Chapter Seven

MOTIVATION AND EFFICIENCY OF COGNITIVE PERFORMANCE

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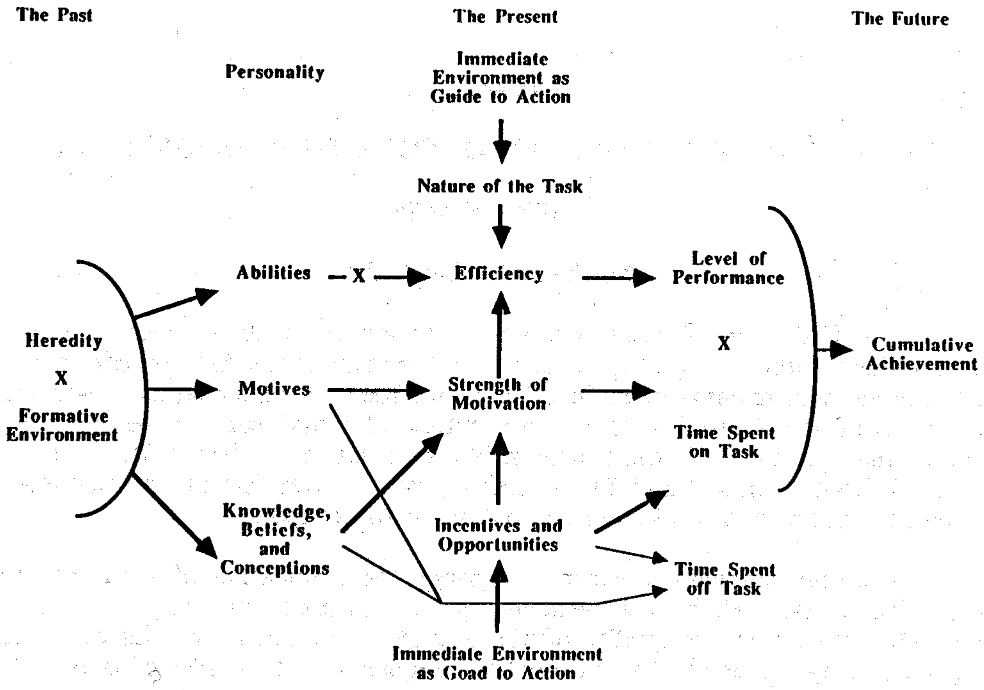
It is fitting in a book written in honor of Jack Atkinson's lifelong contribution to the study of personality and human motivation to consider the motivational determinants of cumulative achievement. In this chapter I will show how parts of the theoretical framework outlined by Atkinson can be filled in to answer the question of what determines cumulative achievement. Figure 1 (adapted from Atkinson and Birch, 1978) gives an overview of the richness of Atkinson's theory, and will serve as an outline of this chapter.

Achievement over a lifespan is logically the cumulation of many separate accomplishments. High achievement is a function of the number of accomplishments and the quality of the average accomplishment. Each of these single acts may differ in absolute quality; frequency and number of outstanding achievements will also differ between people. Évariste Galois and Albert Einstein are known for a few profound insights; Thomas Edison and George Carver are remembered for a lifetime of high productivity. Hank Aaron and Walter Payton have set records in professional sports based partly upon high average levels of performance, but based also upon long and productive careers.

The level of performance on a single task is a function of ability and the efficiency with which the task is performed. Efficiency, in turn, depends upon the nature of the task, and the strength of motivation to engage in that task. Tasks can differ in their difficulty, their importance, and their intrinsic interest. In addition, tasks can differ in the type of cognitive resources they require. Recent work in cognitive psychology allows us to analyze tasks in terms of various components of information processing, and to consider how motivation can effect efficiency in a number of different ways. Efficiency can be analyzed in terms of the tradeoff between spending time doing one class of tasks (e.g., achievement) versus another class (e.g., affiliation), in terms of task choice (whether to do the experimenter defined task or to do the subject defined task), in terms of strategic tradeoffs between working rapidly and working accurately, and in terms of tradeoffs between cognitive resources (e.g., those required for short term memory versus sustained information transfer).

Time spent on a task is a function of the strength of motivation to engage in

FIGURE 1. The multiple determinants of cumulative achievement. (Adapted from Atkinson and Birch, 1978).



that task, as well as the incentives and opportunities to do the task or to do something else. Alternative measures of motivation include choice, latency, persistence, frequency, and total time spent, and can be seen as different levels of measurement of the same underlying construct.

All of these analyses depend upon decomposing the strength of motivation into two components: direction and intensity. Some motivational effects are best explained by their directional characteristics, others (particularly the effect of motivation upon components of information processing) are best understood in terms of their intensity. Central to this decomposition is Atkinson and Birch's (1970) analysis of the dynamics of motivation as a function of time.

Strength of Motivation: The Implications of the Dynamics of Action

Perhaps Atkinson's major contribution to the study of cumulative performance was his work with David Birch which introduced the dimension of time to the analysis of motivational strength and direction. This work was an outgrowth of earlier work by Lewin and other Gestalt psychologists (e.g., Zeigarnik, 1927/1938), Feather (1961), as well as a paper with Cartwright (Atkinson and Cartwright, 1964). The fundamental idea was the recognition that the initiation of an activity should be analyzed in the same manner as the persistence of an activity: the latency of onset of an activity is equivalent to the persistence of not doing that activity.

Although a seemingly simple point, this realization provides a common language for the analysis of choice, persistence, latency, frequency, and time spent. That is, the simple act of choosing to initiate B rather than C after doing A can be analyzed in terms of the choice (B or C), the persistence of A, and the latency of B. If choices are allowed in an unconstrained manner, it is possible to find the frequency of choosing B over C, as well as the total time spent in activities A, B, or C.

In addition, by changing from a static to a dynamic perspective, the issue of what behavior was occurring before the current one becomes of vital importance. That subjects recall more unfinished tasks than finished tasks (Zeigarnik, 1927/1938), or that non-anxious subjects perform better following failure than following success (Weiner & Schneider, 1971) is understandable within a dynamic framework, but hard to understand within a static perspective.

The Dynamics of Action (DOA)

An early formulation of this dynamic model (Atkinson, 1964) considered that the strength of tendency to do r in order to achieve the goal g, ($T_{r,g}$) was greater if there were some unsatisfied "inertial" tendency to achieve success. The inertial tendency was associated with Lewin's need or intention which was thought to persist until satisfied.

Formal specification of this model was provided by Atkinson and Birch (1970) who realized that the combination of inertial tendencies and changes over time could be expressed by differential equations. This meant that the analysis should change from specifying motivational tendency to specifying rates of change in tendency. An advantage of the dynamic model was that it forced investigators to investigate the time course of the behavioral stream. No longer was it possible to assume trial to trial or task to task independence, but rather it was necessary to be explicit in how to treat the different amounts of satisfaction one obtained by succeeding versus failing on a task in order to understand performance on the subsequent trial.

A simple application of the inertial tendency assumption was the demonstration by Revelle and Michaels (1976) that some data which seemed to contradict the conventional theory of achievement motivation (Atkinson, 1957) could be well fit with the addition of inertial tendencies. As Heckhausen (1967) and Hamilton (1974) had shown, persons with a high need for achievement tend to prefer tasks with a probability of success somewhere between .3 and .4 rather than the .5 predicted by Atkinson (1957). Further problematic data had been reported by Locke (1968) who had shown that subjects try harder the harder the goal that they set. When the assumption of inertial tendencies ($T_{sk} = T_{s1} + c_f T_{sk-1}$ following failure but $T_{sk} = T_{s1}$ following success) was added to the traditional (Atkinson, 1957) theory $[T_{s1} = M_s P_s (1-P_s)]$, Revelle and Michaels (1976) showed that Hamilton's data and Locke's data could be fit quite well.

