapted from Humphreys & Revelle, 1984.)

The personality dimension of achievement motivation may be associated with on-task effort. High achievement motivated subjects will spend more time, engage more frequently, and persist longer in tasks that require effort and reflect ability (Atkinson, 1957, 1964; Atkinson & Birch, 1978). Incentives such as money or other rewards as well as higher task demands (Locke, 1968) will also increase on-task effort. Success or failure feedback interacts with achievement motivation to affect on-task effort. For high achievement oriented subjects, failure feedback leads to an increase in effort, success feedback leads to a decrease in effort. Effort is typically assessed in the achievement domain by amount of time spent on task or by the frequency and persistence of choosing a task. Shifts in performance or preference for task difficulty over time can be interpreted as supporting the belief that failure leads to an increase in effort for high achievers (Revelle & Michaels, 1976) or for all individuals with a more rapid shift for high achievers (Kuhl & Blankenship, 1979).

Individual differences in anxiety are associated with both effort and arousal. High levels of anxiety can be associated with high levels of arousal. However, at least among college students, the effects of anxiety can most easily be interpreted in terms of a reduction of on-task effort. Failure feedback and ego-involving instructions increase state anxiety and reduce performance for trait anxious individuals. Success feedback, on the other hand, reduces anxiety and improves performance for highly anxious subjects. Many earlier demonstrations of the effect of anxiety on learning (e.g., Spence, Farber, & McFann, 1956) confounded task difficulty with feedback manipulations. (By their very nature, difficult tasks lead to more failure experiences than do easy tasks.) When feedback and difficulty are deliberately crossed (Weiner & Schneider, 1971), the effects of feedback account for the previously observed difficulty effects: Success feedback facilitates the performance of highly anxious subjects but hinders the performance of less anxious ones. Failure feedback, on the other hand, reduces the performance of high anxious subjects but improves the performance of the less anxious ones. These effects can be interpreted as showing that anxiety inhibits on-going behavior (Atkinson & Birch, 1970, 1978; Gray, 1982) or initiates inappropriate responses (Sarason, 1975; Wine, 1971).

Motivation and Performance

If personality and situations combine to affect two different motivational components, effort and arousal, then how are these components related to performance? To answer this question requires considering at least two different dimensions along which tasks can differ: Tasks can vary in the amount of resources they require for Sustained Information Transfer (SIT), as well as the amount of resources required for retaining information in an available state for short periods of time (Short-Term Memory—STM). Some tasks have a low STM load but require substantial amounts of SIT resources. Other tasks have a high STM load but require only moderate levels of SIT resources. Finally, some (complex) tasks require both large amounts of SIT and STM resources.[13]

Increases in either effort or arousal improve performance on SIT tasks. Both trying harder and being more alert facilitate performance on simple and choice reaction time tasks, letter scanning, vigilance, and simple proofreading. The pattern of results found by Bowyer et al. (1983) is typical for SIT tasks. The performance of high impulsives starts off at roughly the same level as that of low impulsives but then shows a pronounced drop within a few minutes of starting the task. The administration of caffeine inhibits this decay. Caffeine or diurnally induced arousal also facilitates the speed at which simple repetitive tasks can be performed. Anderson (1988) has shown that across five levels of caffeine and for both high and low impulsive subjects, letter scanning improved as a monotonic effect of caffeine. Blake (1967a) found that on tasks we would characterize as having a large SIT component, performance improved from morning to midafternoon. Folkard, Knauth, Monk, & Rutenfranz (1976) found that performance on a simple scanning task was positively correlated with the body temperature of (both of) their subjects when the subjects were on a cycle of rapidly rotating shift work.

In striking contrast to the effect of effort and arousal on SIT tasks is the effect of arousal on tasks that require the availability of material presented a few seconds earlier. A demonstration of this was the finding by Folkard et al. (1976) that when the memory load of a letter-scanning task was increased, the correlation with body temperature went from positive (low memory load) to negative (high memory load). High arousal, as indexed by body temperature, was associated with poor performance. In a conceptual replication and extension of Folkard et al., we found that caffeine facilitated performance on the low memory task but hindered performance on the high memory load version (Anderson & Revelle, 1983a). We have also shown that impulsivity and caffeine interact with memory load in a proofreading task (Anderson & Revelle, 1983b). The results of that study suggested that tasks with a higher memory load are more sensitive to arousal-induced decrements than are tasks with a lower memory load.

I have already discussed Folkard's study showing that the immediate availability of aurally presented material is hindered by high arousal. When discussing our replication and extension of this effect (Puchalski, 1988; Puchalski & Revelle, in preparation), I suggested that this effect is a demonstration of how personality affects the learning and storage of new material. It is the case, however, that this study can also be seen as supporting our hypothesis that arousal has a detrimental effect on some aspect of short-term or working memory. Subjects thought to be most aroused (low impulsives in the morning, high impulsives in the afternoon) made more errors than those who were thought to be

[13]There are, of course, many ways to index complexity. Degrading the stimulus in a signal-detection task will make it more difficult to detect, but the task is still not complex. I am defining complex as requiring both SIT and STM resources.

less aroused (low impulsives in the afternoon, high impulsives in the morning).

We have recently been exploring tasks that show how increases in arousal can have facilitatory effects on one information-processing component of the task and detrimental effects upon other components. In the first of these (Anderson, Revelle, & Lynch, in press), we examined how caffeine and impulsivity affected the ability to do a modified Sternberg memory-search task (Sternberg, 1969). Extending an earlier study by M. W. Eysenck and M. C. Eysenck (1979) that had examined the effects of personality on memory scanning, we varied impulsivity level, caffeine, and category match versus physical match (Burrows & Okada, 1976). The primary result of interest was that caffeine reduced the intercept but increased the slope of reaction time as a function of memory load. Intercept in such memory-scanning tasks is viewed as the time it takes to prepare to respond, whereas slope is seen as the amount of time it takes to process each item in short-term memory. We interpret our findings as lending support for the Humphreys and Revelle (1984) model and not supporting Easterbrook's hypothesis that arousal narrows the range of cue utilization (Anderson, 1981; Easterbrook, 1959).

