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328ATTENTION, EFFORT, AND FATIGUE:
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Attention reflects the deployment of cognitive resources toward internal and external events, and is limited by an individual's capacity for active processing of information. Attentional performance is increased by cognitive effort and diminished by fatigue. Consequently, measures of attention potentially provide excellent indices of ability to resist fatigue and generate effort in the performance of a task. Yet the assessment of attention, effort, and fatigue has been difficult because of problems in operationalizing these phenomena and establishing appropriate methodologies for measurement.

From a neuropsychological perspective, attention is not a single phenomenon, but instead can be dissociated into various components of information processing with biological correlates. Consideration of attention requires a multivariate assessment framework in which variations in stimulus and response characteristics can be simultaneously measured or controlled during serial performance. Attention can then be represented as an index of performance across time. Fatigue may reflect a failure to maintain optimal levels of performance across a number of possible behavioral systems.

Because attention represents multiple processes within the brain and varies over time, the measurement of attention requires similar characteristics. First, attention is a dynamic process necessitating serial assessment in contrast to cross-sectional measurement at a single time point. Second, the assessment should be multivariate, to characterize performance as a function of multiple determinants and outputs. Because attentional processes occur in a biological system, psychophysiological measurement may detect subtle attentional variation based on physiological reactivity.

This paper will review models of attention, effort and fatigue. We will discuss methods for measuring these phenomena from a neuropsychological and psychophysiological perspective. The following methodologies will be included: 1) the autonomic measurement of cognitive effort and quality of encoding, 2) serial assessment approaches to

neuropsychological assessment, and 3) the assessment of subjective reports of fatigue using multidimensional ratings, and their relationship to neurobehavioral measures.

Models of attention

Throughout the history of psychological and cognitive science, attention has been viewed as an important, but difficult to define component of human mental processing. Wilhelm Wundt went to great length in describing the "apperceptive focus" by which an interaction between internal mental events and external reality occurred. (ref. 1)

William James provided the following description:

" Everyone knows what attention is. It's the taking possession by the mind, in clear vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others."(ref. 2)

Despite early interest in attention, there has been much difficulty in operationalizing or even agreeing to what constitutes the boundaries of meaningful study with respect to attention. In the most narrow sense, attention has been used to describe a nonspecific form of sensory perception. In a broader framework, attention can be viewed as a reflection of the fact that performance is not stable over time. Within this view, attention reflects the temporal variation in performance as a function of both stimulus and response parameters, that are not due to fatigue of peripheral sensory or motor systems.

There are now a number of models that relate attention to both stimulus and response factors. While it is beyond the scope of this paper to review all of the recent models of attention, a review of some of the major positions is in order.

Selective attention

Selective attention refers to the process by which an individual selects stimuli, or components of stimuli from a set of inputs for further cognitive operations. Selection implies a stimulus preference for certain information based on some important feature. Broadbent proposed that selective attention occurs as a function of a limited capacity system in which sensory information is initially processed in parallel until it reaches the level of a filter mechanism. The filter serves to limit the information flow in a serial switching process, so that one input can be processed at a time. This theory predicted that perception was dependent on conscious attention. (ref. 3) Treisman

later demonstrated that certain inputs are potentially perceived even if unattended, though attention was thought to attenuate information and to strengthen the probability of perception.(ref. 4) Both models characterized attention as a sensory mechanism by which filtering of information occurred.

Other investigators offered a much different perspective of attention by suggesting that attention and selection of information occurs at a much later stage of processing. Deutsch and Deutsch proposed that response selection determined selective attention.(ref. 5) The view that attentional selection occurred later in processing was supported by Shiffrin, though the attentional mechanism was proposed to be determined by the rate of transfer and loss of sensory information from short term memory, before loss of information occurred.(ref. 6) The rate of search limited the capacity of attention. An important relationship between memory set size and attentional capacity was noted. Sternberg demonstrated the dynamics of these search processes by exploring whether reaction time in decisions about set inclusion would reflect an exhaustive search of all possible choices, or whether termination of search would occur based on a match with memory.(ref. 7) Initial results seemed to favor an exhaustive search model. However, later investigations suggested that memory set may not define attentional capacity under all conditions.(ref. 8,9) For instance, for well practiced material reaction time for response selection was less dependent on memory set size. These divergent findings led Schneider and Shiffrin to postulate two different attentional processes.(ref. 10)

Automatic versus controlled processing

Within the two process theory attention, a distinction was made between serial "multi-frame" tasks that reflect attentional vigilance, and "single frame" simultaneous display tasks in which accuracy of perception is high, but reaction time is affected by search requirements. The two processes were suggested to differ on the dimension of controlled search versus automatic detection.

The paradigm developed for study of the two process model of attention (ref. 10) manipulated a number of important variables that affect attention. The independent variables included: frame time, memory set, frame size, and type of spatial mapping. Frame time reflected the speed of stimulus presentation. Increased speed obviously increased attentional demand. Memory set referred to material presented to the subject prior to the search task, which determines the familiarity with the stimuli during attention. Frame size determines the number of stimuli that have to be searched before a decision can be made about the

presence of a target stimulus from the memory set. The type of spatial mapping was either consistent or variable. In the consistent mapping task, subjects always searched for a given stimulus type among a set of consistent choices. In the variable mapping condition, a random subset of target stimuli were presented on each trial, so that subjects could not anticipate the upcoming stimulus. Within the multiframe search paradigm, a number of trials were presented with the task of accurate detection of target stimuli. Accuracy was strongly related to memory set and frame size in the variable mapping condition, but not in the consistent mapping condition. Under consistent mapping condition, perceptual factors played a larger role. Also, mean reaction time increased in a linear fashion as a function of memory load and frame size.

Interestingly, mean reaction time was not the only factor determining the role of memory and frame size, as variability of reaction time was greatly affected by load when a consistent memory set was not present. Attention was shown to be dependent on the extent of familiarity or previous practice with the information to be processed on consistent mapping tasks, but not with variable mapping, suggesting that with variable mapping, familiarity is much more difficult to obtain and automaticity is not possible. When consistent mapping was used, even complex information could be processed "automatically" with little attentional capacity allocated to them under conditions of high familiarity. However, under novel conditions greater task demand exists and a more effortful, sequential type of processing is required, making automaticity impossible. There is now indication that this type of processing loads more on the response system.(ref. 11,12)

The paradigms suggested in the two process model are important since they establish critical parameters for consideration of attention. To summarize, these parameters include variables such as frame size and complexity, demands on memory set, the consistency of stimuli to be attended, as well as the nature of stimulus presentation(e.g., multi-frame or single-frame). Control of these variables is necessary for the adequate study and measurement of attentional variation. Furthermore, an implicit component of this paradigm is that perceptual requirements are within certain boundaries. When the perceptual task is more complex, there may be a greater effect on attention. Table I defines some of the relevant variables to be manipulated in the measurement of attention.