A more elegant extension of this point was made by Kuhl and Blankenship (1979 a,b) who completely integrated the Atkinson (1957), Atkinson and Birch (1970), and Revelle and Michaels (1976) perspectives. Kuhl and Blankenship (1979a) provide an excellent theoretical treatment of the relationship between the traditional theory of achievement motivation (Atkinson, 1957) and the dynamics of action (DOA, Atkinson & Birch, 1970). Kuhl and Blankenship (1979b) provide empirical support for the prediction that risk preferences should shift over time from an initial preference for intermediate difficulty to a later preference for more difficult tasks. (See also Schneider and Posse's (1982) suggestion that such shifts can be understood in terms of a win-shift, lose-stay strategy.)

Although analytical solutions to the DOA model could only be estimated asymptotically, by approximating the model in terms of a set of difference equations, it was possible to develop computer simulations of the model. Many of us can remember the excitement of testing alternative theoretical assumptions by comparing how the "spaghetti" behaved as assumptions were varied. These simulations showed both the strengths and the weaknesses of the model. It was clear from the simulations that several parameters of the model (the instigating and consummatory lags) which are necessary to make it work have rather fuzzy coordinating definitions in the theory. Yet another difficulty in the DOA is that although the decision rule of what leads to a change in behavior is well specified, it is less clear how the decision is made.

Stimulus-Need-Response Model 1

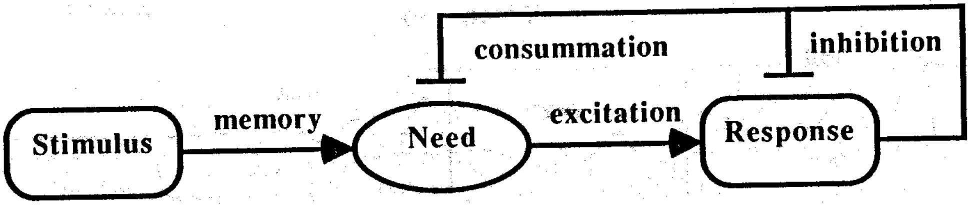
An alternative model to the DOA, which maintains many of the same assumptions but is mathematically simpler, can be derived from concepts developed by British "control theorists" of animal behavior (e.g., McFarland, 1974, Toates & Halliday, 1980). This model has one exogeneous independent variable (the input stimulus), an intervening variable (a need or covert response), and one observable output variable (the overt response). The basic assumption in this model is that a stimulus excites a need, a need excites a response, and a response reduces the need. This may be shown figurally as a box or flow diagram (Figure 2).

This path model may be formalized in terms of the following two differential equations relating stimulation (S), need (N), and response (R) with the constraint that $R \geq 0$:

$$dN = mS - cR \tag{1}$$

$$dR = eN - iR \tag{2}$$

FIGURE 2. A control system model of the interrelationships of stimulus, needs, and responses. Stimulus and response are observable variables, need is an unobserved latent variable.



The coefficients are: m, the strength of the memory associating the stimulus to the need; c, the amount of the consummatory effect of the response on the need; e, the strength of the excitation that a need induces in a response; i, the inhibition or fatigue that making a response has upon that response. The constraint $R \geq 0$ is imposed by assigning all negative values of R to 0. When equations (1 and 2) are simulated and need and response are plotted against time, need and response will achieve stable values (Figure 3).

As should be obvious from the equations, with constant stimulus S, need will achieve an asymptotic level: $N = iR/e$. At this level, response strength will have value $R = mS/c$, and thus, by substitution, need will have the value of $N = imS/ec$. This system is equivalent to several of the systems discussed by Bolles (1980) who showed how a system can achieve an equilibrium without necessarily having a homeostatic set point.

Generalized Stimulus-Need-Response Model (SNR)

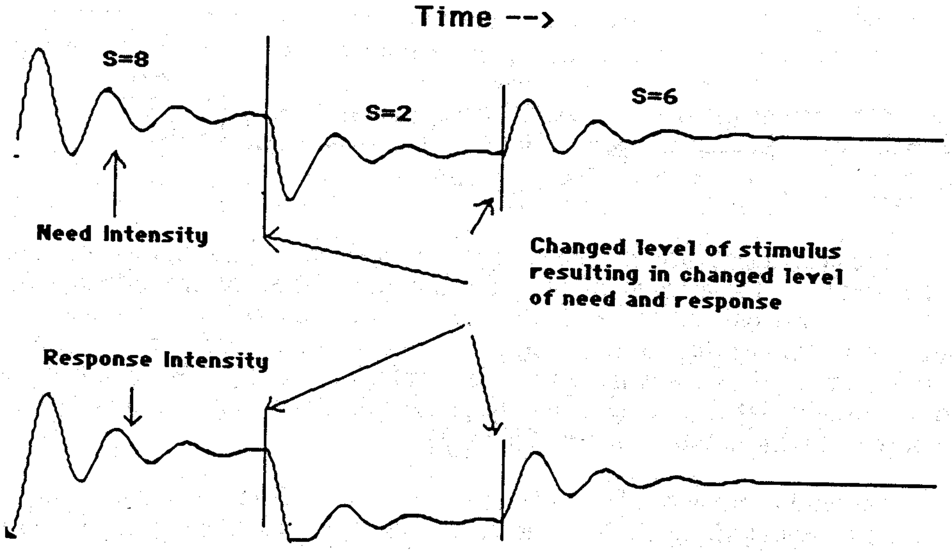
Such a system becomes more complicated (and more interesting) if we consider S, N, and R to be vectors of stimuli, needs, and responses, and introduce the concept of response incompatibility. If doing A is incompatible with doing B (an interesting example of such incompatibility is found in the newt which breaths at the surface of ponds, but copulates under water, Halliday, 1980), then responses can be said to inhibit each other and we have a system which may be seen graphically (Figure 4) or may be expressed by the differential equations:

$$dN = mS - cR \tag{3}$$

$$dR = eN - iR. \tag{4}$$

The coefficients are matrices, the elements of which are: m, the strength of the memory associating a stimulus to a need; *c*, the amount of a consummatory effect of a response on a need; *e*, the strength of the excitation that a need induces

FIGURE 3. Need and response intensity as a function of time. The stimulus (S) has an initial value of 8, and is then changed to 2 and finally to 6. Both need and response intensity achieve new equilibrium values after the change in stimulus intensity.

