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DISCRIMINATING EMOTION AND MENTAL EFFORT WITH AUTONOMIC MEASURES: PUPIL SIZE AND HEART RATE AS DIFFERENTIAL MEASURES OF COGNITION AND ANXIETY

by

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TO THE MEMORY OF MY FATHER

NATHAN DUMOFF

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Abstract

Discriminating Emotion and Mental Effort with
Autonomic Measures: Pupil Size and Heart Rate
as Differential Measures of Cognition and Anxiety

Psychophysiological research has indicated that the pupillary response is a better measure of cognitive activity than emotional activity. These studies also suggested that heart rate response is a better measure of emotional activity than cognitive activity. An experiment was conducted to investigate these hypotheses. The relationship between pupil size and cognitive activity, and heart rate and emotional activity was examined.

Pupil size and heart rate were monitored during performance of word recall tasks of two levels of difficulty. Subjects were grouped according to stressfulness of instructions (high vs. low stress), trait anxiety (high vs. low test anxiety) and intelligence (high vs. low scores on the Vocabulary subtest of the WAIS).

The performance measure was the number of words recalled during the experimental period. Performance was better for the easy task than the difficult task. Interactions between levels of stress, test anxiety and task difficulty were compatible with predictions from Spence's Drive Theory. For the low test anxious group, the effect of stress appeared to impair performance in the easy word condition and improve performance in the difficult word condition. For the high test anxious group, the effect of stress appeared to improve performance in the easy word condition and

impair performance in the difficult word condition.

The results of the pupillary and heart rate data analyses were consistent with the hypothesis that the pupil is a better measure of cognitive activity than emotional activity, and heart rate a better measure of emotional than cognitive activity. Pupil size was larger during performance of the difficult task than the easy task. The stress manipulation did not affect the pupillary response. Heart rate, on the other hand, was not affected by the level of task difficulty, but was higher for the high stress group.

Multivariate analysis of the composite pupillary and heart rate responses revealed significant main effects for task difficulty and stress instructions. Discriminant analysis verified that the pupillary response was of most importance to the task difficulty effect, while heart rate was of most importance to the stress effect.

The results of the experiment are presented as evidence that the pupillary response is cotically mediated while heart rate is autonomically mediated. A modification of Kahneman's capacity model is presented as the rationale underlying the results of the experiment. The modification places the locus of the pupillary response id direct relation to the cortical attention allocation process while heart rate remains closely related to viscero-autonomic processes. Physiological evidence also is presented to support the notion that the pupillary response is cortically mediated.

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One of the earliest scientific descriptions of the pupillary response to sensory and psychosensory stimuli was presented by Fontana in 1765. Other early research (Bernard, 1852; Budge, and Waller, 1851; Darwin, 1872; Bumke, 1903; Bender, 1933; Gang, 1945) reported on the relationship between pupillary activity and both emotional and cognitive activity (Bumke, 1911; Heinrich, 1896; Lowenstein, 1920; Mentz, 1895; Roubinovitch, 1900, 1901). Informative reviews of this early literature can be found in Hess (1965, 1972, 1973) and Janisse (1977). By the time of the 1920 Lowenstein report, the notion of pupillary dilation as a response to psychological stimuli was established and generally understood.

Recent interest in specifying and measuring the parameters of the relationship between psychological variables and pupil size, to clarify the effects of cognitive and emotional activity, has been instigated by the work of Eckhard Hess and his associates (Hess and Polt, 1960, 1964; Hess, 1965). A number of recent literature reviews (Goldwater, 1972; Hess, 1972, 1973; Janisse, 1973, 1974, 1977) revealed that pupillometric research has focused on a wide range of psychological variables, e.g. cognition, stress, anxiety, emotion, sexual arousal, attitudes, attraction and personality.

ANATOMY AND PHYSIOLOGY OF THE PUPIL

Prior to discussion of the psychological literature a review of the neuroanatomical and neurophysiological bases of the pupillary response is in order. The pupil of the eye is an opening in the iris which is in back of the lens. It is the muscles in the iris which change the size of the pupil. Two sets of muscles in the iris are responsible for changes in the size of the pupil: the sphincter pupillae is a ringed band of smooth muscle fiber that goes completely around the pupil. The dilater pupillae are radial fibers of smooth muscle tissue which are arranged around the pupil like spokes of a wheel.

The pupil has been used extensively to study autonomic nervous system activity because the iris muscles described above are innervated by both the sympathetic and parasympathetic divisions of the autonomic nervous system. The sphincter pupillae is innervated by parasympathetic nerves from ciliary ganglion and the dilator pupillae is innervated by sympathetic nerves from the superior cervical ganglion.

Neuroanatomical Pathways of Iris Innervation

Efferent Sympathetic Nervous System Pathway

The posterior hypothalmus regulates sympathetic nervous system activity, which, upon stimulation results in pupillary dilation. Pupillary sympathetic efferent fibers descend from the posterior and lateral regions of the hypothalmus to a group of cells in the grey matter of the spinal cord (ciliospinal center of Budge, C8, T1-2) . The second preganglionic neuron in this pathway leaves the ciliospinal center of Budge via the ventral root to the paravertebral sympathetic chain and continues, without synapse, and terminates in the superior cervical ganglion. The third neuron (postganglionic fibers) leaves the superior cervical ganglion, runs onto the common carotid artery, eventually joins the ophthalamic division of the trigeminal (V) nerve and runs via the long ciliary nerves to innervate the dilator pupillae.

Efferent Parasympathetic Nervous System Pathway

The final common pathway to the sphincter pupillae consists of two neuronal circuits involving the Edinger-Westphal nucleus and the ciliary ganglion. "The Edinger-Westphal nucleus is part of the oculomoter complex which is located in the mesencephalon. The nucleus has its own inherent constrictor tonus or rhythm which is spontaneous and maintains the tone of of the sphincter pupillae muscle" (Zinn, 1972, p. 30). Many excitatory and inhibitory impulses influence the Edinger-Westphal nucleus. The summation of those influences determines the amount of parasympathetic outflow to the sphincter pupillae.

Preganglionic fibers from the Edinger-Westphal nucleus leave the brain stem and are situated on the IIIrd cranial nerve. The postganglionic fibers then synapse in the ciliary ganglion and myelinated, postganglionic fibers proceed to the iris via the short ciliary nerves and terminate on the sphincter pupillae.

PUPILLARY RESPONSE AND COGNITIVE ACTIVITY

The study of Hess and Polt (1964) may be considered as a starting point of continuing research efforts to explore the relationships between mental effort and pupil size. They presented subjects with four multiplication problems of increasing difficulty. Typically, subjects' pupil size showed a gradual increase during presentation of the problem, reached a peak prior to giving the solution and then returned to baseline after giving the solution. Not only was the pupil size related to the presentation-response sequence, but it also increased as a function of the difficulty of the problem. Hess and Polt concluded that pupil size "can be used as a direct measure of mental activity" (1964, p. 1190).

The primary research groups investigating the association of pupil-size changes and cognitive activity have been led by Kahneman and by Paivio and Simpson. One of the controversies in the research is whether the pupillary response reflects mental effort or anxiety. Kahneman (1973) has contended that both anxiety and mental effort play a role in the pupillary response and has provided extensive evidence of the importance of mental effort with respect to pupil response. In fact, in his review of both his own and other research, Kahneman (1973) stated that of all automatic measures, "dilation of the pupil is the best single index" of mental effort. (p. 18) .