The spatial characteristics of directed visual attention have been studied using paradigms involving automatic search strategies. For instance, Hughes and Zimba used spatial precuing techniques to prompt attention on a signal detection task (ref. 13). Using reaction time

measurement, spatial maps were created based on expectancy effects. Attentional expectancy seemed to be greatest along the major vertical and horizontal meridians suggesting a spatial gradient that may exist along intrinsic cartesian coordinates. Other recent studies have shown similar topographic maps of three dimensional space that relate attentional expectancy with spatial location.(ref. 14) Correct directing of attention to spatial location can have small, but significant benefits, while incorrect orientation can have significant costs. The cost of inattention increased as a function of spatial distance between cued location and actual target position. The reorientation of attention across the horizontal and vertical meridians of space was related more to ocular-motor requirements for search rather than pure sensory mechanisms. The implications of these studies, as well as recent work in other primates(ref. 15), is for an increased role of motor and pre-motor influences in directed attention.

Attentional capacity

Kahneman suggested that there is only a limited degree of energy available for performing mental operations which limits the capacity of all stages of information processing.(ref. 16) Since the earlier stages of sensory processing occur more "automatically", attentional demand is not as great as when response production is required. An important aspect of this model is the emphasis placed on the energetics of the individual's nervous system in defining capacity.

Shiffrin and several of his colleagues have investigated the parameters that determine capacity and have demonstrated equal successive and sequential performance under certain conditions of consistent mapping.(ref. 17, 18, 19). This finding was initially viewed as a reflection of parallel processing and indication that capacity was not important. However, subsequent interpretations have suggested the conditions of consistent mapping and fixed stimuli across trials may lead to conditions of automaticity. With automaticity, parallel processing is possible and capacity is less relevant. However, under conditions of variable mapping, when such processing is not possible, sequential processing is required and is determined by rate limitations of the individual's capacity.

While defining what constitutes "available energy" is difficult, the capacity model creates an important bridge to the biological characteristics of the individual. This biological constraint consists of a natural variation over time as the state of the organism changes. Furthermore, this approach predicts a relationship between attention and both central and peripheral nervous system arousal and activation. Attention cannot be viewed solely as an

information processing system, since important neurobehavioral constraints exist which mediate attention. Neurobehavioral factors may ultimately define the salience of stimuli which serve to drive attentional states.

Consideration of most current attentional models leads to a reciprocal linkage between effort and task characteristics. Tasks with high demand characteristics require greater attentional effort for successful performance. Salient stimuli or tasks with less inherent demand may elicit greater attentional effort as a result of their meaningfulness or contextual relevance. An example of the effects of salience on attention and effort may be seen in other paradigms ranging from early works on classical conditioning and the orienting response(ref. 20) to more recent cognitive studies of memory encoding. In the case of the orienting response, the salience of a stimulus in the environment ultimately determines the intensity of attentional response that occurs. This relationship will be discussed in greater detail later in this review.

Memory and attention

Recent studies of memory encoding have also suggested a relationship between task salience, the amount of attentional effort directed on the task, and incidental memory performance. Jennings and his colleagues demonstrated a relationship between variations in alertness and attention during encoding of semantic information, and subsequent recall of the information.(ref. 21) Cohen and Waters demonstrated a similar effect using a levels of processing memory paradigm.(ref. 22) When subjects performed more salient semantic tasks, as compared to phonemic and less salient semantic tasks, greater attentional activation was noted. This finding seemed to suggest an attentional explanation for the levels of processing effect, rather than the usual interpretation of a spread of activation or associative elaboration process for semantic information. While the levels of processing effect may have occurred because of greater associative elaboration on semantic tasks, it was clear that the semantic task also elicited a greater attentional response on trials that were subsequently recalled. These studies suggest that in information processing tasks requiring complex mental operations, there is substantial attentional variation that is intimately linked to the salience of the information at each moment of presentation. Furthermore, physiological activation was highly correlated with this attentional effect.

The linkage of memory encoding effects with selective attention is extremely important at a conceptual level. Typically, attention is studied as an isolated function

within paradigms that are designed to demonstrate relevant components. However, studies of other cognitive functions such as memory encoding often demonstrate strong attentional bases for memory effects. While there is a danger in making attention over inclusive, it is clear that there are attentional components in literally all cognitive tasks. Therefore, the methodological chore of researchers in this area is to establish techniques for extracting the attentional component from a range of cognitive tasks or formal neuropsychological measures. By doing so it may be possible to determine the consistent capacity that an individual possesses for a given cognitive function(e.g., word generation) from the alterations in performance that are associated with variations in attention. Based on the large body of literature previously mentioned, this variation in attention will be dependent on numerous factors including: spatial topography of the information, memory load, rate and redundancy of presentation (ie., temporal characteristics), salience of information, the modality of the task (e.g., language vs. visual analysis), as well as the available capacity or "energy" for the task.

Influence of fatigue

The term fatigue has been even more problematic for investigators than that of attention and effort. Part of the difficulty in studying fatigue has arisen from fundamental disagreements on relevant systems of study, as well as the proper level of analysis. Physiologists have long referred to fatigue within the context of neuromuscular changes occurring at a peripheral or even cellular level. On the other hand, behavioral investigators use the term fatigue to refer to subjective experiences of difficulty or inability to persist on tasks. Fatigue may also refer to actual performance decrements over time that are related to central processing depletion. In this context fatigue may have some relationship to the process of habituation, though it is typically assumed to involve a failure of action, rather than a passive extinction.