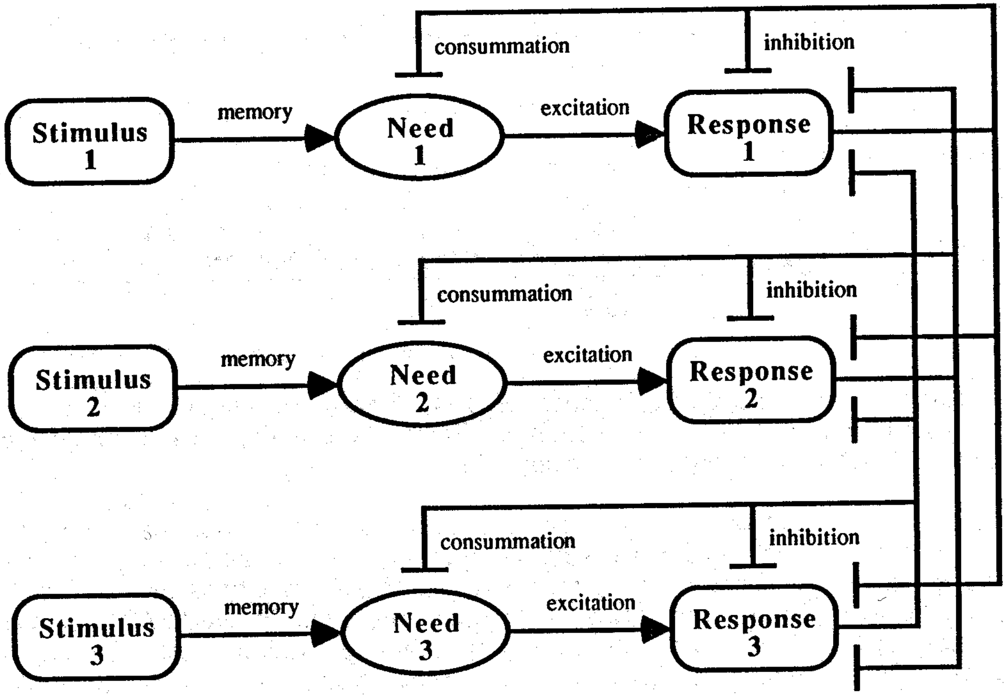


in a response; *i*, the inhibition or fatigue that making a response has upon that and other responses. The constraint $R \geq 0$ is imposed by assigning all negative values of R to 0.

If the inhibition matrix is diagonal, then responses are mutually compatible and all responses can occur at the same time. Thus, each need may achieve a steady state. However, if the responses are incompatible, then only one response occurs at a time and the needs do not achieve a steady state. Instead, needs grow and decline over time as first one and then another response is expressed (Figure 5).

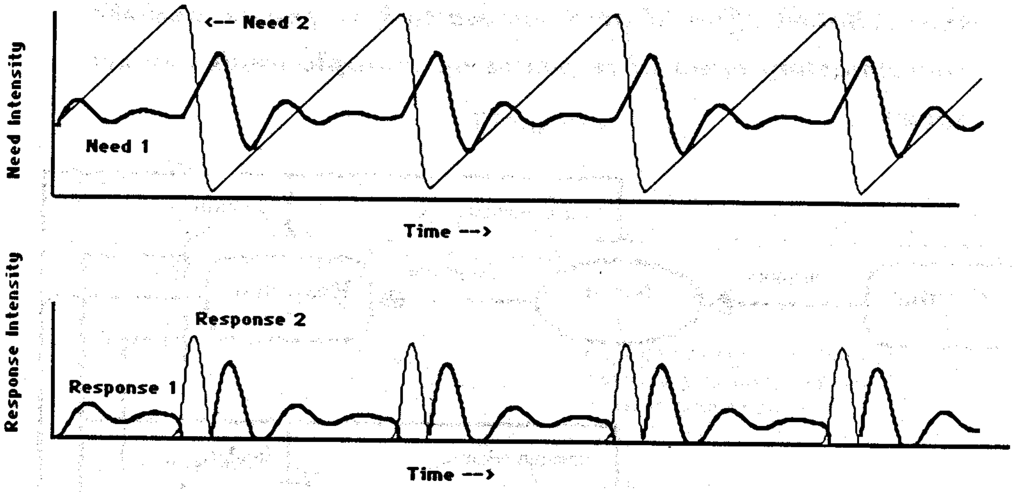
The benefits of the matrix representation is that it recognizes that a stimulus actually can be formed as a complex pattern of stimuli, and similarly, that a single response may be formed from a pattern of simpler acts. In addition, the matrix representation introduces the concept of a state space, in which it is possible to consider how behavior changes an individual's location in a multidimensional space, the dimensions of which are the separate needs. If responses are mutually incompatible (mutually inhibitory), producing a response which reduces one need will simultaneously lead to a move away from homeostatic balance along the other need dimensions.

FIGURE 4. A generalized control system model of stimuli, needs, and responses. Mutual inhibition between responses is shown. The generalized effect of stimuli on multiple needs, the excitatory effect of needs on multiple responses, and the consummatory effect of responses on multiple needs are not shown.



A further benefit of the matrix representation is simplicity. For instance, all relationships between stimuli and needs are summarized in the *m* (memory) matrix. The diagonal elements correspond to the direct effect a stimulus has upon a need; the off-diagonal elements correspond to generalization effects. That is, to the extent that two stimuli are similar, they should have similar effects upon a need. Similarly, the diagonal elements of the *c* (consummation) matrix reflect the degree to which doing an activity reduces the need to do that activity; the off diagonal elements may be thought of as representing substitutions: the extent to which doing an act reduces other needs. The diagonal elements of the *e* (excitation) matrix represent direct excitatory effects of needs upon responses; the off diagonal

FIGURE 5. Need and response intensity as a function of time for two mutually inhibitory responses.



elements represent possible displacement effects. Finally, the diagonal elements of the *i* (inhibition) matrix represent fatigue effects; the off diagonals represent the degree to which two responses are incompatible.

It is important to note that these matrices need not be symmetric. Thus, an anxious response might inhibit working on an exam, but working on the exam does not necessarily inhibit one's anxiety. This suggests that formulations such as Gray's (1982) Behavioral Activation System/Behavioral Inhibition System (BAS/BIS) can be captured within the structure of the excitation and inhibition matrices. Furthermore, the matrices need not be square nor of the same rank. That is, a vector of ten stimuli might only excite three or four needs, which in turn elicit only one of two responses.

As a final note, by representing the SNR model as two matrix difference equations, it is easy to simulate the model on even the simplest micro-computer. The basic model requires slightly more than 100 lines of Pascal and executes on an Apple II computer. The graphics for this chapter used a more convenient (and somewhat longer) version of the model, running on a Macintosh and originally written in MacPascal.

Stimulus-Need-Response as a Distributed Motivation Model

Recent work in cognitive science has suggested that it is appropriate to think of human information processing as a massively parallel operation in which memory is distributed across millions of nodes or connections. The SNR model is in some sense an analog of such a memory model in that different needs grow and decay in simultaneous response to many different stimuli. Although responses tend to be in sequential order, there is parallel processing of stimuli. The mechanism behind the shift from parallel processing of stimuli and needs to sequential output of responses is in the "winner take all" effect of mutual inhibition. If two responses are mutually incompatible (mutually inhibit each other), the response with the slightly greater initial strength will dominate and suppress the other. It is only when the need to do the suppressed response grows strong enough that the suppressed response will become active and suppress, in turn, the previously dominant response.

Stimulus-Need-Response vs. Dynamics of Action

The SNR model can be viewed as a reparameterization of the DOA. The instigating forces of DOA are equivalent to stimuli in SNR. Action tendencies of DOA are equivalent to the needs of SNR. In DOA, the dominant action tendency is expressed in behavior which in turn reduces the action tendency; in SNR needs excite responses which in turn reduce needs. What then is the difference? DOA needs to introduce lags (both instigating and consummatory) for the time from when an action tendency becomes dominant to when doing the action will have a consummatory effect and reduce the action tendency, and for the time from stopping an activity to the time that consummation is stopped. Functionally, these lags are equivalent to the distinction between needs and responses. Response strength lags behind need strength, and changes in need do not occur until after responses are produced.