The second study that compared performance on different task components made use of geometric analogies similar to those used by Mulholland, Pellegrino, and Glaser (1980). Our multiple-choice analogies are presented on a computer screen and response times and accuracies are taken for each problem (Onken & Revelle, 1984; Fig. 11.7). Problems can vary in the number of elements per term as well as the transformations per element.[14] Mulholland et al. (1980) suggested that transformations reflect memory load and affect accuracy, whereas elements merely affect solution time.

Using our computerized version of this task, Melissa Benzuly (1985) crossed 0 and 4 mg per kilogram body weight of caffeine with high and low impulsivity between subjects and varied the number of elements and transformations within subjects. Caffeine interacted with transformations but not with elements: Performance on low memory load problems was facilitated with caffeine, performance on high memory load problems was not (Fig. 11.8). In that the number of elements reflects the Information Transfer load of the task, and that transformations are related to the short-term memory load, these results are consistent with our two-factor model of performance.

In an earlier study using this same task, Margie Leon and I found that high anxiety led to slower and less accurate performance when subjects were under low time pressure but to faster and still less accurate performance under high time pressure (Leon & Revelle, 1985). We failed to detect the interaction of anxiety with transformations (i.e., memory load) predicted by M. W. Eysenck's (1979, 1981) hypothesis that anxiety reduces working memory capacity. We interpreted our results as supporting the Humphreys–Revelle interpretation of

[14]Mulholland et al. (1980) categorize their problems in terms of the total number of transformations, which will be simply the number per element times the number of elements.

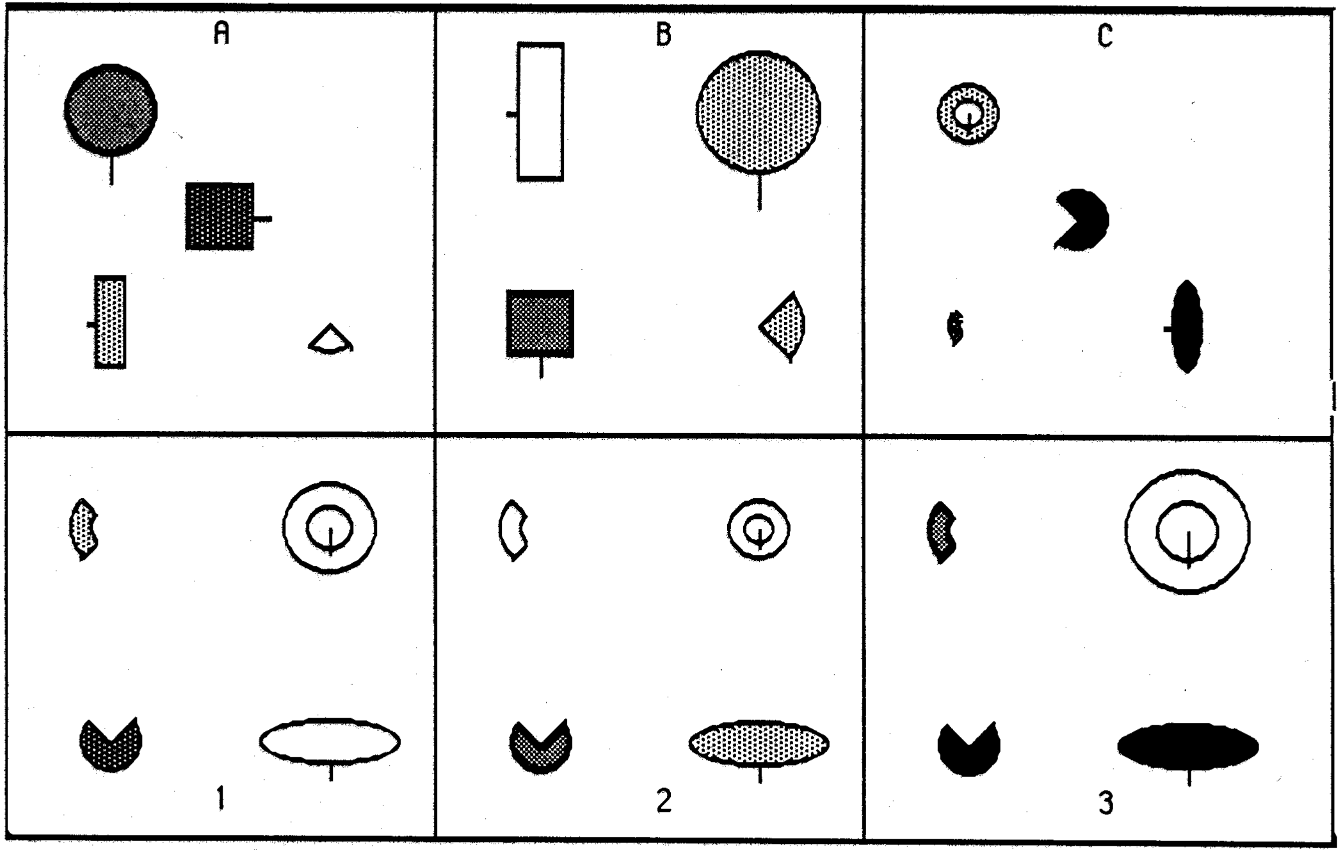

FIG. 11.7. A multiple-choice spatial analogy with four elements and three transformations per element. Problems can vary in the number of elements and the number of transformations.