Because of the many ways in which fatigue can be conceptualized and defined, some theoreticians have questioned the usefulness of the term.(ref. 23) Broadbent discussed the difficulties in developing a test of fatigue and also raised questions about the utility of the construct.(ref. 24) Nevertheless, fatigue is a reported experience of individuals under conditions of prolonged effort, task demands and vigilance. To some extent the experience of fatigue bears on questions related to processing capacity. Clearly, changes in central nervous system arousal may elicit this experience even in the absence of a task. This is commonly noted in individuals with affective disorders,(ref. 25) as well as certain

neurological disorders affecting subcortical systems. (refs. 26, 27)

An important differentiation must be made in the study of fatigue between the subjective reports regarding an individual's experience of fatigue and actual performance decrements. These two factors may or may not be linked. A description of some recent developments in the study and measurement of fatigue will be discussed later in this paper.

Physiological correlates of attention and effort

Early studies of autonomic psychophysiology related the orienting response to attentional registration of novel stimuli. Sokolov placed much emphasis on defining the orienting response relative to perceptual matching of incoming stimuli with existing "neuronal models".(ref. 28) The diminishing of the orienting response over repetitive nonreinforced trials was defined as habituation. Much research has focused on determining whether the process of habituation is a passive extinction of response, or whether it requires an active neuronal mechanism that overrides the attentional response of orientation and causes inhibition.(ref. 29) While various neurophysiological mechanisms have been identified that may underlie orientation and habituation(ref. 30), the integration of these fundamental psychophysiological processes into more complex cognitive paradigms has been more difficult.

Recent investigations have revealed that autonomic reactivity is differentially associated with a variety of factors ranging from sensory factors to "cognitive load" and the amount of memory involvement. Lacey and Lacey provided one of the first formulations of a differentiation of heart rate response related to different task demands.(ref. 31) Heart rate deceleration was thought to relate to environmental intake, while acceleration was associated with cognitive elaboration or the rejection of information. A number of subsequent investigations examined these relationships, though more emphasis was initially placed on defining the role of cardiac deceleration in passive attention. A number of characteristics that influence this response have been investigated and for the most part they reflect the constraints of the orienting response as described by Lynn and others. Important characteristics include: 1.Stimulus significance , 2.Expectancy, 3.Stimulus intensity and rate of onset, 4.Estimation of stimulus contiguity, 5.Termination of anticipation, 6.Perceptual factors, and 7.Stimulus detection difficulties(i.e., noise or interference).(ref. 20, 32, 33) Much debate has centered on the specific role of cardiac deceleration, with explanations ranging from "the holding of available

processing capacity"(ref 34) to an enhancement mechanism for perceptual processing.(ref. 35) Obrist and his colleagues have argued that deceleration occurs due to "motor quieting" in readiness for response.(ref. 36) Without attempting to resolve this debate at the moment, it is evident that most explanations propose an adaptive basis for this response. Cardiac deceleration seems to be related to the readiness for perceptual intake.

A few studies have investigated the role of cardiac acceleration in information processing. Kahneman et al. showed a direct relationship between acceleration and transformation difficulty on a paced serial addition task.(ref. 37) Jennings later showed a dissociation between attentive listening which has been shown to cause deceleration and cardiac acceleration associated with cognitive transformations when input and output requirements were controlled.(ref. 38) This relationship has been expanded in several studies in which physiological reactivity was shown to vary in subtle ways based on conditions of memory encoding. Jennings and Hall varied memory load on task in which subjects were to process 5 and 10 item word sets.(ref. 21) Cardiac acceleration was related to the encoding phase of the task, in so much as words later recalled had greater acceleration associated with them. However, acceleration was not related to cognitive load (ie., number of items in set) directly. Instead increased acceleration occurred during encoding and seemed to relate to the degree of directed attention or effort. This interpretation was also offered in other studies. (ref. 39, 40)

Attention has been studied in other physiological systems. Kahneman and Beatty demonstrated a direct relationship between pupil dilation and the amount of information being processed in short term memory.(ref. 41) Siddle and his colleagues found that skin conductance response occurred proportional to the degree of shift in semantic category.(ref. 42) Yuille and Hare extended these findings to include a variety of other autonomic measures and also showed a direct relationship between short term memory and physiological reactivity.(ref. 43)

The results of most previous studies of information processing components and physiological reactivity suggested a relationship between task demands and autonomic activation. Except under certain cases of perceptual intake, cardiac acceleration occurred as tasks required increasing cognitive manipulations. Furthermore, a relationship between physiological activation, task demands and ultimately short term memory characteristics emerged.

Analysis of the motor systems has revealed interesting relationships between motor activation and

cognitive processes. The history of theories of covert motor involvement in thinking has origins in the work of Watson on subvocalization. Recent studies by Cacioppo and Petty have suggested that cognitive tasks such as classification based on attributes may result in different patterns of muscle response (EMG) depending on the required "level of processing".(ref. 44) Other investigators have related the memorization of words to EMG changes based on the phonetic features, thus providing evidence for a subvocal motor mechanism.(ref. 45) However, studies investigating the effect of suppression of subvocalization on short term memory performance have provided mixed results.(ref. 46)

Cohen and Waters (ref. 22) provided a methodology for dissociating some of the effects of motor system activation from other autonomic correlates of memory performance. This study provides a good example of how physiological measures can help to identify important factors that are not apparent from behavioral or cognitive measures alone. For instance, the levels of processing effect was initially viewed as a function of the "depth" or elaboration of associative processes. Cohen and Waters provided evidence for the role of attentional and psychophysiological activation in mediating the levels effect. This activation would not have been apparent without the use of physiological measurement. Since this study is an illustration of the merging of psychophysiological methods with paradigms derived from cognitive psychology, further discussion of the specific methodology and results will be provided.

Levels and stages of processing.

Cohen and Waters (ref. 22) demonstrated a levels of processing effect(ref. 47) in which words processed using more complex semantic operations resulted in greater incidental memory than words processed with less complex semantic operations. Both semantic tasks produced better recall than a phonemic task. Within this memory framework a paradigm was created that allowed for measurement of several physiological systems during different stages of the task. Figure 1 contains a schematic diagram of the stages of processing. Subjects first were presented with a cue stimulus that identified the required level of processing for the upcoming word. Seven and a half seconds later a word appeared, and subjects were required to covertly think of responses for the word (7.5 sec). In the third stage, subjects were asked to vocalize their response during a twenty second interval. Thus, analysis of heart rate, skin conductance, skin temperature, and two sites of EMG was conducted across the three stages of processing. Dependent measures consisted of the phasic change for each physiological measure relative to baseline, determined by

subtracting the average activity during a rest interval prior to each trial from the activity during each stage of the processing for that trial.