Another difference between the two models is in the treatment of *negaction*. There are two types of stimuli in DOA, instigating forces and inhibitory forces. Instigating forces lead to action, inhibitory forces lead to negaction, which is then subtracted from action to produce resultant tendency strength. Although there is no formal equivalent to negaction in SNR, it is easy to create responses which behave like negaction. For example, a test could lead to two different needs, achievement and anxiety, which in turn could excite two different responses, approach and avoidance. If the avoidance response inhibited the approach response, but was not in turn inhibited by the approach response, the delay in initiation of the achievement-approach response would mimic the effects of negaction in DOA. (See also Gray, 1982 for a discussion of how anxiety affects the behavioral inhibition system).

Perhaps the greatest difference between the two models is the decision rule of which response to make. In DOA the stronger resultant tendency is always expressed in action. That is, if A is chosen over B, then $T_a > T_b$. In SNR, on the other hand, the strongest response is always expressed in action, but the strongest need is not necessarily expressed. If A is chosen over B, this means that the inhibitory effect of doing A is greater than the excitatory effect of the need to do B

($iR_a > eN_b$). This implies that increasing the response strength of an activity without changing need strength will increase its persistence.

There are logically two different choice situations: Doing A and then choosing to change behavior to initiate B, or doing some ongoing activity O, and then choosing to initiate B rather than A. In general, DOA assumes local independence (the choice between A and B should be independent of the other alternatives) and treats both of these situations the same. In DOA, changing from A to B implies that $Ta < Tb$, just as does choosing to stop continuing to do O and to initiate B rather than A. SNR, on the other hand, does not assume local independence, but notes that the ongoing activity affects choice. That is, changing from A to B implies that the need to do B is greater than the inhibitory effect on B of doing A. Changing from O to initiate B rather than A implies that the need to do B is greater than the inhibitory effect of doing O on B, and that the need to do A is less than the inhibitory effect of doing O on A. It does not imply that the need to do B is greater than the need to do A. One can have very strong needs to initiate an activity A, but if doing that activity is incompatible with (inhibited by) the current activity, not initiate A, but rather initiate a less desired but more compatible (less inhibited) activity B. Although it is possible in DOA to consider compatibilities between action tendencies, doing so breaks down the direct correspondence between choice and tendency.

(Consider the situation of someone discussing a complex idea with some colleagues while sitting in a bar drinking beer. After several beers one can very much want to go to the rest room but, because leaving the table is incompatible with continuing the discussion, defer going and instead have another beer. In DOA, we need to say that the tendency to drink the beer is stronger than the tendency to go to the rest room. In SNR, by emphasizing the inhibitory effects of the ongoing activity, we only can conclude that having another beer is less inhibited by the conversation than is going to the rest room. We are unable to say that the need to drink beer is greater than the need to go to the rest room. An interesting prediction that follows from SNR is that if the conversation becomes less interesting, the likelihood of going to the rest room will increase.)

A second characteristic of the SNR decision rule is that it is a natural consequence of the mathematics. The effect of mutual inhibition is to lead to a winner take all decision rule which does not need a separate comparator examining the strengths of all competing action tendencies. Mutual inhibition is, of course, a standard characteristic of the brain physiology and is a natural way to implement a decision maker (McDougall, 1903, Ludlow, 1980).

An important characteristic of both the DOA and SNR models of motivation and choice is that they imply that stable personality characteristics (traits) affect the rate of change of behavior rather than behavior per se. If individual differences in achievement motivation, anxiety, impulsivity, or sociability are associated with the coefficients in equations 3 and 4, then these stable dimensions of individual differences produce differences in the rates at which behavior changes rather than the behavior itself. But, by affecting rates of change, they will also affect choice, latency, persistence, frequency, intensity, and the total time spent in an activity.

Two Components of Motivation

An important characteristic of both dynamic models (DOA and SNR) is that they lead us to separate motivational strength into two components: direction and intensity. Direction can be associated with choice or preference, intensity perhaps can be associated with physiological arousal. What is interesting about both components is that different ways of indexing motivation will lead to different conclusions about motivational strength. Because most of the theorizing of Atkinson and his associates has centered around the directional component of motivation, it is fruitful to spend some time considering alternative measures of direction.

Direction. The most obvious measure of direction is choice. A consequence of both of these dynamic models is that the longer one has been doing an activity A, the more likely one is to switch to another activity. Ongoing activities will tend towards stable response and need strengths (see Figure 5), while needs for other actions will grow until they are strong enough to be initiated. The likelihood of continuing in the next time unit as will be a negatively decreasing function of time. This differs from a simple stochastic process, in which the likelihood function should be flat. This implies that choice is not independent of the situation, but rather depends upon how long one has been doing an activity.

Two measures of motivational strength other than choice are latency and persistence. Latency may be measured by how long it takes to initiate A and is equivalent to the off-time of A. Persistence may be defined as how long A is on once it is initiated, and is equivalent to the latency of not A. In a situation with only two possible acts, of course, persistence of A is equivalent to the latency of B.

Choice, latency, and persistence are measures taken at one change in behavior. Two other measures of direction, requiring averaging across many changes of behavior, are frequency and time spent. Frequency is merely how many times an act was initiated or chosen. Time spent is the sum of the persistences. These two measures are not interchangeable nor even necessarily correlated. An individual can do something frequently, but not spend very much total time doing it. For example, I sleep 8 hours or one third of a day, but I only go to sleep once a day. During a day I might talk to 20 different people, but only spend 1 hour talking to people. (See Figure 5 for an example of a 2 choice situation in which both activities occur equally often but one takes up 80–90 % of the time.)

Intensity. The second motivational component is intensity. Unfortunately, while direction is easily indexed (although not consistently) by choice and persistence, there is no easy index of intensity. Furthermore, our intuitive definitions are not very helpful, for by saying that someone is trying hard, do we mean that he or she is spending a great deal of time, or exerting a great deal of energy? It is tempting to equate physiological arousal with intensity, but given the complexities of the concept of arousal, one is loath to make hard and fast definitions. It is possible to show that manipulations thought to affect physiological arousal such as stimulant drugs, the time of day, or sleep deprivation affect tasks differently from manipulations that seem to affect task choice or persistence such as incentives, success or failure feedback, or ego threat (Humphreys & Revelle, 1984).

Task Variables Affecting Efficient Performance

In addition to the strength of motivation, another important determinant of efficient task performance is the nature of the task to be performed. Unfortunately, much of the research concerned with motivational effects upon performance has either used an overly simplistic analysis of task variables, or has used none at all. Tasks tend to be chosen because they have been used before or for convenience but not for any important theoretical reason. In addition, very little contact has been made with relevant theories of cognitive psychology or of information processing.

Rather than accuse others of careless disregard for task parameters, it is appropriate to cite some of my own research for examples of such naive practices. In a study of how introversion-extraversion and arousal affected performance, Revelle (1973) chose tasks because they had been used before in studies of achievement motivation. Digit symbol substitution, a maze task, and some anagrams were used as performance measures. Although task difficulty was varied within each type of task, there was no attempt to understand the cognitive processes involved for these tasks. In a later study Revelle, Amaral and Turriff (1976) used practice Graduate Record Examination items because they were convenient and were more challenging for undergraduates than the anagrams used earlier. Revelle, Humphreys, Simon and Gilliland (1980) continued to use GRE items in order to establish the reliability of the Revelle et al. (1976) results but still did not concern themselves with the task parameters.