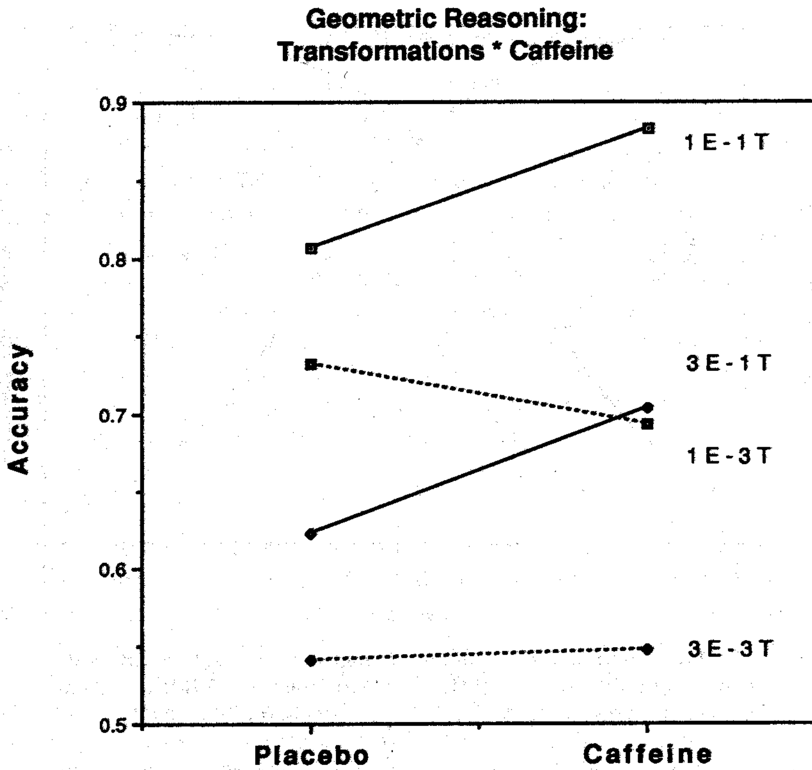

FIG. 11.8. Geometric analogy performance as a function of number of Elements (SIT load), number of Transformations (STM load), impulsivity, and caffeine. Task complexity is a combination of the number of Elements and number of Transformations: e.g., 1 E–1 T is a one element, one transformation per element problem (from Benzuly, 1985).

Sarason (1975) and Wine (1971) that anxiety reduces the amount of effort applied to the task.

In a recent review of many of these studies (Revelle, Anderson, & Humphreys, 1987) we have shown how caffeine has a facilitatory effect on those tasks that have a low memory load for all subjects. We have also shown that caffeine has either a detrimental effect or interacts with impulsivity to help low aroused subjects (high impulsives in the morning) but to hurt high aroused subjects (low impulsives in the morning).

To explain the results that have cross-over interactions (caffeine helps high impulsives but hurts low impulsives) and to explain rather than describe inverted-U relationships, we have argued that one must consider the combination of two monotonic functions. One of these is a monotonically increasing relationship

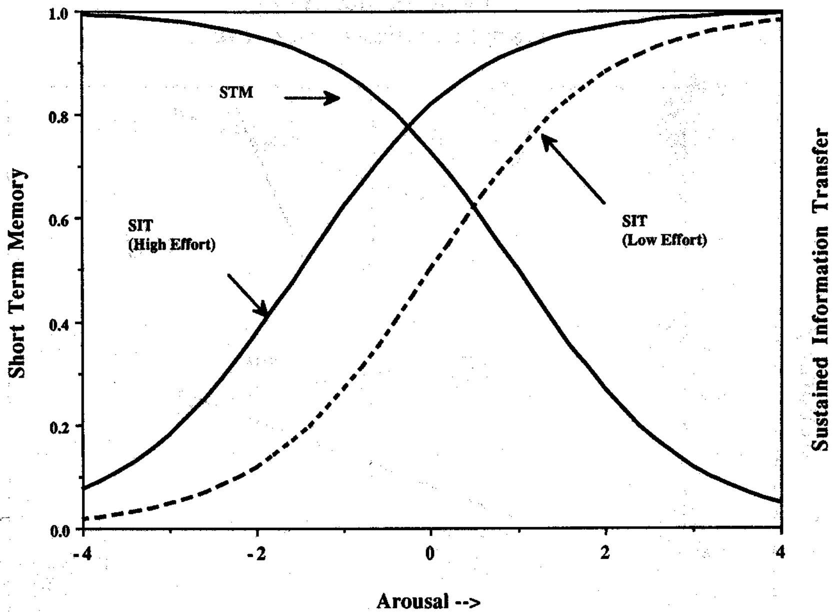

FIG. 11.9. Hypothetical relationship between arousal, effort, sustained information transfer (SIT), short-term memory (STM), and complex performance (adapted from Humphreys & Revelle, 1984).

between arousal and resources available for SIT. The other is a monotonically decreasing relationship between arousal and availability of working or short-term memory resources. A simple combination of these two functions can produce curvilinearity and furthermore can predict peak performance at lower levels of arousal for tasks with high degrees of memory load (Fig. 11.9). At low levels of arousal, performance is limited by a lack of resources for sustained information transfer. Response speed is slow and the probability of detecting new stimuli is low. Immediate availability of recently detected stimuli is high, but unhelpful, given the lack of SIT resources. As arousal increases, SIT resources increase with a decrease in availability of recently presented material. Performance improves until the decrease in immediate or short-term memory resources is greater than the gain in SIT resources. Performance at high arousal levels is memory limited, and improvements in speed or accuracy of stimulus detection do not compensate for the lack of availability in immediate memory. Increases in on-task effort increase SIT resources but have no effect upon resources available for working memory (Humphreys & Revelle, 1984; Revelle et al., 1987).[15]

[15]It is, of course, difficult to impossible to have a pure STM task. In that effort increases SIT resources available for detecting and encoding stimuli, effort can have a positive effect on immediate memory *tasks* even though we claim that effort does not affect the availability of information that has been encoded but is no longer attended to.