A number of interesting results emerged from the study. First, across all three levels of processing there were significant increases in physiological activation for each word item for the later stages of the task (i.e., vocalization produced more activation, as compared to covert processing, and covert processing produced more activation than the cue/anticipation stage). This activation was significant across a number of systems including heart rate, skin conductance and EMG. The magnitude of response change was greatest for skin conductance and heart rate. The heart rate response always reflected an acceleration, even in the case of the cue/anticipation stage, suggesting that even though this stage involved readiness for a stimulus, the anticipatory effect was reflected in the cardiovascular system. This finding suggested that under conditions of increased task demand the deceleration response may be overridden by competing factors of arousal associated with expectancy. This anticipatory response habituated over the course of the 39 trials, while response to covert processing and verbalization failed to habituate.

With respect to the levels of processing effect, a different pattern emerged. Significant effects as a function of level of processing were noted for heart rate and skin conductance, but not for EMG. Furthermore, there was a significant interaction between level and stage of processing, such that the verbalization of a response tended to be the point in which the greatest differential activation across levels occurred. Yet, this activation was not related to the overt motor demands of verbalization, since a levels effect was not noted in the EMG system. Table 2 shows the relationship between levels and stage of processing across the different physiological systems. These findings indicate an important relationship between task characteristics during encoding, the production of actual responses, and physiological activation. Figures 2 and 3 illustrate the main effects of this study.

As Jennings and Hall had noted earlier, retrospective comparison of items that were later recalled with those that were not, suggested that greater heart rate and skin conductance responses occurred during the encoding stages of those that were later recalled. In addition, the degree of activation noted on recalled trials was unrelated to the levels of processing effect. Therefore, regardless of the task type (i.e., semantic or phonemic), if physiological reactivity was greater on a particular trial, the information was more likely to be recalled later. This finding illustrates the close link between physiological activation and the encoding process and goes

further to point to the role of attentional direction and effort in the production of successful processing of information. The findings also indicate that greater the response production requirements during later processing stages results in greater physiological activation, illustrating the importance of response factors in this type of attentional task.

The significance of the recent studies of physiological correlates of attention are twofold. First, these studies point to relationships between components of attention and physiological activation. Clearly, as task demand increases there is an increased effect on later response components of attention. Secondly, these studies illustrate attentional influences in a variety of tasks that may normally be interpreted as being outside the realm of domain of attentional consideration. Therefore, the study of physiological correlates of cognitive performance provides an important methodology for obtaining indices of attentional variation during performance. These studies emphasize the importance of viewing attention and effort from a biobehavioral standpoint with possible implications for the adaptive functioning of the individual.

Neuropsychological Measurement and Attention

The study of brain-behavior relationships has made significant progress, in part because of refinements in assessment methodologies for accurately measuring and quantifying cognitive performance. One of the foundations of neuropsychological assessment is the use of multivariate approaches that allow for a broad cross section of many different cognitive functions. By comparing an individual's performance across these functions to established normative data, it is often possible to provide detailed information about deficit patterns. Pattern analysis of cognitive deficits can give evidence of localized brain dysfunction. The multivariate approach is critical to neuropsychological assessment because it allows for analysis of common variance across many different measures, as well as the unique variance associated with a particular measure or behavioral deficit.

Neuropsychology has been very successful in identifying performance deficits that may correlate with structural brain dysfunction. An individual's performance can be mapped across areas encompassing language, visual perception and integration, memory, motor dexterity and executive response capability. A mosaic of data emerges from the assessment that provides a cross-sectional picture of the patient's abilities. Neuropsychology has been particularly effective at measuring and providing anatomic mapping of the more static functions such as language and visual perceptual

performance. The dynamic functions of memory and executive control have also been addressed within neuropsychological methodologies. In the case of memory assessment there has traditionally been an emphasis on intentional learning paradigms, though there has been an increasing inclusion of paradigms that assess other memory modalities (e.g., episodic memory). However, the dynamic models that integrate and assess attentional variation have been underutilized in neuropsychology. A reason for this lack of inclusion of attentional methodologies may stem from inherent difficulties in modifying existing tasks to account for attentional effects. Also, the problems associated with the operationalizing of attention (as mentioned earlier) may also account for this neglect.

Within current neuropsychological methodologies, attention is either addressed through interpretation of behavioral tendencies cutting across all tasks of the assessment process, or through certain tests that are thought to load primarily on attentional factors. (For a general review of approaches to neuropsychology and assessment see ref. 48, 49, 50) In the case of the first approach, the clinician usually makes a judgment about the presence of attention deficits based on behavioral observation of the patient's response tendencies. For instance, a patient who clearly shows the capacity to perform certain types of tasks, but who doesn't perform in a consistent manner is often described as showing attentional variation. Many of these behavioral observation approaches have been formalized in the assessment of children with attention deficit syndromes. The work on attention deficit disorders of children has yielded some of the strongest methods for assessing attentional variation, which has led to success in quantifying the degree of deficit in attention, as well as subtypes of attention deficit disorders in children. (51, 52) The methodologies used in this area also have applications for assessment of adult variation in performance.

Several standardized tests are commonly used to assess attentional performance. Since the list of these measures is rather short, a brief description of the most generally used of these tests will be given. (see ref. 48) These include the digit span test, the trail making test, the cancellation tasks, the paced auditory serial addition test (PASAT), the symbol digit modality test, the Stroop test, the continuous performance test, and the span of apprehension tasks.

Within the context of intellectual assessment, the use of selective subtest patterns to define potential deficits has been well established. Specific deficits on the digit span, arithmetic and digit symbol subtests have been associated with certain attention deficit disorders. The

digit span backwards task seems to require considerable mental control and effort. As a result it is very sensitive to deficits affecting memory and response control, though certainly a variety of factors may result in poor performance on this task. The strength of this task lies in the fact that it contains a gradient of difficulty that increases effortful demands as digit length increases. However, on a given trial the time required for sustained vigilance is short, so that assessment of serial attentional variation is difficult. Thus, this task seems to measure short term memory and the capacity for effortful manipulations over a few seconds.

Both the digit symbol and symbol digit modality tasks are among the most sensitive neuropsychological measures for detecting brain impairment since a host of factors can result in impaired performance. Disorders affecting arousal, as well as motor speed will clearly cause problems. Also, task performance will be negatively affected by memory limitations, encoding difficulties or even visual perceptual deficits. However, in the absence of deficits in these other functional areas, it may be safe to assume that performance on this task reflects the ability to maintain consistent and rapid performance for longer intervals under conditions of high cognitive load for new information.