The first relevant experiment of the Kahneman group (Kahneman and Beatty, 1966) investigated pupil size during a short-term memory task, the digit span. In this task a string of digits is presented to subjects at the rate of one per second. Subjects are then required to repeat these digits in the same order and at the same rate. Two important findings emerged from this study : (1) pupil size increased with the presentation of each digit ("loading") and (2) decreased as the subject repeated each digit ("unloading") . The loading phase of the listening and rehersal required greater mental effort than the unloading phase of responding, e.g. the function of the pupil size over time reflected mental effort. Furthermore, peak pupil size was positively related to the length of the digit strings presented, also indicating that pupil size was related to the difficulty of the task or the amount of mental effort required to solve the task . The use of more difficult tasks (e.g. digit transformation and word recall) resulted in further evidence that task difficulty had an effect on the amount of pupillary dilation. Greater pupillary dilation occured when the more difficult tasks were used. As an indicator of mental effort, or "processing load" , pupil size was thus found to be sensitive to both between-task changes in effort as well as within-task changes. Beatty and Kahneman (1966) then attempted to compare "processing load" for long term vs. short term memory via the pupil response. They found greater pupillary dilation to the recall of well-learned telephone numbers than to the recall of a string of seven digits. They concluded that long term memory processing required greater mental effort than short term memory processing. Janisse (1977), however, offered a plausible alternative interperetation of their data : emotional arousal associated with the recall of familiar telephone numbers may have enhanced pupillary dilation in this case.

In a perceptual discrimination task, Kahneman and Beatty (1967) presented data which supported the notion that pupil size was affected by task difficulty. The experimental task was to discriminate whether the pitch of a stimulus tone was higher or lower than a standard tone. The closer the frequency of the stimulus tone was to the standard tone, the more difficult the discrimination and the greater the pupillary dilation. Kahneman, Onuska, and Wolman (1968) presented strings of nine digits to subjects in a grouped (easy condition) or ungrouped (difficult condition) fashion. Pupillary response not only reflected the differences in the way the two types of presentations were processed, but again showed the relationship of overall pupil size to task difficulty. In the two experiments, Kahneman, Peavler, and Onuska (1968) assessed the effects of task difficulty, verbalization, and incentive on pupillary response. Kahneman and Peavler (1969) used incentive as a variable in a paired-associate learning paradigm. They reported data suggesting that larger pupil size to the highly rewarded items was due to the greater amount of mental effort applied to those items.

They also argued that larger pupil sizes to the highly rewarded items was not due to emotional activation.

The research of Kahneman and his associates has been an attempt to demonstrate that the pupillary response is a reliable indicator of mental effort and that a distinction could be made between the relative influences of cognitive activity and emotional activity. In his review (Kahneman, 1973), presented a model in which level of arousal was determined by two components. The first component consists of "the demands imposed by the activities in which the organism engages, or prepares to engage" (1973, p. 17). These demands may be considered to be the mental effort required by cognitive activity and pupil size may be an excellent measure of arousal reflected by these demands. The second component consists of "miscellaneous determinants, including the prevailing intensity of stimulation and the physiological effects of drugs or drive states" (1973, p. 17). The effects of the miscellaneous determinants, e.g. stress, anxiety, drive states, however, may be a confound when using an automatic variable to measure mental effort or cognitive activity. Kahneman maintained, however, that with carefully controlled experiments, pupillary response may be used to guage mental effort. Via his own carefully controlled research, Kahneman has attempted to demonstrate that pupil size changes before, during, and after a cognitive task can be accounted for by changes in mental effort rather than anxiety.

The investigations of the Paivio and Simpson groups has also established the relationship of pupillary dilation to cognitive activity, Paivio and Simpson (1966) presented evidence suggesting that task difficulty in a cognitive task affected the degree of pupillary dilation. Subjects were required to generate mental images to words which varied along the dimensions of abstractness and pleasantness. While the pleasantness dimension was not significant, pupillary dilation was greater for attempts at imagining abstract words than for imagining concrete words. Imagining abstract concepts was more difficult, leading to greater effort, more arousal and therefore larger pupil size. However, the requirement of an overt motor or verbal response appeared to have an effect on the amount of pupillary dilation, given an experimental manipulation. In studies of pupillary dilation during imagery tasks (Paivio and Simpson, 1968; Simpson and Paivio, 1966), differences between dilation to abstract and concrete words were not significant when the requirement to make an overt response was eliminated. Simpson and Paivio (1968) showed that a motor or verbal response was required to find a significant difference between dilation to concrete vs. abstract words. Other experiments (Hakerem and Sutton, 1966; Bernick and Oberlander, 1968) have shown that the pupillary response is enhanced when a verbal response is required.

A series of studies by Simpson examined the possible reasons for the enhancing effect of the overt response requirements. Using a pitch discrimination task, Simpson's (1969) results suggested that pupillary dilation was enhanced by overt responding because of evaluation apprehension as well as muscle tension in preparation for a response. In a subsequent study, Simpson and Climan (1971) investigated the effects of muscle tension on pupillary response. They found that the pupillary response was enhanced by motor activity, but that the influence of muscle tension on pupillary dilation was greater when the required response was relevant to the cognitive task. Simpson and Molloy (1971) examined the relationship of evaluation apprehension and overt responding to pupillary dilation. Results suggested that evaluation apprehension did, in fact, contribute to to the size of the pupillary response. Finally, an experiment was conducted to demonstrate that the decision process itself influenced pupil size (Simpson and Hale, 1969) It was found that the requirement to make a simple decision prior to a motor response enhanced pupillary dilation. The upshot of these series of experiments by Simpson and his associates was that pupillary dilation is associated with cognitive activity, evaluation apprehension, muscle tension and decision processes.

Other studies also provide evidence that the pupillary response is a reliable indicator of cognitive activity. Elshtain and Schaefer (1968), for example, found a positive linear relationship between pupillary dilation and the processing requirements of a verbal recall task. Examining pupil size changes in a number of intellectual tasks, Schaefer, Furguson, Klein and Rawson (1968) noted pupillary dilations during digit-span, multiplication and word-definition tasks. Payne, Parry, and Harasymiw (1968) used a series of multiplication problems to show that the percentage of pupillary dilation was associated with task difficulty. Kuc (1976) essentially verified the results of Kahneman and Beatty (1966) finding that pupil size increased during the listening phase of a digit span task and decreased during the responding phase.

Bradshaw (1967) has presented data which is compatible with the results of other investigators. Using cartoons and anagrams, subjects responded with greater dilations to the more incomprehensible cartoon drawings as well as the unsolvable anagram problems. With solution of an anagram problem, pupillary dilation reached a peak at the moment of verbalization. In a decision-making task, Bradshaw (1968) also reported a positive relationship between pupil size, task difficulty, and the rate of presentation of stimuli. The results supported the hypothesis that cognitive load determines pupillary dilations in a continuous processing task.

In conclusion, a great deal of research by Kahneman (1973), Paivio (1973) and numerous others has provided consistent evidence that pupillary dilation is a reliable indicator of mental effort. The studies reported have indicated that the pupillary response is sensitive to both between-task and within-task differences. By carefully designing experiments, the multiplicity of factors influencing the pupillary response may be controlled and the confound of these variables eliminated. In this way, the influence of each of the contributing factors, and their interactions, may be specified. Results have shown that a number of factors contribute to the pupillary response, e.g. level of cognitive difficulty of the task, decision-making requirements, evaluation apprehension, muscle tension and response requirements.