Multiple Levels of Analysis and Resource Trade-Offs

One important finding from much of our work is that the effects of various sources of motivation do not show similar effects, even though they are presumed to affect the same system. For example, Anderson (1988) found that increasing levels of caffeine facilitated letter cancellation, but that the presumably less aroused high impulsive subjects cancelled more letters than did the more aroused low impulsives. Puchalski and Revelle (in preparation), using the identical letter-cancellation task, found that although high impulsives cancelled fewer letters in the morning than in the afternoon (when they were presumably more aroused), the high impulsives also cancelled more letters than did the low impulsives (who were assumed to be more aroused). The lack of parallelism of impulsivity and either the caffeine or the time of day manipulations forces one to wonder why we claim that all are arousal related.

Multiple Levels of Analysis

The answer to this question is to realize that behavior is multiply determined and that performance on any one task will have several sources of variance. One source is arousal. Other sources that also affect performance are a *strategic* preference for speed versus accuracy and a *directional* tendency to engage in a task versus devoting time elsewhere. Yet another source of variability is *stylistic* differences in task choice and preference. Each of these sources of variance accounts for behavior at different levels of temporal aggregation.

Theories that explain behavior at one level do not necessarily explain it at another level. Stable personality dimensions such as anxiety and impulsivity can affect behavior at each of these levels in different ways. At one level, impulsivity combines with time of day to affect arousal. Arousal in turn affects the relative amount of resources available for SIT and for STM processes. At a broader level, impulsivity leads to a bias toward responding rapidly rather than accurately (Dickman & Meyer, 1988; H. J. Eysenck & M. W. Eysenck, 1985). This is probably due to a greater sensitivity to rewards and a tendency to respond on the part of the high impulsives. At this same level, anxiety leads to a bias to respond carefully, avoiding mistakes (Sabates, 1986). At an even broader level, anxiety increases the number of off-task thoughts, thereby reducing the SIT resources applied to the experimenter-defined task. And, at yet an even broader level, impulsivity and anxiety affect task choice. High impulsives prefer to engage in tasks that require rapid responding or have deadlines, low impulsives avoid such tasks. Highly anxious students will avoid classes in their major and devote more time to work on other projects (Atkinson & Birch, 1978; Atkinson & Raynor, 1974). It is possible that the effects at this level are also due to differential sensitivity to rewards, or alternatively, to learning from past experience. Highly impulsive students might wait until the last night to finish a term paper because they know that they work well under deadline pressure and are able to stay up until late at night working on the paper. Low impulsive students, on the other

Types of Resource Tradeoffs	Mechanism/ Measure	Personality Dimensions Impulsivity	Anxiety
Level I: Automatic SIT/STM	Arousal: facilitates SIT impairs STM	Caffeine on complex tasks: facilitates high Imps hinders low Imps	
Level II: Strategic Speed/ Accuracy	Sensitivity to reward Sensitivity to punishment	High Imps fast Lows Imps accurate	Low Anx fast High Anx accurate
Level III: Directional Effort	Allocation of effort to on task or off task thoughts		Low Anx on task High Anx off task
Level IV: Temporal/ Stylistic Choice, Frequency	Latency to initiate task Persistence on task Act frequency	Low Imps slow to initiate but persistent High Imps fast but not persistent	Low Anx choose challenging tasks High Anx avoid possibility of failure

FIG. 11.10. Multiple levels of trade-offs related to impulsivity and anxiety (adapted from Revelle, 1987).

hand, might learn that they do not function well under time pressure nor can they work all night. As a consequence, they will learn to better budget their time and start the work well ahead of time.

These distinctions between different levels of analysis can be used to organize some of the effects of individual differences upon performance. At each level, different trade-offs are involved, and different mechanisms are presumed to operate. The personality dimensions of impulsivity and anxiety have effects at several of these levels, but the causes for the effects can be quite different. These levels of analysis may be organized figurally with trade-offs arranged in increasing order of the temporal breadth of the effects (Fig. 11.10).

Given the concept of levels of analysis, it is easy to see why a manipulation that interacts with a personality trait at one level does not necessarily have the same effect at another level.[16] Caffeine interacts with impulsivity to affect performance by increasing arousal and changing the relative amount of resources

[16]Another form of levels of analysis is to consider data at the subject level versus the aggregate level (Anderson, 1988). All of the analyses discussed here are at the group level, where data are aggregated across subjects. The underlying assumption here is, of course, that such aggregation preserves the relationships that exist at the subject level.

available for immediate or delayed processing. It is unrealistic to expect caffeine to change the speed–accuracy trade-off strategy of a subject or to turn a procrastinating high impulsive into a conscientious low impulsive. Similarly, changing the payoffs for speed versus accuracy will change performance strategies but affect neither SIT nor STM resources.

Performance Efficiency and Resource Trade-offs

An important question to ask once again is why should performance not be maximal? Why should performance not demonstrate level of competence? To Blodgett or Tolman and Honzik, the answer was easy. Without food as an incentive, the rats did not need to perform; the rats had better ways to use a scarce resource: their time or their energy. Why run down a maze if there is nothing in the goal box? Why not just spend the same amount of time strolling through the maze looking for other ways to get out?

