## Chapter Seven

# MOTIVATION AND EFFICIENCY OF COGNITIVE PERFORMANCE

**William Revelle**

**Northwestern University**

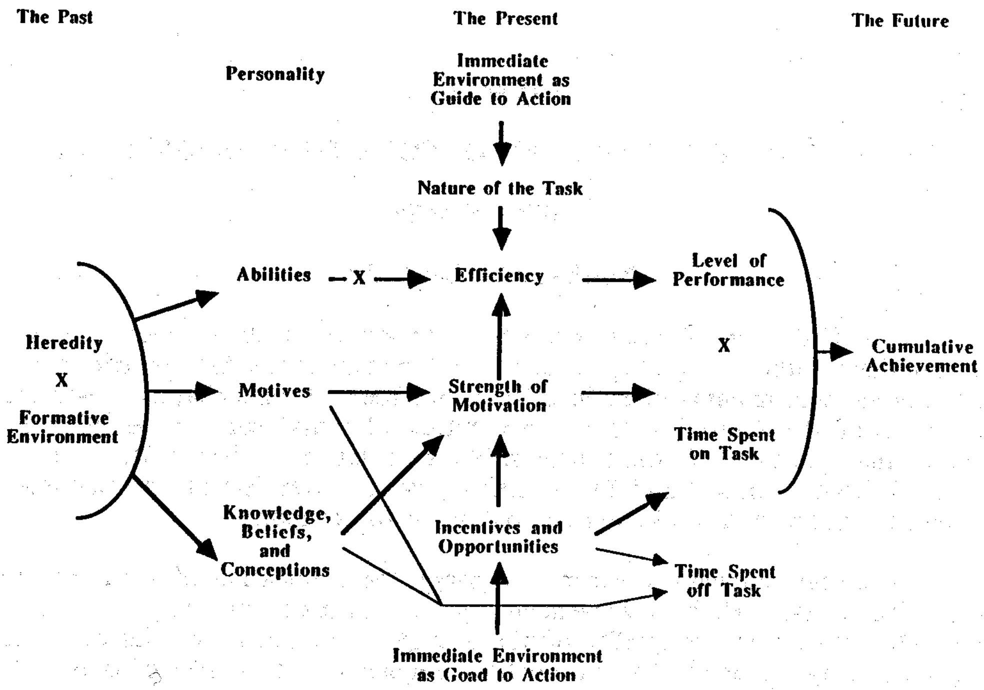
It is fitting in a book written in honor of Jack Atkinson's lifelong contribution to the study of personality and human motivation to consider the motivational determinants of cumulative achievement. In this chapter I will show how parts of the theoretical framework outlined by Atkinson can be filled 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*

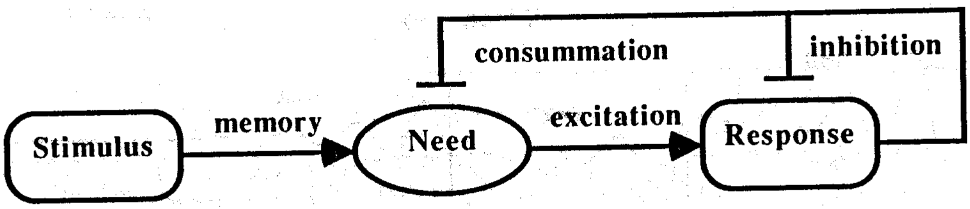
An alternative model to the DOA, which maintains many of the same assumptions but is mathematically simpler, can be derived from concepts developed by British "control theorists" of animal behavior (e.g., McFarland, 1974, Toates & Halliday, 1980). This model has one exogeneous independent variable (the 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)*

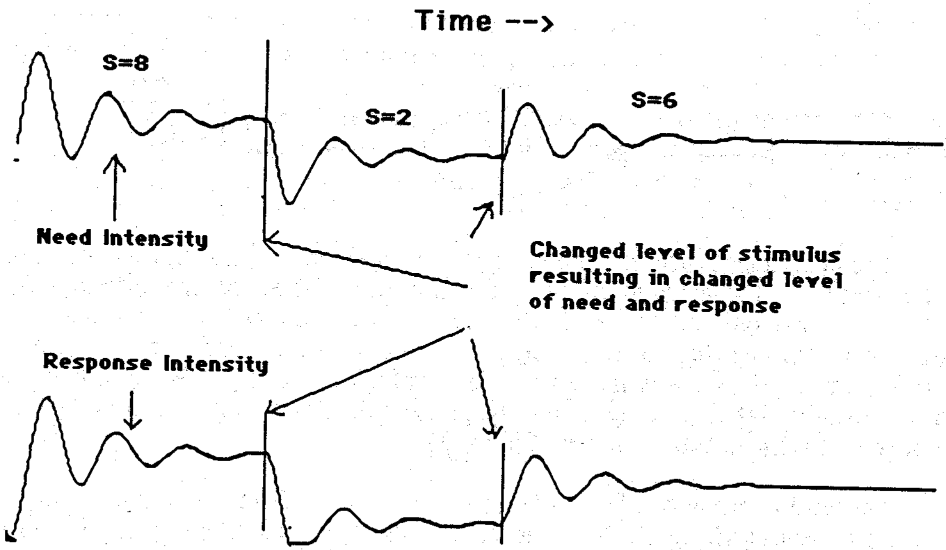
Such a system becomes more complicated (and more interesting) if we consider S, N, and R to be vectors of stimuli, needs, and responses, and introduce the concept of response incompatibility. If doing A is incompatible with doing B (an interesting example of such incompatibility is found in the newt 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.*