All of these studies considered the concept of difficulty, but they did not distinguish between difficulty as indexed by error rate, number of problems finished, or number of trials needed to achieve a certain criterion. Nor did any of these studies take into account current models of information processing. In fact, although these studies were meant to be examining the Yerkes-Dodson "Law" (Yerkes & Dodson, 1908), they did not distinguish between rates of learning (i.e., number of trials to criterion in a discrimination task, Yerkes & Dodson, 1908), and speed of retrieval of synonyms and antonyms in a verbal performance task.

Partly in response to criticism of the lack of theoretical meaning of such tasks as the GREs, but mainly in order to explain the Yerkes-Dodson Law, Humphreys and Revelle (1984) tried to organize the motivation and performance literature in terms of several dimensions of information processing.

Learning vs. processing. A primary distinction to make is between those tasks which involve learning to make new associations and those which require processing (reorganization or retrieval) of available material. The study of motivational effects in learning has a long history. The original Yerkes and Dodson (1908) experiment and a subsequent replication of it (Broadhurst, 1959) made use of a discrimination learning task. Spence, Farber and McFann (1956) examined motivational (anxiety induced drive) effects on paired associate learning of easy and difficult lists. Weiner and Schneider (1971) extended the Spence et al. results by showing the importance of feedback rather than item difficulty in determining the error rate when learning paired associate lists.

Recent experiments have looked for motivational effects upon the processing of available information rather than the learning of new information. Several studies have examined the relationship of motivational intensity and GRE performance (Anderson, 1985; Gilliland, 1980; Revelle et al., 1976, 1980). Anderson and Revelle (1982, 1983) tested the effect of caffeine on proofreading and letterscanning. Bowyer, Humphreys and Revelle (1983) showed that caffeine induced arousal interacted with time on task to affect recognition memory. Anderson, Revelle and Lynch (1985) found that caffeine facilitates the intercept but increases the slope in a Sternberg memory search task.Within the processing domain, it is possible to organize the types of information processing resources demanded along three separate dimensions: sustained information transfer, short term memory, and long term memory. (See Humphreys & Revelle, 1984 and Revelle, Anderson & Humphreys, in press, for more extensive reviews of studies examining arousal mediated effects upon information processing.)

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

Short Term Memory (STM). A second dimension measures the amount of information which must be retained for short periods of time. Tasks with high memory load include traditional experimental measures of STM (e.g., recognition or recall tasks), derived measures such as the speed of memory scanning in a Sternberg paradigm, or simple tasks in which a memory load has been added. Example of the latter include a letter search task in which one is to identify strings of 20 letters that include a memory set of 6 letters (Anderson & Revelle, 1981) or geometric analogies with several transformations from the A to B term (Mulholland, Pellegrino and Glaser, 1980).

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

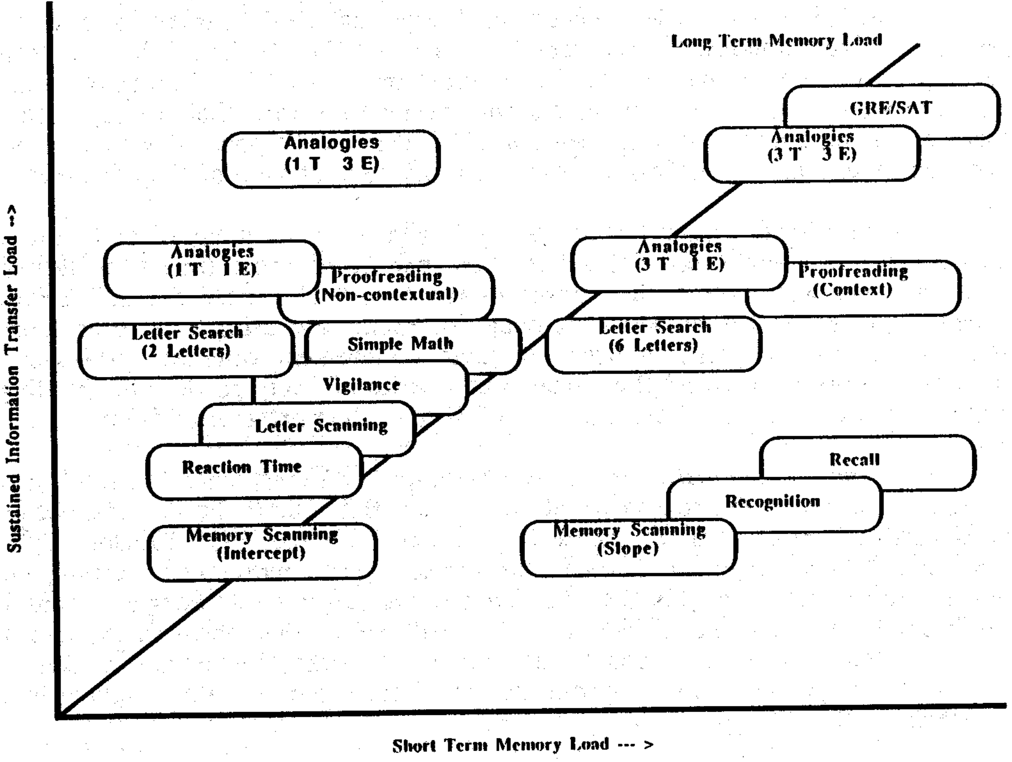
A typology of tasks. These three dimensions of information processing can be combined to allow for a classification of many different tasks (Figure 6). Sixteen different measures used in recent studies in my lab have been organized in terms of their SIT, STM, and LTM requirements. Although the absolute location in this 3-space is somewhat arbitrary, the relative location is not. Thus, the intercept in a memory scanning task has less STM load than does the slope taken from the same measure. The SIT load in this task is less than that in a recognition or recall task where a subject is required to detect the stimulus as well as retrieve it later. Searching for two letters has less STM load than searching for six letters, just as proofreading for non-contextual errors has less STM load than proofreading for contextual errors. Proofreading, however, has more LTM load than a letter search. Geometric analogies can range from those with few SIT or STM demands (one element and one transformation, to those with greater SIT demands (three elements and one transformation per element), or greater STM demands (one element but three transformations per element) to problems with large STM and SIT demands (three elements and three transformations per element). Finally, the GRE analogies we used in Revelle et al. (1980) were high in SIT, STM, and LTM demands.

The example of analogical reasoning. Perhaps the best way to understand these dimensions is to consider how they relate to a particular task. A recent study of analogical reasoning (Mulholland, Pellegrino & Glaser, 1980) used geometric analogies which differed in the number of elements within each term of the analogy, as well as in the number of transformations applied to the elements. Increases in both elements and transformations led to slower decision times; only increases in transformations increased the error rate. Mulholland et al. proposed that transformations were affecting the short term memory requirements of the task, but elements were not. In our terms, increasing the number of elements increases the SIT demands; increasing the number of transformations increases the STM demands. Geometric analogies have far fewer long term memory demands than than do the verbal analogies found in the Graduate Record Exam or the Scholastic Aptitude Test. Unfortunately, in those exams, the typical problem has only one element per term, and the number of transformations is not as easily determined as it is in geometric analogies.