The trail making test may be more analogous to Shiffrin and Schneider's "single frame" method since visual search is required on a fixed map containing twenty five points. However, unlike that paradigm a physical response of tracking between points is required. Since the sequence of points to be tracked on Trail A contains a continuous series of numbers, the task should be rather automatic with respect to memory and cognitive demand, and most of the task's effort is associated with visual search. On Trail B, a more complex task is given in that subjects must alternate between a number and letter sequence of twenty five items. The demand of this task is greater since a switching operation is required in conjunction with visual search. This added demand typically results in a slowed response time, even in normal individuals. This task probably is affected by attentional variation, though in its normal administration, the only dependent measure is total time for completion of the sequence. Therefore, attentional variation during the course of the task is not to be measured.

Vigilance within a neuropsychological framework usually refers to the ability to sustain attention for prolonged time periods. Tasks which assess vigilance are typically simple to perform on a single trial in that detection of a stimulus (e.g., number or letter) is required. Difficulty arises because of the large quantity of trials that are administered, and the fact that it is often taxing to persist over time. The strength of this

type of task is that it fits the multiframe methodology with low memory load and relative ease of detection for any given trial. However, because these tasks are inherently simple in stimulus and response characteristics, vigilance tasks lack salience or contextual relevance. While they do provide a relatively clean measure of sustained attention, they may reflect more on capacity to resist habituation or "boredom" rather than to actively process the environment. The most commonly used measures of vigilance include: the letter, digit and symbol cancellation tasks, the perceptual speed task, and the continuous performance task. The cancellation tasks are among the most easily administered vigilance tasks, and are easier than the perceptual speed and continuous performance tasks, in that stimuli and response times are not varied. On the perceptual speed task, the target stimulus shifts between lines, thereby requiring a shift in response set. The difficulty of the continuous performance task arises from the speed of stimulus presentation and the requirement that the subject keep up response speed as well as accuracy.

The Paced Auditory Serial Addition Test is a good multi-frame task of attention. On this test a continuous performance format is used in which the rate of stimulus presentation is controlled. Instead of a simple detection task, this test requires subjects to add a number that is being presented to a number which has been previously presented. The strength of the test stems from the use of a more complex cognitive operation in conjunction with a methodology requiring sustained performance. Since the cognitive operation (addition) is relatively easy, the effect of task complexity is mainly to increase the required effort and attentional demand. However, this demand is controlled for by the rate of stimulus presentation. Faster presentation results in an increased difficulty level. Therefore, this test controls for many of the requirements for multi-frame tasks as described by Schneider and Shiffrin, though the mental operation is more complex.

The Stroop Test measures a somewhat different attentional component, associated with focused attention and freedom from distractibility. On the interference trial, subjects must block the effects of non-relevant information. The task requires an override of automatic processes of word reading for successful completion and therefore has interesting theoretical implications. The Stroop test shows that automatic processes can be countered, but that this requires much effort and that capacity is affected. Many norms are available on this test for a variety of different clinical populations.

There are several other measures included under the category of measures of executive control that reflect on

motor, pre-motor and response control and planning capabilities. These include the motor imperistance tasks, the grooved pegboard task, the word generation task, and the Porteus Maze Test. All of these measures have strong attentional requirements. For instance, the Stroop Test directly measures freedom from distractability or interference. It is beyond the scope of this paper to review all of these measures; however, it should be noted that measures of executive control emphasize the response system's capabilities.

Review of the set of "attentional" measures used in neuropsychological assessment leads to a mixed appraisal. On one hand, a number of strong measures exist that require simple cognitive operations, and therefore allow for an index of the ability to persist on multiframe serial tasks, and on single frame search tasks (e.g., Trail Making). Analysis of performance on these measures may lead to isolation of different types of attentional difficulties, especially in the absence of deficits on other more "static" measures of cognitive function.

The major limitation of these tests results from the very nature of these attentional tasks. Many of the tasks are designed to make minimal demands on cognitive operations. Therefore, these tests generally fail to measure attentional variation associated with the complex types of information processing required in many situations. Individuals may be capable of persisting on simple vigilance tasks, but may show considerable attentional variation on more complex tasks, or in certain modalities of function (e.g., the processing of language input). Therefore, there is a need for the development or modification of cognitive tasks that will allow for assessment of serial variation in performance across a variety of functional areas.

Methodological adaptations and applications

Most approaches to neuropsychological assessment are multivariate and therefore meet an important requirement for enhancing current methodologies for measuring attention. As mentioned previously, a fundamental problem with the current attentional measurement systems results from a tendency to measure attention in the context of a special attentional test. By design, most attentional tests control for task demands, stimulus characteristics and other variables so as to directly measure vigilance, visual search or some other attentional component. However, these tasks often lack contextual relevance and do not allow for an understanding of attentional variation in the course of performing naturalistic cognitive operations. While performance of addition during paced serial presentation

does reflect on the effects of increased cognitive load over time (ie., persistence), this type of task fails to account for how attention varies under more contextual demands or when other specific cognitive functions are required.

To address this problem, Cohen, O'Donnell and several colleagues are developing methods for measuring the variation in test performance accounted for by attentional fluctuation. The general approach to this work has been the modification of existing neuropsychological measures so as to allow for assessment of serial variability. In addition, several existing measures are analyzed with respect to the degree of consistency in performance. Examples of these modifications are reflected in the analysis of performance on measures such as Digit Span or the Peterson Distractor Task. In the case of Digit Span, analysis of the number of trials in which one of the two digit sequences is missed is conducted. One would expect that if the errors were due primarily to the length of the digit sequence, error should occur only on the last one or two sequence lengths. If attentional variation related to some other influence is playing a role, errors may be expected on earlier trials. In a sense, this method formalizes a method of interpretation that is often anecdotally described and used by clinicians. In the case of the Peterson Distractor Test, a modification was made so that a repeated measures analysis could be performed, thus indicating whether there was significant variability across trials of the test, independent of the length of the distractor period for a given trial. While analysis of recall as a function of time of distraction may be more important from the perspective of memory assessment, a repeated measures analysis may reveal more information about attentional variation.