PUPILLARY RESPONSE, STRESS AND ANXIETY

Kahneman (1973) and others pointed out that stress and anxiety may contaminate the measurement of the pupillary response to cognitive activity. As mentioned previously, for example, Simpson and Molloy (1971) showed that evaluation apprehension enhanced pupillary dilation during a cognitive task.

A number of studies, however, have directly assessed the impact of stress and anxiety on the pupillary response in cognitive or other tasks. With respect to cognitive activity, Carver (1971) and Johnson (1971) both suggested that subjects became more anxious when tasks became difficult and that anxiety was the cause of enhanced dilation rather than mental effort. In a verbal recall experiment, Johnson (1971) noted an increase of arousal just prior to recall which was attributed to anticipation of recall. Although cognitive effort was still considered a viable influence on pupillary dilation, Johnson (1971) demonstrated the important contribution of an emotional factor to the pupillary response.

In a series of studies in which subjects read or listened to verbal passages, Carver (1971) <u>did</u> <u>not</u> find an association between the difficulty of the passage and the pupillary response. His results indicated that pupil size was not a good measure of cognitive information processing. In fact, he posited that anxiety or emotion that occurs with higher levels of information processing causes pupillary dilation in cognitive tasks. In support of the hypothesis relating pupillary response to mental effort, Janisse (1977) criticized Carver's (1971) study as follows :

> Carver's conclusion (1971) that the pupil cannot serve as an objective measure of connected discourse seems unwarranted. The difficulty here appears to be that Carver did not follow the process in a sequential, time locked fashion as did Wright and Kahneman (1971) and Stanners et al. (1972). Rather he used grand means for the entire listening period, which obscured variations in cognitive processing as reflected in pupil size (pp. 100-101).

Peavler (1974) directly addressed the question of whether anxiety caused by task difficulty was responsible for pupillary dilation. He presented subjects with digit strings of various lengths (5, 9, 13 digits) for immediate recall without prior knowledge of the length of the strings they were to recall. Subjects would now that a string was to be 13 digits upon hearing the tenth digit during presentation. Since the 13 digit task would be quite difficult, a dilation response would be expected at the presentation of the tenth digit if anxiety was the determining factor. Peavler (1974) found that the pupil stopped dilating after the presentation of the ninth digit. He argued that "presumed anxiety associated with information overload is not characterized by additional dilation resulting from momentary emotional states" (1974, p. 565).

The direct effect of a stressor on pupillary dilation has been assessed and has generally shown a relationship between anxiety and dilation. Using noise as a stressor, several researchers found pupillary dilation to high intensity sound (Frith, 1976; Nunnally, Knott, Duchnoski and Parker, 1967; Patrick, 1969). In a study using pupil size as a dependent measure of fear, Sturgeon (1969) found that subjects fearing snakes showed greater dilation to slides of snakes than control slides. Sweet (1975), however, described scenes that were to arouse anxiety in subjects fearful of snakes and did not find differential pupillary responses to the experimental conditions. He argued that his affective variable was not as potent as the cognitive activity required to visualize the descriptions he presented. Thus, mental effort was the dominant variable to influence the pupillary response. It should be noted that this analysis contradicts the interpretation Carver (1971) gave to the data from a somewhat similar paradigm. But, in another experiment, Polt (1970) threatened subjects with electric shock for incorrect answers in a mental arithmetic task. The threat condition produced greater pupil size. Janisse and Dumoff (1976) found pupillary dilation in an experiment using the cold pressor, indicating the relationship of the pupillary response to a physical stress.

Other types of stress situations have been found to cause pupillary dilation. As mentioned previously, Simpson and Molloy (1971) considered the presence of an audience to be a stressor, at least for high audience-anxious subjects. The authors assumed that high anxious subjects had a higher level of autonomic arousal because of exposure to stress. In a digit span task, Kuc (1976) stressed some of the subjects by emphasizing that their performance was related to intellectual efficiency and subsequent academic performance. The high stress group had a significant stress by time interaction during both the presentation and recall phases of the experiment. That instructional set has an impact on pupillary response to a task has been demonstrated in experiments by Buckhalt (1975), Kahneman and Wright (1971), and Stanners and Headley (1972).

Other studies have used paper and pencil measures to determine the relationship of pupil size to anxiety or related constructs. A paper and pencil measure used in pupillary research which is considered to be associated with anxiety (Gray, 1970) is the Eysenck Personality Inventory (EPI) (1967). The EPI has been used extensively and successfully to relate differential physiological responsivity to personality differences. The neuroticism and extraversion dimensions of personality measured by the EPI are theoretically tied to a physiological basis (Eysenck, 1967). The EPI, therefore, is a measure most suitable to identifying individual differences in physiological responding. Francis (1969) presented anxiety arousing words to subjects and found that those scoring highest in neuroticism (as measured by the EPI) displayed the largest pupillary dilations. In a subsequent study using words having connotations to religion, Francis and Kelly (1969) also found a relationship between neuroticism and pupillary dilation for Roman Catholics.

Stelmack and Mandelzys (1975) examined pupillary responses of extraverts and introverts to affective and taboo words. Their results generally showed that introverts yielded the largest pupil size and the largest magnitude of change from pre-stimulus levels. Furthermore, their results showed that changes in pupil size were greatest for taboo words over affective and neutral words. The authors related their results to Eysenck's hypothesized relationships between extraversion and cortical arousal, i.e., introverts are characterized by higher levels of arousal. Measuring speed of dilation and constriction, Holmes (1967) found fast constrictors to be more introverted than slow constrictors.

In his doctoral dissertation, Boddicker (1972) examined the relationship of neuroticism and extraversion to pupil size. In contrast to the Francis (1969) study, Pupillary dilation was greatest for those subjects scoring low on the EPI neuroticism dimension. With respect to the extraversion dimension, introverted subjects had the largest pupillary dilation to visual stimuli. Dumoff and Janisse (1976), using auditory stimuli, also found the largest pupillary responses to be displayed by subjects scoring low on extraversion and low on neuroticism, although differences between neurotics and stables did not reach significance.

Liakos and Crisp (1971) used the EPI and the Middlesex Hospital Questionnaire to determine if there was a difference in resting pupil size between neurotic psychiatric patients and normal controls. Although no difference in pupil size was found between the two groups, pupil size within the control groups was related to neuroticism as measured by the EPI as well as the anxiety scale of the Middlesex Hospital Questionnaire.

Studies relating the Repression-Sensitization Scale (R-S) (Byrne, 1961) to the pupillary response have shown mixed results. Fredericks (1970) used the R-S scale in a study of the pupillary response to pleasant and unpleasant pictorial stimuli. Sensitizers were found to show greater dilation to pleasant stimuli. Good and Levin (1970) found a tendency for sensitizers to dilate more to pictorial stimuli than repressors, although results did not reach statistical significance. Tanck and Robbins (1970) noted a tendency (although not statistically significant) for sensitizers to dilate more to visual stimuli than repressors. Finally, Salter (1973) used speed of pupillary constriction to a light stimulus as a dependent measure. Personality variables defined by the EPI or R-S scale were not found to be associated with the pupillary response.