Inefficiency as an Inappropriate Tradeoff

Atkinson (1974) claimed that the level of performance with which a task is executed depends upon one's ability and efficiency. Implicit in his analysis was the idea that individual differences in ability are not perfectly reflected by individual

FIGURE 6. A typology of tasks. Tasks are characterized in terms of their relative loading on the dimensions of Sustained Information Transfer, Short Term Memory and Long Term Memory. (Adapted from Revelle, et al., in press).



differences in performance. If we take maximum performance as an index of ability, then any level of performance below that can be said to be inefficient. Furthermore, Atkinson (1974) suggested that efficiency depends upon one's strength of motivation and the type of task. Although task variables can be shown to be very important determinants of efficiency (Humphreys & Revelle, 1984), the strength of motivation can lead to less than maximal performance in at least four different ways.

Each of these sources of inefficiency can be expressed as a tradeoff between applying resources to the externally defined reference task versus some other task or task component. Three of these tradeoffs may be analyzed in terms of the directional component of motivation, one in terms of the intensity component. By examining performance on the reference task as a function of performance on other tasks, it is possible to better understand the many meanings of the term "inefficiency."

Time spent between tasks—macro level analysis. Perhaps the simplest tradeoff is merely that between spending time doing something versus doing something else. If one task is considered important by an outside observer (the reference task), but other tasks are considered important by the subject (alternative tasks), then performance on the reference task will be inefficient or less than maximal to the extent that the subject spends time doing the alternative tasks. Graduate students or faculty members who spend time with their family rather than working on a manuscript are being inefficient from the point of view of their academic colleagues, but performing well from the point of view of their families.

It is this sort of tradeoff which is relevant to the broad study of motivation. Individuals with a high need for achievement will spend more time in achieving situations than will those with a lower n-Ach or a higher need for affiliation. Students who spend the weekend studying for exams are using their time more efficiently from the point of view of their achievement oriented professors; students who prefer to spend the weekend at a series of lively parties are spending their time more efficiently from the point of view of their extraverted friends.

Time spent within tasks—micro level analysis. At a much narrower level, it is possible to consider how subjects spend their time within a task. Recent analyses of the effects of anxiety on performance (e.g., Leon & Revelle, 1985; Sarason, 1975; Wine, 1971) have suggested that anxious subjects spend more time worrying or engaging in off task thoughts than do less anxious subjects. Although seemingly inefficient from the point of view of the experimenter, time spent in evaluating one's self esteem, or thinking about what one will do when the test is over can be seen by the subject as a more appropriate use of time than actually engaging in a threatening task.

Leon and Revelle (1985) found that anxious subjects do not do worse because of some differential processing deficit. They found that anxious subjects were slower and less accurate on all types of geometric analogies than were less anxious subjects. The analogies varied in number of elements (SIT load) and number of transformations (STM load). These results supported predictions derived from Sarason and Wine, but contradicted predictions derived from drive theory (Hull,1952; Spence & Spence, 1966), cue utilization theory (Anderson, 1980; Easterbrook, 1959), and working memory theory (Eysenck, 1979).

Strategic allocation of resources. Another reason for inefficient performance that is under the subject's control is the strategic allocation of priorities for different task components. Perhaps the best example of such strategic allocation is found in the tradeoff of speed for accuracy. In even the most basic reaction time task, faster performance can be achieved if there is an increased tolerance for errors. A typical reaction time finding is that RT is linear with log odds (i.e., the logarithm of the probability of correct responses divided by the probability of incorrect responses).

Many tests are scored for the total number correct which is, of course, the product of the number of problems attempted and accuracy on those attempted problems. If accuracy is a negatively accelerated but increasing function of time spent on a problem and the number of problems attempted is a decreasing function of the total time spent per item, then the number of problems correct will be a complex function of task difficulty and error rate. Assume that the probability of passing an item (p) is a logistic function of ability (a), item difficulty (d), and time spent on the item (t):

$$p = e^{(a+t-d)}/(1+e^{(a+t-d)}) \tag{5}$$

and that the number of test items (N) completed in a fixed amount of time (T) is a function of the total time divided by the time spent per item (N=T/t). Then the total number of correct items is Np:

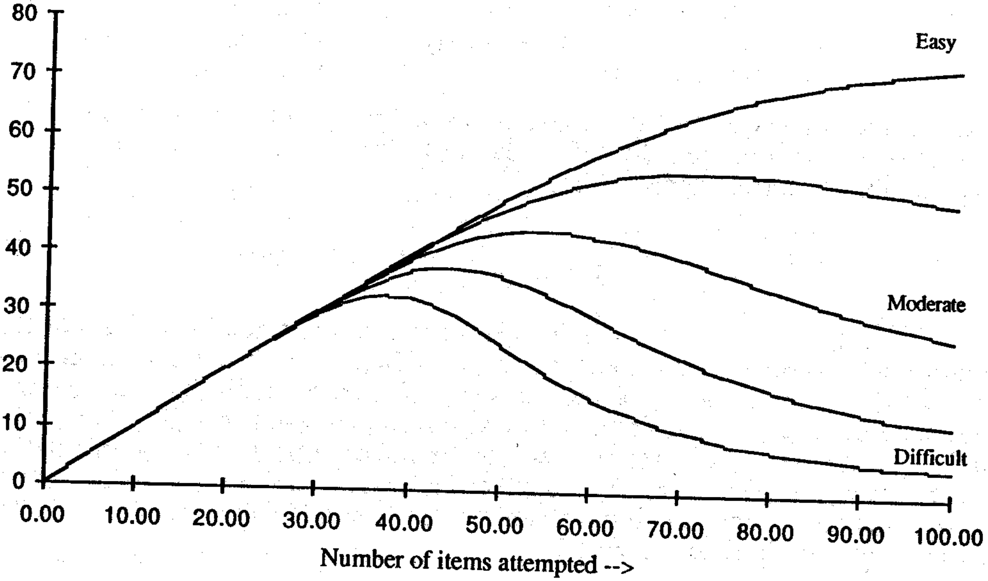
$$Np = Te^{(a+t-d)}/(1+e^{(a+t-d)})t. \tag{6}$$

Finding the optimal level of the speed for accuracy tradeoff in terms of total number of problems correct becomes quite difficult, for it depends upon ones's ability (a) and the difficulty of the items (d). If there are individual differences in the tolerance of errors, then even subjects with similar levels of ability will work at different rates (t) and differ in their total number correct (Np). Manipulations which increase accuracy may lead to either increases or decreases in total problems correct, depending upon the subject's ability, the item difficulty, and the initial bias towards speed or accuracy (Figure 7).

Atkinson (1974) reviewed evidence suggesting that anxious subjects are more sensitive to failure than are less anxious subjects. Gray (1981) also has suggested that anxiety is related to a sensitivity to punishment or non-reward. Thus, we would expect anxious subjects to prefer to work slowly in order to minimize errors. Impulsive subjects, however, would be expected to work rapidly, trying to maximize the number of problems attempted with little concern for making errors. An example of the effect of anxiety on speed-accuracy tradeoffs comes from Geen's (1985) comparison of speed versus accuracy in a Stroop color-word naming task. Geen found that when given instructions "to do your best" anxious subjects were slower but more accurate than were non-anxious subjects. However, the two groups did not differ when given instructions to be as accurate as possible or to be as fast as possible.