Similar modifications were made in a variety of other neuropsychological measures to allow for either repeated measure analysis of performance across trials or an analysis of performance across blocks of time when a particular test is not structured with trials. The other tests in which these modifications were made include: Word Generation, Grooved Pegboard, Symbol Digit Modality Test, Trail Making Tasks, Stroop Interference Test, and the Continuous Performance Test. These tests were analyzed in manner similar to that described for the Peterson Distractor Task.

Several standard measures of cognitive functioning were modified in a way more analogous to that described for the Digit Span Test, in that analyses were conducted to determine the degree of variability in performance. For instance, the Paired Associate Learning Test was analyzed to give the number of instances when a drop in performance was

noted over successive trials. Since a normal learning curve would be expected, such a drop would suggest attentional variation. Similar strategies for analysis were used of the Block Design subtest and other verbal subtests of the WAIS-R.

These methods were later applied to investigations of patients with affective disorders, multiple sclerosis and other neuropsychological damage. The conclusion of this paper will propose applications of our neuropsychological and psychophysiological methodologies to the assessment and prediction of attentional variation and performance. Examples from recent clinical investigations will be discussed to demonstrate the sensitivity of these techniques.

Fatigue associated with multiple sclerosis.

While fatigue is not the most debilitating problem associated with multiple sclerosis (MS) it has been shown to be the most frequently reported symptom of MS patients and may be the most frustrating for some individuals.(ref. 27) However, there has been disagreement on whether symptoms of fatigue in MS are associated with actual neuromuscular deficits, or with central nervous system effects associated with motivational or cognitive changes. Furthermore, the relationship between subjective complaints of fatigue and behavioral decrements was not clear.

Cohen and Fisher recently studied 29 patients with MS whose illness was of moderate severity.(ref. 53) Patients were assessed using many of the measures mentioned in the preceding section. Evaluations were repeated, so that each patient had three evaluations in conjunction with a cross over design drug study (Amantadine). While almost all patients showed substantial motor slowness on all measures, this was not the deficit most often associated with the symptom of fatigue as reported by the patients. Instead, it was noted that patients showing greater within test variability were more apt to report fatigue. Fatigue seemed to be associated with capacity to sustain consistent performance. Patients with greater variability in general performance also tended to have more difficulty on memory tasks, particularly when distraction was involved. Fatigue consisted of an increased variability in performance, rather than a linear decrement over time.

Patients maintained a fatigue diary that was scored using a multi-dimensional rating system. Based on subjective reports, fatigue was usually felt to involve motivational and general changes in "energy" rather than muscular weakness or tiredness.

The study of fatigue in MS may be of broad interest

because of the role of subcortical influences in mediating motivational and energy states. MS affects the white matter of the lower brain systems and presumably disrupts the ease of signal transmission in the brain. Therefore, the present findings illustrate the relationship between neurological systems involved in arousal and nerve signal transmission, and associated cognitive, as well as affective changes. From a methodological standpoint, this study demonstrates the importance of serial assessment approaches, since variability across trials proved to be the most important correlate of the attentional difficulties and fatigue noted by patients.

Attentional bases of affective disorders

In another investigation, Cohen, Fennell and Bauer investigated two groups of patients with major affective disorders.(ref. 54) One group of 19 patients were diagnosed as manic, while a second group of 24 patients were experiencing major depression with symptoms of psychomotor retardation. Comprehensive neuropsychological evaluations were conducted on all patients. In addition, several of the manic patients were studied longitudinally to provide indices of any fluctuation in performance as a function of changes in their bipolar state. Previous neuropsychological investigations had suggested that non-dominant hemisphere dysfunction was a correlate of affective disorders. This interpretation was based on the finding of greater impairment on non-verbal visual motor tasks, as well as other tasks thought to be associated with the right hemisphere.(refs. 55, 56) However, analysis of performance on many of the "non-dominant hemisphere" tasks revealed that the difficulties of the affective patients was often due to a failure to generate sufficient effort and to maintain consistent attention. Tasks such as the Block Design subtest require much greater effort for successful completion than many verbal measures such as the Vocabulary subtest. On many of the verbal tests, performance is determined by either the presence or absence of a certain competency level. On many non-verbal tasks, competency may present and yet scores will be low if an individual does not have the capacity to persist. It is not surprising then that patients with disorders affecting motivation, energy level and drive would have greater difficulty on tasks with greater demands. Analysis of bipolar patients during different stages of affective state reveals variation in error types depending if they are manic or depressed.

The study of attentional variation in affective disorders illustrates the importance of extending performance measures to give indications of temporal variability in performance. The importance of determining the task demands and their relationship to available capacity is also evident.

Circadian and Drive State Influences

The performance of individuals under altered states of arousal and affect was noted in the affective disorders, and is in even more apparent in patients with damage to subcortical systems that control arousal and drive state. The importance of maintaining an optimal state of arousal during information processing was alluded to before in discussion of psychophysiological mediation of attention. Kleinsmith and Kaplan demonstrated an inverted U shaped function with optimal memory performance during periods of moderate arousal. (ref. 57) More recently, studies by Folkhard and Monk have demonstrated that this effect operates under circadian influences, and that optimal memory performance tends to occur at certain times of the day. (ref. 58, 59)

Cohen and Albers recently studied a woman (AH) with a history of craniopharyngioma that had adhered to the inferior hypothalamus. (ref. 60) AH presented with a strikingly impaired sleep-wake pattern, as well as other disturbances of arousal and behavior. The basis of her behavioral disregulation seemed largely related to destruction of the suprachiasmatic areas of the hypothalamus, which in other animals has been shown to serve as a circadian pacemaker. The unusual aspect of AH's presentation was the extreme irregularity and variation in behavior from moment to moment. Figure 4 is a graph of her sleep-wake cycle over a week's time. Neuropsychological studies conducted over the course of three separate sessions revealed similar inconsistency in cognitive performance (see Table 3). Even within the course of an hour during the evaluation the patient exhibited moments of excellent performance (e.g., successful completion of the most difficult items of the Similarities subtest) that would be followed by periods of complete logical failure. In this case, scores on a particular test do not provide an index of the type of dysfunction that had occurred. Only through longitudinal analysis of performance over the course of the session and across multiple sessions, could the fluctuation in arousal and executive control be determined. This case study again demonstrates the delicate balance between internal systems regulating drive states, arousal and mental processes, and the expression of behavioral disturbances of attention and arousal.