Studies using paper and pencil measures of anxiety have also resulted in equivocal reports. Arima and Wilson (1972), for example, presented the Stroop Color Test to subjects as a stressor. There was a tendency for pupillary dilation to be greater to the stressor than to a task using more congruous word lists. In addition, Arima and Wilson (1972) examined the relationship of the pupillary response to scores on the Manifest Anxiety Scale (MAS) (Taylor, 1953). No significant main effects were found between high and low anxious subjects; there were significant 3-way interactions, however, suggesting that high anxious subjects dilated more to the stressor than low anxious subjects. Adams (1969) attempted to find response differences between subjects scoring high and low on the IPAT Anxiety Scale, but without success.

As mentioned previously, Simpson and Molloy (1971) found a significant difference between subjects scoring high and low on the Audience Sensitivity Inventory (ASI) (Paivio, 1965). Pupil size for high anxious subjects was significantly larger than for low anxious subjects throughout a short-term memory and digit transformation task. In a pause period prior to responding, the low anxious group showed a decrease in pupil size while the high anxious group retained a large pupil size. The authors considered their results to indicate that high anxious subjects were functioning at a higher level of arousal causing pupil size to enlarge.

Using the Test Anxiety Scale (Sarason, 1972), Kuc and Janisse (1976) did not find a main effect for test anxiety on a digit-span task. However, a Test Anxiety by Intelligence interaction was significant indicating that among those scoring high on an intelligence measure, high test-anxious subjects displayed a larger pupil size than low test-anxious subjects. In addition, there was a significant Test Anxiety by Seconds interaction during a six second rest period between trials. This result suggests the importance of examining Test Anxiety in interaction with other, moderating, variables.

The research examining the relationship between the pupillary response and personality constructs, especially anxiety, has not provided clear and consistent results. As reported above, the Audience Sensitivity Inventory and the extraversion dimension of the Eysenck Personality Inventory have been successfully related to the pupillary response. Paper and pencil measures of anxiety, however, have not been very useful as predictors of pupillary responsivity in a variety of experimental situations. One of the shortcomings of these investigations may very well have been the ambiguity associated with the construct of anxiety. In order to effectively investigate the relationship between anxiety and the pupillary response, a clear concept of the construct of anxiety must be employed consistently by researchers. The general area of anxiety research is fraught with imprecise definition and inconsistent use of the concept of anxiety. Spielberger (1966) has pointed out how the use of a variety of constructs for anxiety has resulted in confusion about the meaning of the term as well as the validity of its experimental application. The following section will consider how definitions of anxiety may be catagorized differently, and will consider the reliability and validity of these various definitions.

THE CONSTRUCT OF ANXIETY

For scientific purposes, the definition of anxiety must be precise, objective and measurable. In scientific investigations, the construct of anxiety is operationally defined in terms of specific types of responses to particular stimuli. These operational definitions only partially define the construct. But, if anxiety is a unitary construct, then all of the partial operational definitions should be positively correlated. This section will consider the reliability, validity and appropriateness of the categories of operational definitions of anxiety appropriate to this study: (1) physiological and behavioral indicators, and (2) paper and pencil measures.

Physiological Indicators

Anxiety can operationally defined in terms of physiological signs such as heart rate, blood pressure, respiration rate, GSR and pupillary dilation. These physiological measures reflect autonomic nervous system activity in response to emotional stimulation. Typically, subjects can not alter or control their autonomic nervous system activity. For this reason, physiological measures can be considered to have an advantage over other measures which may be biased by voluntary misrepresentation. In addition, physiological measures are not affected by the use of denial as a defense against awareness of anxiety (Levitt, 1967).

Defining anxiety in terms of physiological measures presents a number of problems. One of the most troublesome aspects of defining anxiety in this way is that patterns of physiological measures are not consistent across subjects. Intercorrelations of physiological measures are low and often insignificant whether measured at rest or after an experimental manipulation. Krause (1961) cited a number of reports showing that physiological response patterns differ between persons, e.g., mean inter-correlations for seven variables was .09 (Ax, 1953). Individuals are found to be consistent under repeated identical experimental situations. Lacey (1953), for example, found that subjects have different patterns of autonomic responses which can be reproduced over time and are consistent for various stressors. Furthermore, the sensitivity of various autonomic measures of anxiety are person-specific, i.e., for one person some measures are more sensitive to changes in anxiety level than others.

Investigators have not found a consistent pattern of physiological responses which differentiates anxiety from other emotions. In a review of the evidence, Martin (1961) could not report conclusive evidence of a particular physiological pattern for anxiety. He compared the results of a number of studies to determine if a consistent pattern of responses to anxiety could be distinguished from responses of fear or pain. He reported some evidence for a definable anxiety pattern. However, there are inconsistencies across experiments, perhaps because : (1) different stimuli elicit different response patterns, (2) the stimuli that elicit anxiety are person-specific, (3) it is difficult to determine whether stimulus conditions evoke anxiety reactions or some other emotional reaction, and (4) studies which compare anxious groups with normals are contaminated by the possibility that those diagnosed as anxious also experience some other emotion such as anger.

Cattel and Scheier (1961) and Izard (1971) both indicated that part of the problem of finding a consistent pattern of physiological responses for anxiety is due to a faulty assumption by experimenters.

Investigators assume that experimental treatments produce a single, pure anxiety response. Cattel and Scheier (1961) hypothesized that there is a constant response pattern for anxiety; however, environmental stimuli are not pure and produce mixed response patterns. They suggested that multivariate, factor analytic methods be used to tease out and identify the pure anxiety response pattern. They concluded from their studies that the anxiety pattern consists of more than one physiological indicator and presented a list of responses which describe the physiological pattern of anxiety. Similarly, Izard (1971) maintained that anxiety is not a unidimensional construct. Anxiety is a composite of fear and two or more other primary emotions, and, therefore, a single, pure anxiety response can never be defined. A number of physiological patterns would equally represent anxiety depending upon the composite of primary emotions being measured.

In addition, there may be differences in the physiological response patterns of trait anxiety and state anxiety. The differentiation between trait and state anxiety was proposed by Spielberger (1966) in order to bring specificity to the use of an otherwise ambiguous term. As mentioned previously, concepts of anxiety as applied to experimental research have been inadequate. One reason for this inadequacy was the failure to differentiate between anxiety as a transitory state (A-State) and as a stable personality trait (A-Trait). A-State and A-Trait have been defined as follows (Spielberger, Gorsuch and Lushene, 1970):

> State anxiety (A-State) is conceptualized as a transitory emotional state or condition of the human organism that is characterized by subjective, consciously perceived feelings of tension and apprehension and heightened autonomic nervous system activity. A-States may vary in intensity and fluctuate over time.

> Trait anxiety (A-Trait) refers to relatively stable individual differences in anxiety proneness, that is, to differences between people in the tendency to respond to situations perceived as threatening with elevations in A-State intensity (p. 2).

The State-Trait Theory of Anxiety assumes that the arousal of A-State is a process which involves the concepts of stress, threat, cognitive appraisal of stress as personally threatening, sensory and cognitive feedback mechanisms, defense mechanisms and coping behaviors as well as the concepts of A-State and A-Trait. Spielberger outlined the process as follows :

> It is hypothesized that the arousal of A-States involves a sequence of temporally ordered events in which a stimulus that is cognitively appraised as dangerous evokes an A-State reaction. This A-State reaction may then initiate a behavior sequence designed to avoid the danger situation, or it may evoke defense manuevers which alter the cognitive appraisal of the situation. Individual differences in A-Trait determine the particular stimuli that are cognitively appraised as threatening (Spielberger, 1966, p. 17).