Automatic allocation of resources. The tradeoff between cognitive resources available for short term memory and sustained information transfer involves the intensity of motivation rather than its direction. Increases in arousal lead to increased resources available for SIT tasks, but to decreased resources available for

FIGURE 7. The effect of speed (number of problems attempted) on performance (number of problems correct) for various levels of problem difficulty. For easy problems maximum performance is achieved by maximizing the number of problems attempted. As problem difficulty is increased, however, the optimal number of problems attempted decreases.



STM tasks (Humphreys & Revelle, 1984; Revelle, Anderson, & Humphreys, in press). Although the construct of arousal is clearly an oversimplification, it is useful as a way of organizing the effects of a variety of seemingly different variables. It should be construed as a conceptual dimension ranging from extreme drowsiness at one end to extreme excitement at the other. It may be manipulated, physiologically indexed, or behaviorally observed. Any particular measure will, however, introduce some irrelevancies. It is the convergence of multiple measures that allows us to use the term arousal. Stimulant drugs (e.g., caffeine and amphetamine), lack of sleep deprivation, time of day (afternoon versus morning), and time on task (early versus late) seem to facilitate performance on SIT tasks but hinder performance on STM tasks. Performance on tasks with low STM loads (tasks on the left side of Figure 6) is facilitated by caffeine while performance on tasks with higher memory loads (tasks on the right side of Figure 6) is hindered by caffeine (Revelle, et al., in press). Performance changes due to arousal can be seen as a tradeoff between resources available for SIT or STM processing.

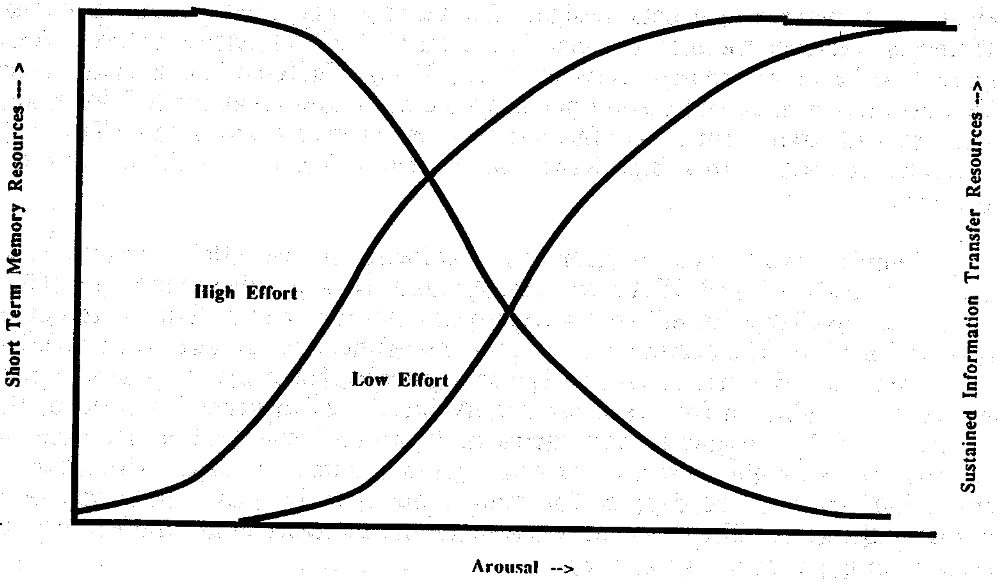
A clear demonstration that caffeine induced arousal facilitates performance on tasks with low memory load but hinders it on tasks with a high memory load is the recent study by Benzuly (1985) who studied the effects of caffeine and impulsivity on geometric analogies. Benzuly crossed two levels of information transfer load (1 and 3 elements) with two levels of memory load (1 and 3 transformations) to form four types of analogies. She used 0 and 4 mg/kg body weight in a between subjects design. Impulsivity was used as an individual differences variable thought to relate to arousal (low impulsive subjects were expected to be more aroused, Revelle et al., 1980). Caffeine had a main effect effect on performance (improving performance no matter what the SIT load, and interacted with transformations (facilitating those problems with a low STM load, but hindering those with a high STM load). The effect of impulsivity was not significant.

Complex tasks such as geometric analogies or the GREs require large amounts of both SIT and STM resources. Arousal has a positive monotonic effect on resources available for SIT, but a negative monotonic relationship for resources available for STM. The combination of these two functions can lead to an inverted U function. At low levels of arousal (given a placebo, following sleep deprivation, early in the morning, or for less aroused individuals), performance is limited by the availability of SIT resources and increases in arousal will lead to increases in performance. At higher levels of arousal (given a stimulant drug, without sleep deprivation, later in the day, or for more aroused individuals), performance is limited by the availability of memory resources and increases in arousal will lead to decreases in performance (Figure 8).

Anderson (1985) tested these ideas in a within subject design with five levels of caffeine induced arousal. High and low impulsives were given a simple letter scanning and a complex reasoning (GRE verbal items) task. Performance on the letter scanning task (requiring SIT resources) was a positive monotonic function of caffeine dosage for both high and low impulsive subjects. Performance on the GRE (requiring both SIT and STM resources) was an inverted U function of caffeine for the more aroused (low impulsive) subjects, but was an increasing positive function for the less aroused (high impulsive) ones.

A plausible explanation for the automatic effect of arousal on the allocation of resources for SIT, STM, and LTM is that increases in arousal lead to a reduction in the length of the psychological moment. To use an analogy from digital computers, arousal increases the tick rate of the internal clock. The faster tick rate means that information is sampled from the environment more frequently, which leads to faster (and better) performance on SIT tasks such as reaction time, letter scanning, or simple arithmetic. In addition to improving SIT performance, a faster tick rate leads to more samples of the environment for storage in LTM. Increasing the number of samples is roughly equivalent to the effect of increasing study trials in a verbal learning experiment and will improve recognition and recall after long

FIGURE 8. The relationship between arousal, sustained information transfer, and short term memory. Increases in arousal increase resources available for SIT but decrease the availability of resources required for STM. (Adapted from Humphreys and Revelle, 1984).



delays. As well as producing the benefit of improving SIT and LTM performance, however, an increased tick rate increases the rate at which information is lost (interfered with) in short term memory. This is a direct consequence of the increased tick rate. For a fixed retention interval, a faster tick rate will lead to more samples from the environment than will a slower tick rate. This is analogous to lengthening the intervening interval or increasing the interference in a short term memory task. Interference from these additional samples will lead to decreased performance in short term memory paradigms.

Summary and Conclusions

Motivational strength affects performance in several different ways. The directional component of motivation determines what tasks are chosen, the latency before starting a task, persistence once started, and the frequency with which a task is chosen. In addition, direction affects tradeoffs of time spent between and within classes of tasks, and strategic tradeoffs between task components. The intensity component of motivation affects efficiency by controlling the tradeoff between the cognitive resources available for sustained information transfer and short term memory.

Both components of motivation need to be considered as dynamic and changing over time. Alternative conceptions of these behavioral dynamics lead to similar conclusions and are useful for understanding how personality traits manifest themselves in everyday behavior. Stable individual differences are seen not in stable behavioral differences, but as consistent differences in the rates of change of behavior. Finally, dynamic models of motivation are compatible with recent developments in distributed models of memory and cognition in that they specify how parallel processing of stimuli and needs can lead to sequential outputs of responses.

Jack Atkinson's contribution to the field of psychology is the result of his high level of performance as well as his dedication to the problem of human motivation. Both the time he spent and his level of performance reflect favorably on his ability and on the strength of his motivation.