Work site applications

While neuropsychology usually emphasizes the study of cognitive functions in brain injured individuals, this methodology may be easily adapted for assessing and predicting normal human performance. The neuropsychological evaluation we propose utilizes three

types of measures to concurrently assess attentional variation: 1. Performance, 2. Physiological response, and 3. Subjective report. The adaptation of the methodologies discussed earlier in this paper primarily requires a situation that allows for concurrent sampling of physiological and performance variables over the course of normal work activities. Table 3 lists some of the variables that need to be considered.

The aerospace setting should be ideal for this, since physiological measurement may already be part of the operating procedure. After sampling relevant variables, correlation of physiological measures with behavioral and cognitive responses would allow for a determination of indices that reflect attentional variation. The determination of specific markers in behavioral and physiological response that predict impending attentional failure, would be the ultimate goal this strategy. Also, the use of subjective measures of self-report of fatigue and mood may provide important information, though there still needs to be much work in determining the relationship to actual performance decrements.

The use of neuropsychological methods provides a useful approach to the assessment issues in the work site. These tests have been shown to be very sensitive to changes in different cognitive functions, and they reflect fluctuations in brain state. There is also a large body of normative data for most common neuropsychological tests. As mentioned previously, adaptations can be made to make various tests more sensitive to attentional demands, and to enable an extraction of variance associated with attentional fluctuation.

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Table 1. Important variables affecting attention

- Perceptual complexity
- Response demands
- Required cognitive operations
- Memory requirements
- Task length (Vigilance demands)
- Task or information salience
- Individual capacity differences
- Intrinsic factors affecting arousal

Table 2. Summary: mean differences derived from Duncan's Multiple Range Tests*

HR	Cue	PL HSL >LSL
	Covert processing	HSL LSL >PL
	Verbalization	HSL> LSL >PL
SC	Cue	PL> HSL LSL
	Covert processing	HSL LSL >PL
	Verbalization	HSL> LSL >PL
ST	Cue	PL HSL LSL
	Covert processing	PL HSL LSL
	Verbalization	HSL> LSL PL
EMG	Verbalization>covert processing>cue (HSL LSL PL)	

*Variables in bold type are not significantly different ($\alpha=0.05$).
 PL = Phonemic level LSL = Low semantic level HSL = High semantic level

Table 3. Factors to be controlled in attentional assessment

- Multivariate assessment framework
- Range of tasks from different cognitive systems
- Serial / Multi-frame design
- Tasks varying in perceptual requirements
- Tasks varying in response production demands
- Means of quantifying demands and required effort
- Quantification of internal capacity limitations
- Correlation of physiological factors with task demands

FLOWCHART ILLUSTRATING SEQUENCE ON EACH TRIAL

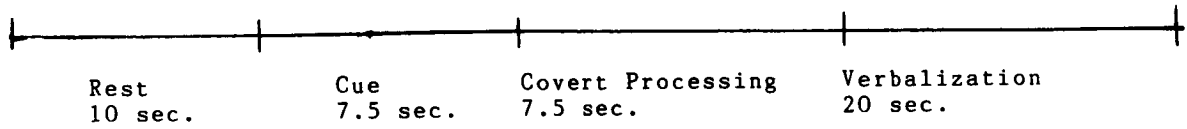


FIGURE 1. Flowchart illustrating stages for each trial of levels of processing paradigm

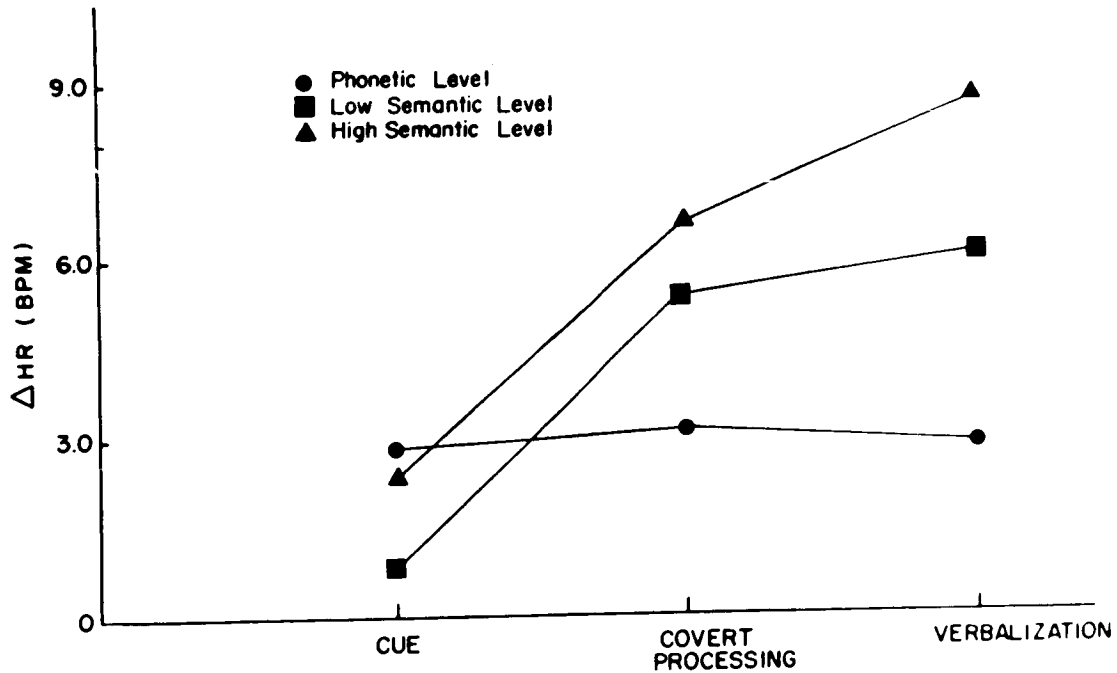


FIGURE 2. Heart rate change across the three stages of the task for each processing level