In more formal terms, performance of several tasks with shared or partly shared and limited resources will involve trade-offs between those resources. If multiple resources are required for each task, and if these resources are limited to some extent, then performance along one dimension may reduce the resources available for the other dimension. To the extent that resources are limited, maximal performance along one dimension will typically result in submaximal performance along the other dimension. The analysis of performance along both of these dimensions will result in an performance operating characteristic (POC) curve showing the degree of trade-off between them.

In our work, the differential effect of arousal upon SIT, STM, and LTM (long-term memory) resources can be analyzed in terms of such trade-offs. High arousal facilitates the ability to respond rapidly, but at a cost of reducing the availability in memory of recently occurring events. This trade-off is beneficial in a situation where a premium is upon rapid responding without much processing of what has led up to the situation. An additional benefit of high arousal is that even though there is a temporary unavailability, events are remembered better later. When one is required to work rapidly *and* process stimuli that are no longer present (i.e., use working memory) increases in arousal lead to increases in net performance if one is initially not very aroused, but to decrements if one is already aroused.

Trade-offs also occur at the strategic level. Impulsives typically make use of a strategy that puts a premium on speed rather than accuracy. It is possible to change this strategy by instructions and make low impulsives respond more rapidly or to make high impulsives respond more slowly. There are indications, however, that each group performs best when using their normal strategy (Dickman & Meyer, 1988). Anxiety is also related to this strategic trade-off of speed for accuracy (Geen & Kaiser, 1985). For instance, Angela Sabates found that a self-report measure of test-taking strategies involving a preference for accuracy rather than speed correlates very highly (.5–.7) with various anxiety scales (Sabates, 1986). Other trade-offs occur between doing the experimenter-defined task versus doing the subject-defined task (such as maintaining self-esteem) or between choosing to do one task versus another. Trade-offs are particularly important at these broader levels and involve a consideration of the various ways of measuring preference. We follow the logic of Atkinson and Birch (1970, 1978) in proposing that preference can be measured by choice (choosing to do A versus B), latency (delay in initiating B when doing A), persistence (in a two-task situation, persistence of A is the same as the latency of B), frequency (how often is A done), or total time spent (frequency of A times average persistence). Although frequently correlated, these measures are not identical in any dynamic system (Atkinson & Birch, 1970, 1978; Revelle, 1986).

Cumulative Performance

Finally, when discussing cognitive competence and performance, it is important to note that performance over the short run is not the same as cumulative performance summed over a long period of time (e.g., 4 years of academic performance as measured by grade point average (GPA) for an undergraduate, or a lifetime of productivity as measured by the total number of patents issued for an inventor). Cumulative performance is the sum of many separate acts that themselves are a function of individual differences in ability and moment-to-moment fluctuations in efficiency of performance. Issues of concern for the study of cumulative performance include all the variables relevant to momentary performance as well as determinants of total time spent engaging in the relevant activities. Even a very able student's GPA, for instance, will not be very high unless he or she spends considerable time in academic rather than social activities. Thus, the study of cumulative performance is concerned with the broader stylistic issues of task choice, frequency, and persistence, as well as the narrower issues of moment-to-moment efficiency. (For a more detailed consideration of cumulative performance, see Atkinson, 1974, and Revelle, 1986.)

Personality, Cognition, and the Psychological Spectrum

As a way of relating these multiple levels of trade-offs to fundamental issues in personality and cognition, it is useful to organize psychological phenomena in terms of their average duration (Fig. 11.11). At this conference we have heard reports of measures that range over 12 orders of magnitude: from discussions of neural firing rates lasting a millisecond (10^{-3} seconds) to cumulative performance over a lifespan representing 95 years (3×10^9 seconds). To some extent, psychological theorists tend to specialize at different parts of the spectrum: Psychophysiologists examine high frequency–short duration events (e.g., rates of neural transmission, frequency of resting EEG alpha activity, heart and