According to the Trait-State Anxiety Theory, it is expected that those high in A-Trait will display elevations in A-State more frequently and with greater intensity than those low in A-Trait. Those high in A-Trait are more likely to interpret a stressful situation as personally threatening and thus react with state anxiety. However, measures of A-Trait only offer information about the likelihood that a particular stress situation will arouse state anxiety in a particular individual. It is necessary that measurement of A-State be taken to determine if an individual is experiencing state anxiety.

Given a particular experimental treatment, the response patterns for high trait anxious individuals may be different from those of low trait anxious individuals. Cattel and Scheier (1961) reported that physiological patterns differentiate persons high or low in trait anxiety and that these differences were mainly the same as those that defined differences in state anxiety. However, Cattel (1966) noted that despite the great similarity, the physiological pattern of anxiety as a trait could be distinguished from the state pattern on most autonomic variables.

Behavioral Indicators

Behavioral definitions of anxiety are closely related to physiological definitions and at times the distinction between the two becomes arbitrary. As with physiological definitions, investigators seek an identifiable pattern of behavioral responses which differentiate anxiety from other emotions.

One type of research which examines behavioral evidence of anxiety is that which considers the effects of stress on task performance (Gaudry and Spielberger, 1971). The effects of anxiety on task performance are not always distinguishable from motor or physiological signs. The types of tasks which appear to be affected by anxiety are learning and memory tasks such as paired-associate learning (Gaudry and Spielberger, 1970) and serial learning (Spielberger and Smith, 1966) as well as perceptual tasks (Denny, 1966). In a review of the relevant studies, Martin (1961) concluded that the effects of stress are greater on tasks involving strong competing responses and that stress facilitates performance to a point and then impairs it. However, he did not find evidence that these performance effects could be identified anymore with anxiety than other constructs such as "drive or arousal". He pointed out that task performance may be helpful in defining a response pattern for anxiety, but that independent measures, (e.g. physiological measures) of anxiety are required to differentiate the construct of anxiety from its effects on performance. Separating the evidence of anxiety from its effects is an arbitrary distinction.

The validity of intercorrelations of behavioral measures is compromised because behavioral indexes can not be assessed simultaneously. The nature of behavioral measures of the effects of anxiety often requires that different tasks be presented serially or at different times. Time and order effects will distort the correlations obtained. Although Martin (1961) reported low intercorrelations between behavioral measures of anxiety, an anxiety factor did emerge in a factor analysis of these measures. Nevertheless, other factors emerged which indicated that performance on a task is also influenced by intelligence, motivation and the nature of the task. In other factor analytic studies (Cattel and Scheier, 1958), an anxiety factor emerged, but loadings on this factor were consistently high only for self-report type measures. Few of the behavioral-physiological measures had loadings over 0.30. Are the various behavioral measures of anxiety measuring the same thing ? Martin asserted that the interpretation of factors and the construct validity of the assessment procedures should be clarified by using the factor as a variable in experimental research.

Research on behavior or performance measures does not offer an unequivocal definition of anxiety in terms of a pattern of behaviors for several reasons : (1) most performance studies are univariate; it is difficult to measure simultaneously more than one behavioral index; (2) few studies compare behavioral effects across different emotional states; (3) the relationship of behaviors (or performance) to anxiety is not monotonic; poor performance may be indicative of very low or very high anxiety (Stennet, 1957; Gaudry and Spielberger, 1971); (4) although performance effects may indicate that some emotion is present, they do not sufficiently indicate that it is anxiety that is present; and (5) the effects on task performance may be evident only with intense anxiety (indicating the lack of sensitivity of these measures).

Paper and Pencil Indicators

Many researchers assess anxiety by use of a paper and pencil inventory consisting of a number of statements or words which describe the way an individual may feel about himself in general or in a particular situation. Subjects are required to give an introspective report by indicating the degree to which the statements match their feelings, mental state or physiological reactions. The subjects' degree of agreement with each of the statements is quantified and contributes to a total score which reflects the level of anxiety. In some ways the inventory can be considered a "verbal surrogate for behavior samples (Lader and Marks, 1974)."

A number of inventories to determine anxiety levels have been used extensively in experimental studies. The Manifest Anxiety Scale was one of the earliest inventories and stimulated a great deal of research on anxiety. It consists of a subset of MMPI items and is used as a measure of trait anxiety. The IPAT Anxiety Scale, the S-R Inventory of General Trait Anxiousness (S-R GTA), the Test Anxiety Scale (TAS) and the Achievement Anxiety Test (AAT) are examples of other inventories which have been used to measure trait anxiety. As examples of research using these measures, Sarason (1972) used the TAS to divide subjects into high and low test anxious groups in order to determine the interactive effects of pretest instructions with test anxiety; Endler and Schedletsky (1973) used the S-R Inventory of Anxiousness as a measure of trait anxiety to study the influence of trait anxiety on state anxiety in different ego threat and physical threat conditions. The State-Trait Anxiety Inventory (STAI) and the "Today" form of the Affect Adjective Check List are examples of inventories which measure state anxiety.

The reliabilities and validities of various scales depend on the intended purpose of the scales (Lader and Marks, 1974). Researchers must distinguish between inventories which measure state vs. trait anxiety and pathological vs. normal anxiety. They must also consider whether the inventory is designed to produce diagnostic profiles or to qualify the severity of illness in those already diagnosed. Measures of trait anxiety, for example, should not be used to measure changes in state anxiety with treatment because of the differences in the design criteria in the two types of scales. Lader and Marks (1974), for example, reported reliabilities from 0.56 to 0.94 for a number of general anxiety scales from various studies. Endler (1975) reported high reliability for the SR-GTA (0.62 to 0.86). As an additional example of inventory reliability, Spielberger (1970) reported high test-retest reliability for the STAI A-Trait scale (0.73 to 0.86) and a lower test-retest reliabilty for the A-State scale (0.16 to 0.54). These differences in reliability are consistent with the intended purpose of the scales. However, the K-R(20) coefficients were 0.83 to 0.94 for the A-State scale and 0.86 to 0.92 for the A-Trait scale.

The paper and pencil inventory is the most popular measure of anxiety for experimental purposes. Sarason (1966) noted that the self-report scale is the procedure of choice for measurement of constructs in all major personality theories. Inventories are inexpensive, can be administered to groups quite easily and can be scored quickly. They are more reliable than other measures of anxiety in that they are less affected by uncontrollable variables in the experimental situation.

Sarason (1966) expressed reservations about the validity of anxiety scales as they are currently formulated. He questioned the assumption that high scores in anxiety scales actually "reflect the tendency to experience and manifest frequently the overt behavioral characteristics of... unambiguous anxiety (p. 68)." Unambiguous anxiety was defined behaviorally as that intense pattern of behaviors marked by pain, anticipated danger, terror, attempt at flight, etc., which would be readily labelled as anxiety by observers. He also questioned the assumption that high scores on anxiety scales have shown that anxiety causes disruptive effects on performance. Since there is little basis to assume that anxiety scales measure only anxiety, it is possible that some other associated process accounts for disruptive effects. Sarason (1966) called for a behavioral definition of anxiety and behavioral validation of self-report measures. He rejected the notion that anxiety can be defined as 'that which anxiety scales measure'. He stated that "... a self report about an affect involves processes not contained in a definition of the affect. What I have been suggesting is that the verbal response to our scales may be telling us more about the self than about the affect (1966, pp. 78-79)."