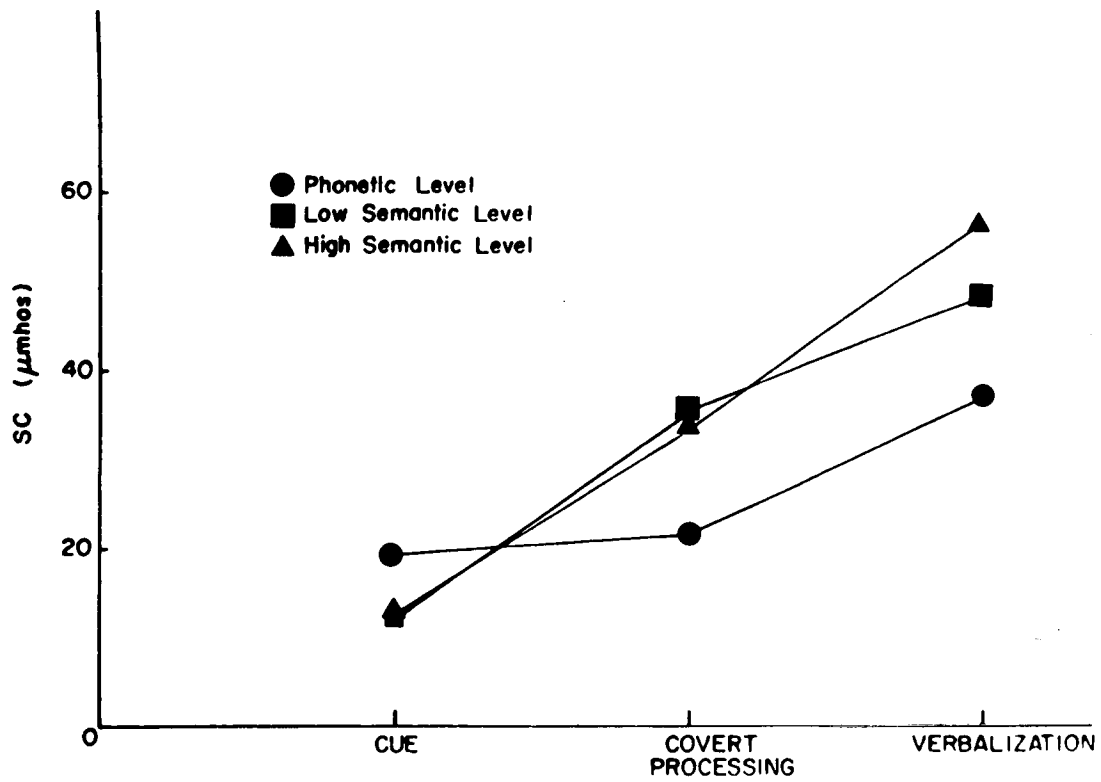


FIGURE 3. Skin conductance response across the three stages of the task for each processing level

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Sleep Periods

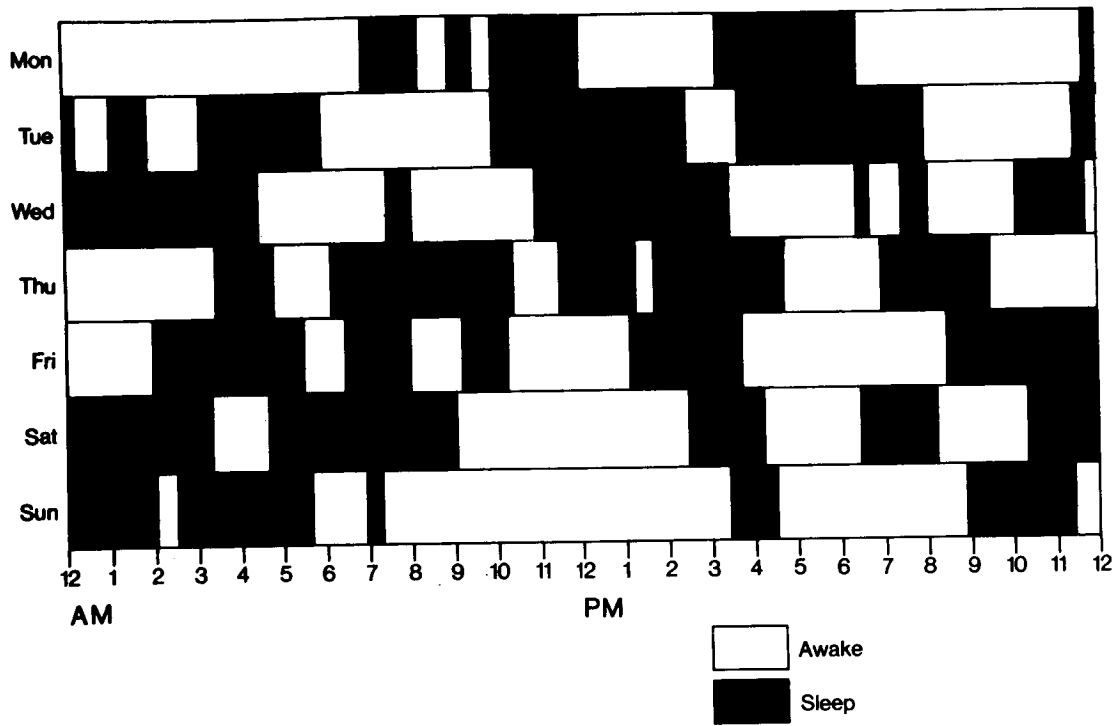


FIGURE 4. Sleep / Wake pattern for A.H., a patient with a history of craniopharyngioma

SUMMARY OF NEUROPSYCHOLOGICAL RESULTS

	FIRST EVALUATION		SECOND EVALUATION
	1ST TRIAL	2ND TRIAL	
FSIQ	90		86
VERBAL IQ	95		94
PERFORMANCE IQ	86		81
INFORMATION	7		7
DIGIT SPAN	13		11
VOCABULARY	10		8
ARITHMETIC	11		10
COMPREHENSION	7		8
SIMILARITIES	6		8
PICTURE COMPLETION	6		6
PICTURE ARRANGEMENT	8		7
BLOCK DESIGN	10		9
OBJECT ASSEMBLY	6		6
DIGIT SYMBOL	5		3
MQ=	74		70
NEW PAIRED ASSOCIATES	0/4		0/4
LOGICAL STORIES	2-0		4-0
RAVLT	6/15		7/15
RECOGNITION	13/15		12/15
BOSTON NAMING	51/85		45/85
WORD GENERATION			
(WORDS/CATEGORY)	5	10	3
TRAIL A (SEC)	52	33	65
TRAIL B (SEC)	124	75	208
STROOP			
WORD	75	86	84
COLOR	54	42	53
INTERFERENCE TRIAL	32	23	26