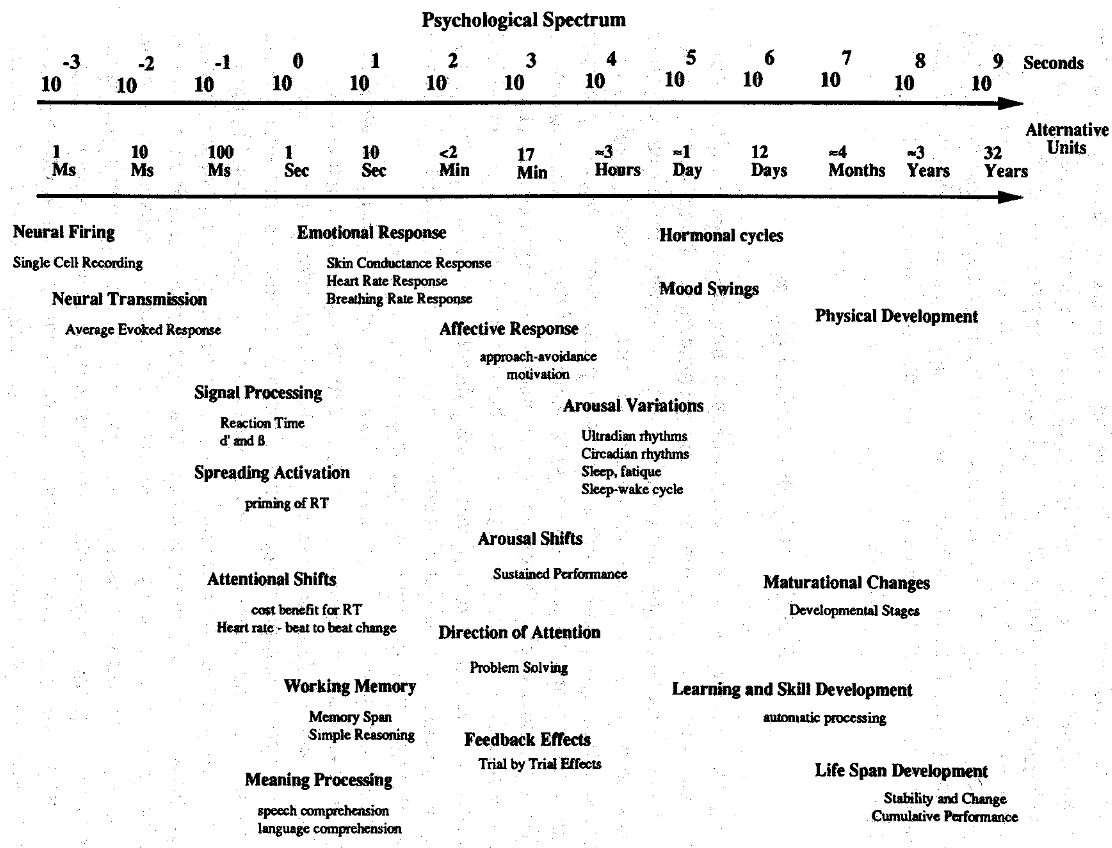

FIG. 11.11. The Psychological Spectrum: An organization of psychological phenomena across 12 orders of magnitude.

breathing rates, and skin conductance responses); cognitive psychologists tend to specialize in events ranging in duration from 100 milliseconds (e.g., priming effects in reaction time) to 10 seconds (e.g., limits of working memory); theorists of affect examine emotional-affective responses that are seen as lasting for periods ranging from a few seconds (emotions) to a few hours (moods); developmental psychologists examine growth and change indexed in months (3×10^6 seconds) to life spans (3×10^9 seconds). Individual differences occur at all parts of this Psychological Spectrum. It is only in conferences such as this that the full range of the psychological spectrum can be examined and the degree of relationship of individual differences across this range of temporal frequencies can be studied.

SUMMARY AND PROSPECTS

In this chapter, I have reviewed how an understanding of personality allows for a clearer distinction between competence and performance. The stable personality dimensions of impulsivity and anxiety, in combination with situational stressors such as time pressure, feedback, or particularly time of day and caffeine, have systematic, although complex relationships to performance. Without a proper theoretical framework, these results make it seem as if there is no consistency in the effects of individual differences in personality on performance. That is, I hope, an error. Consistency in results exists, but one needs to consider individual differences at multiple levels (physiological, directional, strategic, stylistic) as well as to consider how different components of tasks (SIT, STM, LTM) will respond differently to different motivational states.

We need to consider at least seven classes of variables: (a) individual differences in stable predispositions; (b) manipulations such as stimulant or depressant drugs, time of day, or time on task that change physiological state; (c) cognitive/affective manipulations such as feedback, incentives, or threat; (d) the resulting motivational states of arousal and effort that reflect a combination of stable traits, physiological manipulations, and cognitive/affective manipulations; (e) stylistic and strategic components of task performance that include preferences for speed over accuracy or a sensitivity for reward versus a sensitivity to punishment; (f) the differences in task components and requirements such as the demands for sustained information transfer and retrieval of recently or not-recently presented information; (g) and finally, the many ways in which we can measure outcomes such as accuracy, speed, persistence, frequency, or latency. When these seven classes of variables are considered, consistent patterns emerge. Moreover, when one does not pay attention to the complexities involved, there seems to be a hopeless confusion of results. Sophisticated methodologies, as have been proposed at this conference, will only be of use when applied to appropriate data to test adequate theories.

OPEN DISCUSSION

Discussion following Revelle's talk started with a clarification of the meaning of the effort construct. Further discussion focused on the relations between impulsivity, learning, and intelligence. Additional questions were devoted to the variance-accounted-for in Revelle's higher-order interactions, to the tactics of aptitude-treatment interaction studies, and to strategies for the experimental manipulation of effort and arousal.

Mulder: What are the psychological mechanisms underlying effort in your model? What does effort do?

Revelle: I think of effort as the volitional focusing of attention, that is, the focusing of an individual's resources. Atkinson, for example, has suggested that effort refers to the subjective feeling of trying hard and feeling more alert. The important theoretical question is whether there is a path between increases in effort and increases in arousal. For instance, it is the case that you cannot will yourself to be awake via effort. If you try driving a long distance, or sitting in a long colloquium, you often cannot keep yourself awake no matter how hard you try. So I am not sure how effort is going to change the amount of resources available, but it may change the allocation of those resources. I think of effort as changing the allocation of resources to the experimenter or to the salient task. Effort is what most people think of as motivation. In fact, I try to add the word arousal to our motivational constructs. I think it is an unfortunate tendency to just think of effort when we say that a person is motivated. We mean that the person is trying hard, but there is also more involved—the intensity or arousal component. In a historical sense, we have rediscovered the D and K components of drive theories. I am quite willing to map arousal fairly closely into D. With respect to incentives and motivation, I would relate those to K. Spence's K component. As you can see, there are not that many new concepts being developed. We are just relabeling them and trying to change our terminology.

Kleinbeck: I have no problems with your simple models, but could you please help me understand the interactions between impulsivity, arousal, and time of day? Specifically, I don't recall you saying that you had controlled for effort in these experiments. If you did not, perhaps effort is a variable that affects your data. Thus, could effort be viewed as a kind of confounding variable?

Revelle: We did not control for effort. What makes me think that it [effort] is not a confounding variable, though, is that we have looked at anxiety manipulations, which we think relate to effort (i.e., trait anxiety, state anxiety) in all of these studies. Routinely, we do not find the same pattern of interactions. That is, the pattern of interactions we get with caffeine or time of day manipulations almost never interact with our anxiety or incentive manipulations. And the things that anxiety or incentive manipulation variables affect almost never produce patterns of results similar to those we obtain with the caffeine manipulations. So what we are really getting from our results are two different patterns of effects.