ANXIETY AND PERFORMANCE UNDER STRESS

Much of the early research relating anxiety to performance was inspired by the development of the Manifest Anxiety Scale. The theoretical basis of this scale is Spence's Drive Theory (Spence, 1958; Spence and Spence, 1966) which assumes that the relationship between anxiety or drive level on performance depends upon the relative strength of the correct or competing response tendencies evoked by a particular task. The theory predicts that high anxious subjects should perform better on easy tasks, where correct responses are dominant; on more difficult tasks, where competing response tendencies are stronger than correct responses, performance will be impaired. Many studies (e.g. Farber and Spence, 1953; Montague, 1953; Ramond, 1953; Spence, 1964; Taylor and Chapman, 1955), in fact, have supported this theory with the finding that high anxious subjects perform better on easy tasks than low anxious subjects, and conversely, that high anxious subjects perform worse than low anxious subjects on difficult tasks.

Spielberger, Goodstein, and Dahlstrom (1958), for example, investigated the effects of anxiety on performance in a recall task and interpreted the results as consistent with Drive Theory. Subjects scoring high and low on the MAS were presented nine geometric designs of varying complexity. The order of presentation maximized the range of recall difficulty. After an unrelated, brief interpolated task, subjects were asked to reproduce the geometric designs. In accordance with Drive Theory, high anxious subjects performed better on the easier geometric designs than low anxious subjects, while the low anxious subjects were superior in recalling the more complex designs.

Spielberger and Smith (1966) also used the MAS to study the effects of anxiety on performance in a serial rote-learning task. Subjects were required to learn a moderately difficult list of 12 CVC nonsense syllables. Drive Theory predicted that low anxious subjects would perform better than high anxious subjects early in learning, and inferior to high anxious subjects later in learning. High anxiety would facilitate performance later in learning when correct responses were dominant. Subjects scoring high and low on the MAS were given standard, non-threatening instructions for the serial learning task. The results of the study indicated no differences, at any stage of learning, between those scoring high and low in anxiety. In a second experiment, however, Spielberger and Smith (1966) repeated the above experiment with one change : subjects were told that performance on the task was highly related to intelligence in order to make the situation more stressful. Under these conditions, a difference was found between high and low anxious subjects according to the predictions from Drive Theory.

The results of these two studies are important for several reasons. Firstly, they pointed out the importance of the effects of stress on performance as well as the interrelationship between stress and anxiety as it affects performance. Secondly, the results suggested that measures of trait anxiety may be inadequate in that they do not necessarily imply that subjects are experiencing anxiety (A-State) during the experimental task. Therefore, an adequate stressor must be applied to insure that anxiety is aroused in subjects and a measure of A-State is required to assure that the stressor has adequately served its purpose.

The concepts of state and trait anxiety have other important implications for research on the relationship of anxiety to performance and physiological responsivity. Some of these implications are related to the controversy between the role of trait variables as opposed to situation variables in anxiety research. Bowers (1973) and Mischel (1968) have levelled a number of criticisms at the trait approach to personality theory. The Trait-State Anxiety Theory is basically a trait approach to research on anxiety. As pointed out by Mischel (1968), the predictive utility of trait assessments has been quite poor. This implies that measures of trait anxiety will not provide accurate predictions of state anxiety. According to the person by situation interaction model, "the situational characteristics have to be taken into account when describing and predicting an individual's anxiety state (Magnusson and Ekehammer, 1975, p. 27)." The joint, or interacting, affects of A-Trait and situations will more accurately serve to predict behavior (A-State) than A-Trait alone. Because the meaning of a situation is a function of individual cognitions, those measures of A-Trait which do not specify situations can not expect to capture those occasions to which a person will respond anxiously. Bowers (1973) has also indicated that response variables (anxiety indicators) account for a large proportion of total behavioral variance. Therefore, as Endler and Hunt (1969) have indicated, situations and response indicators should be categorized after which individuals may be classified into homogeneous groups on the basis of the ways they respond across categories of situations. Thus, personality description may be improved, and therefore research using personality description improved, via a more ideographic approach of classifying individuals according to the interactions of individual difference variables with situational variables. Basically, then, A-Trait measures will more specifically define a person's potential to react anxiously in a particular way to a particular type of situation.

Spielberger (1975), for example, maintained that research on anxiety should attempt to identify those stressful stimuli that evoke differential levels of state anxiety for people who differ in A-Trait. More specifically, Spielberger (1975) was referring to those stressful conditions involving ego threat or threat to self esteem. Rappaport and Katkin (1972) and O'Neill, Spielberger and Hansen (1969) have found greater changes in A-State by those high in A-Trait than by those low in A-Trait under conditions which are ego threatening. However, for physical danger situations, levels of A-Trait do not differentiate between levels of A-State response. Katkin (1965) and Hodges and Spielberger (1966) found that levels of A-Trait, as measured by the MAS, did not differentiate between changes in A-State, under conditions of threat or shock. Hodges and Spielberger (1966) did find, however, that a Fear of Shock Questionnaire (FSQ) was an effective predictor of heart rate changes under conditions of threat or shock.

Endler and Shedletsky (1973) used the S-R Inventory of Anxiousness (Endler, Hunt and Rosenstein, 1962) as a measure of trait anxiety, as opposed to the MAS or the A-Trait scale of the State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch and Lushene, 1970). The MAS and the STAI are unidimensional, measuring only interpersonal trait anxiety, while the S-R Inventory of Anxiousness is multidimensional and measures trait anxiety associated with interpersonal, physical danger and ambiguous threat situations.

These studies point out that the multidimensional nature of anxiety must be considered when investigating a person (trait) -by-situation interaction. As Endler, (1975) has noted, "In order for Person (A-Trait) by Threatening Situation interactions to induce differential changes in A-State, the dimension of A-Trait classification should be congruent with the threatening situation (p. 153)." Thus, an appropriate stressor must be applied to subjects distinguished by an appropriate measure of trait anxiety in order to fruitfully examine the relationship of state anxiety and performance.

One measure of trait anxiety which is situation specific is the Test Anxiety Scale (TAS) (Sarason, 1957). This scale measures the anxiety that is aroused by tests or other similar evaluations or assesments. Sarason (1972) pointed out that test anxiety may be viewed "as a proneness to emit self-centered, interfering responses when confronted with evaluative conditions (p. 383)." These interfering responses consist of two components, autonomic reactivity, and cognitive activity, which interfere with task demands. Research on test anxiety has investigated the relationship between test anxiety and performance on verbal and motor learning (Sarason, 1960; Sinclair, 1969), classroom examinations (Gaudry and Bradshaw, 1970; Paul and Eriksen, 1964), college achievement (Alpert and Haber, 1960; Sarason, 1961; Spielberger, 1962), as well as intellignece test performance (Phillips, Martin and Meyers, 1972).