REFERENCES

Anderson, K. J. (1980). *The current status of the Easterbrook hypothesis*, unpublished manuscript, Northwestern University.

Anderson, K. J. (1985). *Impulsivity, caffeine and task difficulty: A within subjects test of the Yerkes-Dodson Law*. Unpublished manuscript, Colgate University.

Anderson, K. J., & Revelle, W. (1982). Impulsivity, caffeine, and proofreading: A test of the Easterbrook hypothesis. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 614–624.

Anderson, K. J., & Revelle, W. (1983). The interactive effects of caffeine, impulsivity, and task demands on a visual search task. *Personality and Individual Differences*, *4*, 127–134.

Anderson, K. J., Revelle, W., & Lynch, M. J. (1985). *Arousal and memory scanning: A comparison of two explanations for the Yerkes-Dodson effect*. Unpublished manuscript, Colgate University.

Atkinson, J. W. (1957). Motivational determinants of risk-taking behavior. *Psychological Review*, *64*, 359–372.

Atkinson, J. W. (1964). *An introduction to motivation*. New York: D. Van Nostrand.

Atkinson, J. W. (1974). Strength of motivation and efficiency of performance. In J.W. Atkinson & J.O. Raynor (Eds.), *Motivation and achievement* (pp. 117–142). New York: V.W. Winston.

Atkinson, J. W., & Birch, D. (1970). *The dynamics of action*. New York: Wiley.

Atkinson, J. W., & Birch, D. (1978). *Introduction to motivation*. New York: D. Van Nostrand.

Atkinson, J. W., & Cartwright, D. (1964). Some neglected variables in contemporary conceptions of decision and performance. *Psychological Reports*, *14*, 575–590.

Benzuly, M. (1985). *Caffeine and memory load: Their effect on analogical reasoning*. Unpublished honor's thesis. Northwestern University.

Bolles, R. C. (1980). Some functionalistic thoughts about regulation. In F. M. Toates & T. R. Halliday (Eds.), *Analysis of motivational processes* (pp. 63–75). London, Academic Press.

Broadhurst, P. L. (1959). The interaction of task difficulty and motivation. The

Yerkes-Dodson Law revived. *Acta Psychologica, 16*, 321–338.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66*, 183–201.

Eysenck, M. W. (1979). Anxiety, learning, and memory: A reconceptualization. *Journal of Research in Personality, 13*, 363–385.

Feather, N. T. (1961). The relationship of persistence at a task to expectation of success and achievement related motives. *Journal of Abnormal and Social Psychology, 63*, 552–561.

Geen, R., & Kaiser, M. (1985). *Test anxiety and performance on the Stroop color word task*. Unpublished manuscript. University of Missouri.

Gray, J. A. (1981). A critique of Eysenck's theory of personality. In H. J. Eysenck (Ed.), *A model for personality* (pp. 246–276). Berlin: Springer.

Halliday, T. R. (1980). Motivational systems and interactions between activities. In F. M. Toates & T. R. Halliday (Eds.), *Analysis of motivational processes* (pp. 205–220). London: Academic Press.

Hamilton, J. O. (1974). Motivation and risk taking behavior: A test of Atkinson's theory. *Journal of Personality and Social Psychology, 29*, 856–864.

Heckhausen, H. (1967). *The anatomy of achievement motivation*. New York: Academic Press.

Hull, C. L. (1952). *A behavior system*. New Haven: Yale University Press.

Humphreys, M. S., & Revelle, W. (1984). Personality, motivation, and performance: A theory of the relationship between individual differences and information processing. *Psychological Review, 91*, 153–184.

Kuhl, J., & Blankenship, V. (1979). The dynamic theory of achievement motivation: From episodic to dynamic thinking. *Psychological Review, 85*, 239–248.

Kuhl, J., & Blankenship, V. (1979). Behavioral change in a constant environment: Shift to more difficult tasks with constant probability of success. *Journal of Personality and Social Psychology, 37*, 551–563.

Leon, M. R., & Revelle, W. (1985). The effects of anxiety on analogical reasoning: A test of three theoretical models. *Journal of Personality and Social Psychology, 49*, 1302–1315.

Locke, E. A. (1968). Toward a theory of task motivation and incentives. *Organizational Behavior and Human Performance, 3*, 157–189.

Ludlow, A. R. (1980). The evolution and simulation of a decision maker. In F. M. Toates & T. R. Halliday (Eds.), *Analysis of motivational processes* (pp. 273–296). London: Academic Press.

McDougall, W. (1903). The nature of inhibitory processes within the nervous system. *Brain, 26*, 153–191.

McFarland, D. J. (1974). *Motivational control systems analysis*. Academic Press: London.

Mulholland, T. M., Pellegrino, J. W., & Glaser, R. (1980). Components of geometric analogy solution. *Cognitive Psychology, 12*, 252–284.

Pachella, R. G. (1974). The interpretation of reaction time in information-processing research. In B. Kantowitz (Ed.), *Human information processing: Tutorials in performance and cognition*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Revelle, W. (1973). *Introversion/extraversion, skin conductance and performance under stress*. Unpublished doctoral dissertation, University of Michigan, Ann Arbor.

Revelle, W., & Michaels, E. J. (1976). The theory of achievement motivation revisited: The implications of inertial tendencies. *Psychological Review, 83*, 394–404.

Revelle, W., Amaral, P., & Turriff, S. (1976). Introversion-extroversion, time stress, and caffeine: The effect on verbal performance. *Science, 192*, 149–150.

Revelle, W., Anderson, K. J., & Humphreys, M. S. (in press). Empirical tests and theoretical extensions of arousal-based theories of personality. In J. Stelau and H. J. Eysenck (Eds.), *Personality dimensions and arousal*. London: Plenum.

Revelle, W., Humphreys, M. S., Simon, L., & Gilliland, K. (1980). The interactive effect of personality, time of day, and caffeine: A test of the arousal model. *Journal of Experimental Psychology: General, 109*, 1–31.

Sarason, I. G. (1975). Anxiety and self-preoccupation. In I. G. Sarason & C. D. Spielberger (Eds.), *Anxiety and stress*, Vol. 2. Washington, DC: Hemisphere.

Schneider, K., & Posse, N. (1982). Risk taking in achievement-oriented situations: Do people really maximize affect of competence information? *Motivation and Emotion, 6*, 259–272.

Spence, J. T., & Spence, K. W. (1966). The motivational components of manifest anxiety: Drive and drive stimuli. In C. D. Spielberger (Ed.), *Anxiety and behavior*. New York: Academic Press.

Spence, K. W., Farber, I. E., & McFann, H. H. (1956). The relation of anxiety (drive) level to performance in competitional and non-competitional paired-associates learning. *Journal of Experimental Psychology*, *52*, 296–305.

Toates, F. M., & Halliday, T. R. (Eds.). (1980). *Analysis of motivational processes*. London: Academic Press, 1980.

Weiner, B., & Schneider, K. (1971). Drive versus cognitive theory: A reply to Boor and Harmon. *Journal of Personality and Social Psychology*, *18*, 258–262.

Wine, J. (1971). Test anxiety and direction of attention. *Psychological Bulletin*, *76*, 92–104.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimuli to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482.

Zeigarnik, B. (1938). [On finished and unfinished tasks.] In W. D. Ellis (Ed.), *A source book of Gestalt Psychology*. New York: Harcourt Brace. (Reprinted and translated from Psychological Forschung, 1927, 9, 1–85.)