As I indicate in [Fig. 11.6], there are different categories of variables that we need to look at; for example, the set of personality variables, such as impulsivity, anxiety, achievement motivation, if you will. And then there are physiological manipulations, such as time of day, caffeine, how long you have been working at the task. The effects of the physiological manipulations are very different from the effects of our cognitive manipulations, such as feedback, threat, and incentives. They are a different category of variables. Subjectively, one can feel that they are trying very hard when they are aroused. But you can be aroused yet feel that you are not trying very hard. I think you need to look at each one of these sets of variables as having different types of effects.

And yet another type of variable pertains to the type of measure you take. This was discussed yesterday by Dave Lohman. Although theoretically related, accuracy, speed, persistence, frequency, and latency give different patterns of results.

In summary, I don't think that effort differences here present a problem, although we have not controlled for it. When we do look at the effect of anxiety, it is always different from arousal effects; anxiety variables just do not have these interactions with memory load or caffeine or time of day, for example. We always look for it, but we don't find it.

Ackerman: Let's consider impulsivity and learning. If I understand your figures correctly, you would expect that a high impulsive student who is sitting through the classroom lecture would have a very difficult time learning; his/her performance at the end of the day should be less than the low impulsive student?

Revelle: During the morning.

Ackerman: But not so in the afternoon?

Revelle: Yes. If we look at our time of day by learning study.

Ackerman: Given that school runs from 8 o'clock in the morning to 3 o'clock in the afternoon, does it average out so that low impulsives and high impulsives have the same intelligence?

Revelle: The high impulsives have been discriminated against. In 1912 Gates did a study suggesting that we should teach complex topics in the morning and schedule gym and art in the afternoon. I take pity upon the poor high impulsive student who has an 8 o'clock a.m. math class. This student may be really good in the class and have no recollection of it the next day. The one thing that is in their favor, however, is that when they take the stressful exam at the end of the quarter, they may perform well because they are not peaked out—they are not overaroused.

Jenkins: But homework comes at night. So would that be to the high impulsive student's advantage?

Revelle: Maybe—if they can remember to do their homework! The problem with our high impulsives is that they are not very conscientious. They are not going to be doing their homework. But the time of day by learning interaction obtained in our research was done in the school setting. And the conclusion of this study is quite clear. You are being misled if you think that your high impulsive students remember the material right after it has been taught. Teachers often say, "Oh, this kid is not trying hard. He knew it in the classroom but he didn't remember it the next day." In my view, it is not a matter of trying hard—the poor kid was asleep! If I were to give recommendations to educational personnel, I would say that they should have these high impulsive students take their classes later in the day. Have them take gym early in the morning. The first class for a high impulsive student should be something to get them going—something like gym.

Ackerman: But it seems that the cards are stacked against the high impulsive student in today's society. One hypothesis, for example, would be that high impulsives have lower intelligence, as measured at adulthood, than low impulsives.

Revelle: I am not going to respond to that immediately. However, I will point out one interesting finding in that regard. Students in our high school sample were much more impulsive than students who had gone on to Northwestern University. So there does appear to be some weeding out of out high impulsives by the time of college. And perhaps it is the low impulsives who are doing the conscientious schoolwork. But I won't say that the high impulsive is less intelligent. With caffeine, for example, a high impulsive can outscore a low impulsive by 100 SAT points.

Ackerman: So we should give coffee to our high impulsive children before they go to school in the morning?

Revelle: We do—it's called Ritalin. That is what is given to hyperactive children. And the alternative is that you don't give them Ritalin but instead have them wait a couple of hours before taking the complex topic classes. Instead, give them gym first thing in the morning.

Cudeck: Do you remember the approximate size of your three- and four-way interactions? Your designs are quite complicated and I wonder if the interactions are big or discardable interactions, like some of the two-way interactions you obtained in the simpler experiments.

Revelle: Let's go back to the time of day data and talk about variance accounted for in those interactions. In that study [see Fig. 11.3, Puchalski & Revelle, in preparation], when we used ability as a covariate, straight ability measures predicted reading comprehension and accounted for about 11 percent of the variance. When we added short-term versus long-term retention, that added about another 4 percent of the variance. When we added retention interval, time of day, and the interaction of retention interval and time of day, that added another 4 percent of the variance. When we added impulsivity, and all the two-way interactions with impulsivity (none of which were significant), and the triple interaction of impulsivity, time of day, and length of retention, we got up to a total of 25 percent of the variance. So it is about 7 percent on that one triple interaction. And the important thing to point out here is that this is really an extra 12 percent over and above the ability component.

Cudeck: Right, and that indicates that your interactions are not just down to the level of noise because you still have a lot of power. That is, these interactions still describe stable, replicable phenomena that the average individual differences psychologist should consider.

Revelle: Yes, the interactions are not trivial effects. For instance, we report our findings in standard score units so that one gets a fair feeling of the effects. For example, we have standardized the total recall score and these are one standard deviation effect sizes.

Cudeck: OK. Now on to a harder question. Your data suggest some major rethinking in the area. How would you design a series of experiments to investigate intellectual performance, individual differences, and your personality and arousal variables? How can one account for so many possible influences?

Revelle: With good theory. One of the arguments made against looking at interactions is that there are all kinds of possible interactions. For example, think of all the possible triple interactions. That is why we have used simple theories as a way of conceptually organizing the data.

With respect to future research, I would suggest that researchers with access to thousands of subjects routinely include marker variables for some of these personality traits.

Cudeck: But would it be practical to include so many measures? Which specific measures would you suggest be included?