An experiment by Sarason (1961) serves as a typical example of research indicating that performance of high test anxious subjects is poorer than low test anxious subjects under conditions of ego-threat. In a difficult serial learning task, half the subjects were told that the task was an intelligence test and related to their level of ability. Prior to the experiment, the Test Anxiety Scale and the General Anxiety Scale (GAS) (Sarason, 1958) had been administered to all subjects. Under the evaluational condition, subjects scoring high on the TAS performed significantly poorer on the task than those scoring low on the TAS, while no difference occurred under neutral conditions. Furthermore, scores on the GAS were not predictive of success on the serial learning task.

ANXIETY AND INTELLECTUAL PERFORMANCE

Research with respect to the relationship between anxiety and intellectual ability has produced inconsistent findings. In a review of the literature, Matarazzo (1972) pointed out that some of the research reported a negative relationship between trait anxiety and performance on tests of intelligence (e.g. Grice, 1955; Kerrick, 1955; Matarazzo, Ulett, Guze and Saslow, 1954). Most research efforts using measures of trait anxiety resulted in no relationship between the two variables (e.g., Dana, 1957; Jurjevich, 1953; Matarazzo, 1955; Sarason, 1956; Siegman, 1956; Spielberger, 1958).

Investigations of the relationship between anxiety and intellectual performance have been improved by the distinction made between state and trait anxiety (Spielberger, 1966). When subjects have been stressed, producing state anxiety, a negative relationship between anxiety and intellectual performance is found (e.g., Hodges and Spielberger, 1969; Mandler and Sarason, 1952; Moldawsky and Moldawsky, 1952; Morris and Liebert, 1969; Pyke and Agnew, 1963; Walker and Spence, 1964). Furthermore, experiments using the TAS consistently show a negative relationship between test anxiety and intellectual performance (Hill and Sarason, 1966; Paul and Eriksen, 1964; Sarason and Minard, 1962; Sarason, 1963; Sarason, Hill and Zimbardo, 1964). This is to be expected since the TAS is specific to the testing situation and is therefore more sensitive to subjects' state anxiety reactions.

ANXIETY AND INTELLECTUAL ABILITY INTERACTION

Spielberger (1966) presented an extension of Spence's Drive Theory to account for the interaction of intelligence and anxiety as it affects performance. According to Drive Theory, high anxious subjects will perform better than low anxious subjects on an easy task because correct response tendencies are dominant. On a difficult task, competing (incorrect) response tendencies are dominant, and low anxious subjects will perform better than high anxious subjects. However, the difficulty of a task, for a particular subject, depends upon the intelligence or ability of that subject.

A number of studies reported by Gaudry and Spielberger (1972) have demonstrated the importance of considering intelligence and task difficulty when investigateng performance under stress. Gaudry and Spielberger (1970), for example, studied the interactive effects of anxiety and intelligence on performance on a simple paired-associate learning task. Using two levels of anxiety and two levels of intelligence, analysis of the mean reciprocal latency scores showed that :

> (1) early in learning, high anxiety facilitated performance for high IQ Ss and impaired performance for low IQ Ss relative to their low anxiety counterparts;
> (2) later in learning, high anxiety tended to facilitate performance for both high and low IQ Ss;
> (3) at both stages of learning the performance of high IQ Ss was superior to that of low IQ Ss (Gaudry and Spielberger, 1971, p. 60).

Denny (1966) examined the effects of intelligence and anxiety on tasks of moderate difficulty. Using a concept formation task, Denny found that the performance of high IQ subjects was enhanced by anxiety, while their performance was impaired by low levels of anxiety. Similar results were provided by Deese, Lazarus and Keenan (1953) who reported that : (1) among high intelligence subjects, high levels of anxiety facilitated performance, and (2) among lower intelligence subjects, high levels of anxiety impaired performance. Finally, studies of the effects of intelligence and anxiety on difficult tasks (Spielberger and Weitz, 1964; Gaudry and Fitzgerald, 1971) have also shown the same relationship between anxiety, intelligence and performance. In the case of difficult tasks, however, the results are not quite so clear-cut as with simple and moderately difficult tasks. Nevertheless, these studies point out that intellectual ability must be considered when examining the relationship between anxiety and performance.

HEART RATE IN RELATION TO ANXIETY AND MENTAL EFFORT

Kahneman (1973) wrote that pupillary dilation "is the best single (autonomic) index" of effort while "increased heart rate can not be used as a measure of effort (p. 18)." However, heart rate response does distinguish between states of arousal. In their factor analytic studies of variables relating to anxiety, Cattel and Scheier (1961) found heart rate to be strongly related to state anxiety. In a comparison of the evidence from three studies (Ax, 1953; Lewinsohn, 1956; Schachter, 1957), Martin (1961) showed that heart rate increased from resting levels for both fear (anxiety) and anger provoking experimental manipulations. Moreover, "heart rate increased more in fear (anxiety) than anger in all three studies (p. 236)." Martin presented additional evidence (DiMascio, Boyd and Greenblatt, 1957) of a positive relationship between heart rate and anxiety.

Kahneman (1973) has pointed out that high arousal states may be characterized by heart rate increase or decrease. Thus, in some experimental situations, autonomic variables such as pupil size and GSR may indicate sympathetic activity while the response of the heart is either sympathetic or parasympathetic. Because of this "directional fractionation" of autonomic variables, heart rate may not be used effectively as a measure of mental effort. Libby, Lacey and Lacey (1973), for example, presented pictures which varied on the dimension of Attention-Interest. They found that while pupil size increased during the presentations, heart rate decreased. Furthermore, the more interesting the pictures, the larger the pupils and the slower the heart rate.

In more complex, cognitive tasks, Lacey, Kagan, Lacey and Moss (1963) found that different stressors produce different patterns of physiological response. Subjects were required to perform a series of tasks which involved environmental "intake" or environmental "rejection". The former are tasks in which the subject is to passively attend to the environmental inputs. The latter are tasks which require internal cognitive activity (such as mental arithmetic) or which involve noxious stimulation (e.g. cold pressor) wherein environmental events are disruptive to the subject. While other autonomic measures consistently showed a sympathetic response to all tasks, heart rate responses accelerated for the cognitive tasks and decelerated during the tasks requiring only simple environmental reception. In addition, Tursky, Schwartz and Crider (1970) found that passive listening resulted in cardiac deceleration while requirements to cognitively manipulate the presented information resulted in cardiac acceleration.

Kahneman, Tursky, Shapiro and Crider (1969) measured pupil response, skin conductance and heart rate to a digit transformation task. In contrast to the Tursky, et al. (1970) study, they found heart rate increase with the presentation of each digit and deceleration as the subject repeated each digit. However, the Kahneman, et al. (1969) study presented digit transformation instructions prior to digit presentation, Apparently, therefore, the increase in heart rate in the listen phase was due to cognitive manipulation of the digits as they were being presented. In addition, Kahneman, et al. (1969) manipulated the level of difficulty of the digit-span task. The three autonomic responses measured reflected task difficulty in that peak responses were greatest for the most difficult task and smallest for the easiest task. It must be noted, however, that these differences were significant for pupil size ($p \leq .001$) and skin conductance ($p \leq .02$), but only marginally significant for heart rate ($p \leq .09$).

Kuc (1976) also examined pupillary and heart rate response in a digit-span task, but included stress instructions as a variable. He found that the pupillary response discriminated between subjects' intelligence and the correctness of response, while the heart rate was not significantly related to these variables. Conversely, heart rate did distinguish between stress groups. He concluded that the pupillary response was more sensitive to cognitive variables than heart rate.