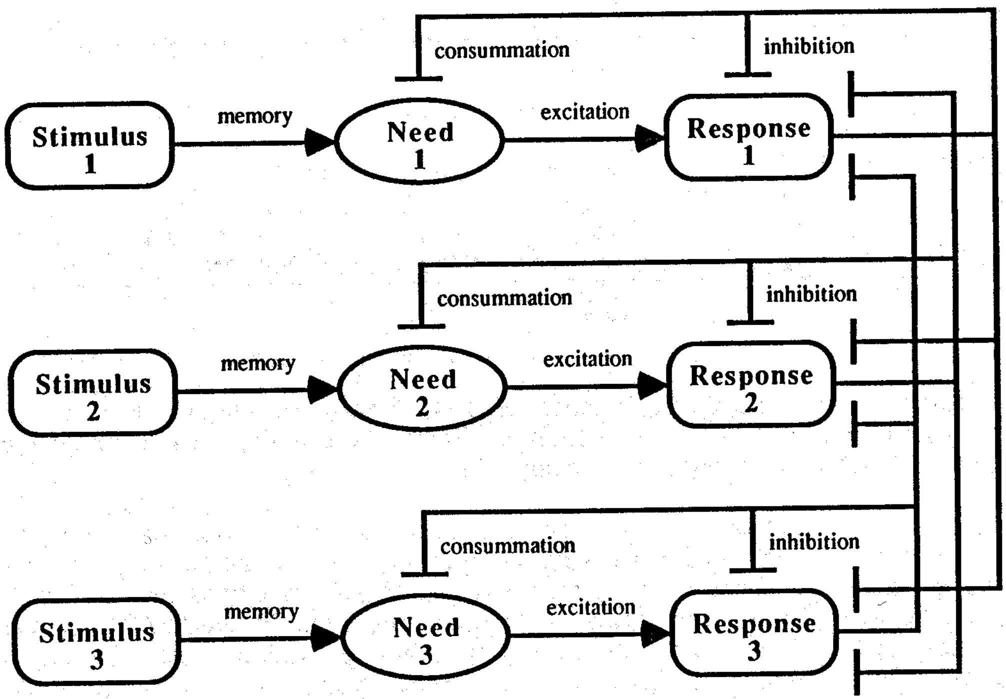



in a response; *i*, the inhibition or fatigue that making a response has upon that and other responses. The constraint R $\geq$ 0 is imposed by assigning all negative values of R to 0.

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).

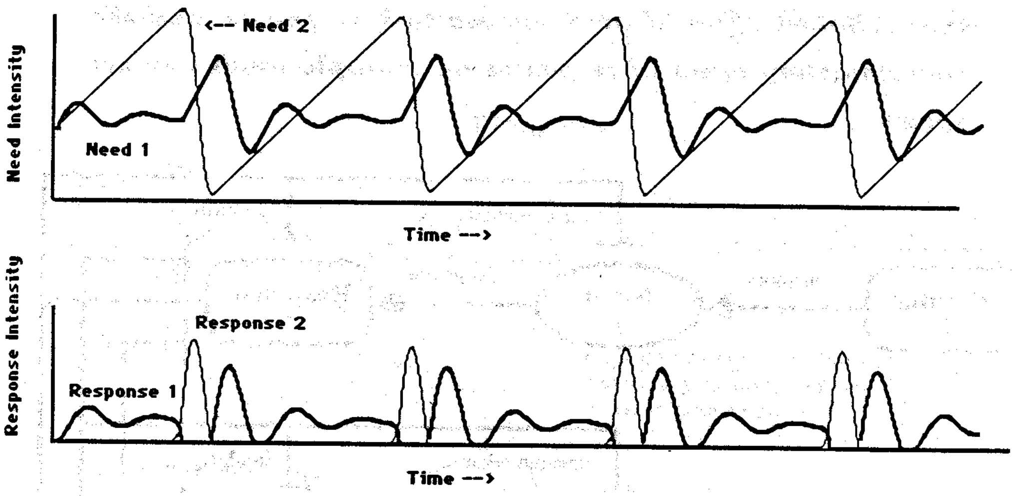
The benefits of the matrix representation is that it recognizes that a stimulus actually can be formed as a complex pattern of stimuli, and similarly, that a single response may be formed from a pattern of simpler acts. In addition, the matrix representation introduces the concept of a state space, in 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.