Revelle: Well, obviously measures of impulsivity and anxiety. Those two variables work pretty well. In terms of the personality taxonomy projects in the United States, a structure of three to five dimensions of personality seems to do a good job. For example, my concept of impulsivity maps fairly well with Norman's conscientiousness factor; anxiety and emotional stability factors are clearly the same.

I would tend to use at least three of the "big five" factors as marker variables. And I would tend to use the ones that adopt the biological perspective put forth by those in England. The problem with the big five factors as developed in the United States is that the rotations are arbitrary and depend on the simple structure rotation criterion the researcher likes to use. In contrast, the Europeans tend to rotate to simple structure of tasks, to rotate their personality factors to task simple structures. Impulsivity is a terrible variable in terms of the unreliability of measurement. But it does relate to a lot of performance tasks.

In addition, I would look at some measure of achievement motivation and I would avoid, if possible, the Thematic Apperception Test (TAT) versions of the achievement motivation construct. And I would include some measure of self-reported effort and willingness to engage in challenging tasks. Those measures also tend to do fairly well.

Cudeck: One final question. Do you think that by using designs that include these individual differences variables, researchers will show that the relationships reported are too low—that by studying them in this fashion the effects will be disattenuated?

Revelle: I think that the result will be that motivational components will disattenuate the relationships between ability measures and performance measures. That is the clear implication of our regression model. We find 12 percent of the variance accounted for by ability and another 13 percent accounted for by these motivational manipulations interacting with the situation. Researchers should be looking at personality and motivation, as well as cognition.

Ackerman: When you do include ability measures, are there any interactions or is it just a . . .

Revelle: Ruth Kanfer asked me about that earlier. Unfortunately, I have not yet looked at any interactions of ability by the personality variables. I suspect, however, that I will not get that kind of aptitude-treatment interaction. I don't know why I never bothered to do that quadruple interaction.

Ackerman: In concert with Pat Kyllonen's discussion about working memory, it seems that it is not just a matter of increasing working memory or decreasing working memory that has to with these other interactions. If you have a threshold of working memory, then it ought to be sufficient for doing the task whether you are very much awake or not very awake.

Revelle: In that sense, there should be a ability by task by motivational state interaction because we are setting a ceiling of resource limitation. However, it probably will not be a disordinal interaction. I prefer disordinal interactions because I like to make sure the effects are not due to scaling artifacts. Many kinds of interactions that we might obtain would just be ordinal interactions.

Kyllonen: Since these variables you have discussed are so important, I am interested in learning more details about the methodology one should use. First of all, am I correct to assume that you typically do not manipulate effort?

Revelle: We have manipulated effort in a couple of studies, primarily in our caffeine studies. In those studies we tell people to try harder and we have attempted to sweep out speed–accuracy trade-offs by telling people to go slowly and accurately.

Kyllonen: But for the most part, then, you just get self-report measures of effort. With respect to arousal, however, you do manipulate arousal by amphetamines or caffeine, or whatever. Are there any other manipulations that you can think of? Also, what do you use as a manipulation check, other than performance on a task?

Revelle: Self-reports of arousal do, in fact, go up with caffeine. We have avoided doing physiological manipulation checks mostly because we don't have the time to simultaneously measure physiology as well as our other variables. Enough other people have shown, however, that caffeine is a stimulant. So I don't bother to show in every study that caffeine does indeed stimulate the individual. We run our studies as double blind studies, using a placebo for caffeine. So that subjects can't taste the difference, we put the caffeine in Tang and cut it with quinine water. It tastes terrible. Some people claim that they can taste the difference but I do not think they can do it reliably. Subjects just know that they are getting an evil concoction.

Kyllonen: Well, I guess it is pretty clear with caffeine. But what about other ways to manipulate arousal?

Revelle: Well, a brisk walk around the building, or standing up at one's seat. Bob Thayer has used exercise as a manipulation. But a lot of people use standing up versus sitting down. This manipulation gives you differences in heart rate and body temperature. Thayer has looked at a lot of self-report measures of alertness, peppiness, activeness, and vigorousness. In fact, these measures do track the pattern that I have been arguing for. The advantage of caffeine is that it is a fairly simple manipulation. The disadvantage of anxiety manipulations is that it is really difficult to convince subjects that they should be frightened, or differentially frightened. They are terrified when they see these geometric analogies—that's bad enough. But I find that it takes more acting ability to do the anxiety manipulations; I far prefer the caffeine manipulations. It also depends partly on my graduate students—whether they like caffeine or anxiety manipulations.

Jenkins: Is there any other way to alter arousal?

Revelle: Alcohol. But the problem is that the predictions are dull. The nice thing about caffeine manipulations is that you predict crossover interactions. With alcohol, you predict that everybody will get worse. That's no big deal. Also, you get a lot of drunks in your lab if you use an alcohol manipulation.

There is also Valium. Research on the effects of Valium on short- and long-term memory gives some interesting results. Things that are learned under Valium result in poor recall for those events. This is why dentists use Valium for surgery—you don't remember that you were in pain when you come out. Valium has that effect and amphetamines have the opposite effect. Some nice Dutch studies investigating the effects of amphetamines on long-term memory provide a very clean pattern of results.

Kazén-Saad: One of the classic definitions for Eysenck was motor reminiscence, that is, improvement in motor performance after a break. I think a modern equivalent to that notion is this phenomenon of hypermnesia, that following an initial level of learning, there is increased memory performance after repeated attempts. I wonder whether the classical distinction between learning and performance has something to do with this phenomenon. Perhaps high impulsives can recall better and then demonstrate a decline in performance without being exposed to the material again? Have you considered that possibility?

Revelle: Actually, no. One of the things that we are thinking about doing is to sweep out the time of day effect. What you are suggesting is that we sweep out over the delay effect. We have not done that yet.

Let's go have some caffeine.

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