Elliot (1969) studied heart rate responses in a conflict situation induced by the Stroop Color Word Test. He found cardiac deceleration to be associated with the inhibition of responses induced by the conflict situation. Elliot concluded that the instigation, anticipation and initiation of responses, as well as the presence of incentives, affect heart rate acceleration. On the other hand, inhibition of responses is associated with heart rate deceleration. In another experiment, Elliot (1975) found heart rate acceleration to anticipation of shock. Campos and Johnson (1966, 1967) also provided evidence that cardiac acceleration is associated with response variables. Thus, if a subject is preparing a verbal response, cardiac acceleration will occur even if he is attending to environmental input. Adamowicz and Gibson (1970, 1972), however, pointed out that the interaction of the attentional demands of a task and the verbalization requirements must be considered in experiments using heart rate as a dependent measure.

Other research (e.g., Deane, 1961, 1964; Jenks and Deane, 1963) investigated the relationship of anxiety to heart rate response. Deane (1961), for example, provided evidence that there are two opposing heart rate responses during experimentally induced anxiety. Subjects were told to expect a shock at some time during a series of visually presented numbers. With this experimental paradigm, all subjects showed an acceleration in heart rate early in the presentation of numbers, and deceleration immediately prior to and during the time the shock was expected. Similar results were obtained when noise was used instead of shock as a noxious stimulus (Jenks and Deane, 1963). Deane (1964) also investigated the possibility that the opposing heart rate responses were attributable to differential respiratory activity as suggested by Westcott and Huttenlocher (1961). He found that subjects required to breathe at a constant rate throughout the experiment also displayed the same pattern of heart rate response as in the previous experiments.

Deane (1964) also found that when subjects were told exactly when to expect a shock, the acceleration and deceleration effects occured on the first trial. However, if the subject did not know exactly when the shock was to be received, the deceleration effect appeared only after several shocks were received. Deane (1964) attempted to relate the opposing heart rate responses to affective states as follows :

> ... when S expects to receive a noxious stimulus a state of anxiety with its associated response of cardiac acceleration is aroused; and, in addition, if S expects the noxious stimulus at a particular instant in time a state of fear with its associated response of cardiac deceleration is aroused immediately prior to and during the time the stimulus is expected (Deane, 1964, p. 772).

May and Johnson (1973) examined the sensitivity of heart rate response to internally produced affective thoughts. Heart rate was found to be highest for stressful words, followed by neutral words, and, finally, lowest for relaxing words. Baker, Sandman and Pepinsky (1975) also investigated the relationship of heart rate response to affective stimuli. Heart rate was measured for neutral and affective topics during rehersal, speech and post speech periods. Results indicated that the affective topic produced increased heart rate as compared with the neutral topic, only during the rehersal period.

Hare (1973) considered the person variable in a study of autonomic response to visual stimuli. He selected subjects who varied in self-reported fear of spiders. Slides depicting spiders produced cardiac acceleration in fearful subjects and, in unafraid subjects produced a plateau in heart rate response followed by a decelatory limb. Klorman, Wiesenfeld and Austin (1975) also considered the person variable by categorizing subjects as high or low in fear of mutilation. In a visual attention paradigm they found cardiac acceleration to mutilation by fearful subjects and cardiac deceleration by those low in fear of mutilation. These results suggested that individual differences in fear determine whether orientation (and heart rate deceleration) or defensive (and heart rate acceleration) reactions occur.

The research findings with respect to heart rate are as yet equivocal. The evidence, however, points to a conclusion that heart rate acceleration is more closely related to anxiety than mental effort. As such, it can effectively be used to complement a paper and pencil measure as an assessment of state anxiety. Although heart rate acceleration has been noted in association with cognitive activity, it does not appear that level of task difficulty is strongly related to the degree of heart rate response (Kahneman, Tursky, Shapiro and Crider, 1969).

THE MODEL

One of the problems in this area of research has been that both the pupil and heart rate seemed to reflect both cognitive and emotional activity. The research of Kahneman and his associates has been an attempt to demonstrate that the pupillary response is a reliable indicator of mental effort and that a distinction could be made between the relative influences of cognitive activity and emotional activity. He and his associates have directed their research program at providing construct validity for the notion that pupillary response is an index of processing load, or mental effort (e.g. Kahneman, Peavler and Onuska, 1968; Kahneman and Peavler, 1969; Kahneman, Tursky, Shapiro and Crider, 1969; Kahneman, Beatty and Pollock, 1967; Kahneman and Wright, 1971).

In his review, Kahneman (1973) presented a capacity model in which level of autonomic arousal was determined by two components. The first component consists of "the demands imposed by the activities in which the organism engages, or prepares to engage" (p. 17). The demands may be considered to be the mental effort required by cognitive activity and pupil size is considered an excellent measure of autonomic arousal reflected by these demands. The second component consists of "miscellaneous determinants, including the prevailing intensity of stimulation and the physiological effects of drugs or drive states" (p. 17). The effects of the miscellaneous determinants, e.g. stress, anxiety, drive states, however, may be a confound when using an autonomic variable to measure mental effort or cognitive activity. Kahneman maintained, however, that with carefully controlled experiments, pupillary response may be used to guage mental effort.

Kahneman and Peavler (1969) distinguished between the concepts of autonomic arousal and processing load, or mental effort, as follows :

> Arousal is often constructed as an essentially autonomic reaction to significant or overwhelming stimuli, whereas

> processing load refers to the demands imposed by activities in which S engages, often voluntarily (p. 317).

The capacity model identifies the concept of attention with mental effort in cases considering the intensive and voluntary aspects of attention. The degree to which an individual attends to a task is related to autonomic arousal, e.g., the greater the demands of a task, the greater the effort (or amount of attention) required to perform that task and the greatest the autonomic arousal associated with the performance of the task.

> In its physiological manifestations effort is a special case of autonomic arousal, but there is a difference between effort and other varieties of autonomic arousal, such as those produced by drugs or loud noises: the effort that a subject invests at any one time corresponds to what he is doing, rather than what is happening to him (Kahneman, 1973, p. 4).

Kahneman (1973) used the capacity model of attention to explain the limitations on information processing as well as the ability to allocate attention (or synonymously, apply effort) among possible alternative actiities. The capacity model assumes that the ability to carry out multiple activities at the same time is limited because the total amount of attention that can be allocated to tasks at any one time is limited.

Moray (1967) described this information processing system as analogous to a central processor of limited capacity which performs functions on information. The functions performed take up the capacity of the system such that difficult transforms reduce the processing capacity available for other functions.

The capacity model starts with the assumption that there are a number of possible activities in which organisms may engage. Each of these activities can be made to occur by an input of attention or effort from the limited capacity. If effort is not applied to a particular task, the activity can not be carried out. Furthermore, mental tasks differ with respect to demands made upon the limited capacity for attention. While easy tasks require little effort, difficult tasks demand a great deal of attention. If the supply of effort does not meet the task demands, performance will be suboptimal. Thus, performance of an activity may be poor because (1) there is not enough capacity to meet the demands of the task, or (2) available capacity has been allocated to other activities.

The capacity model also posits a relationship between effort and autonomic arousal. "...that variations in physiological autonomic arousal accompany variations of effort shows that the limited capacity and the autonomic arousal system must be closely related" (Kahneman, 1973, p. 10). This correlation between capacity and autonomic arousal applies at the lower levels of autonomic arousal. The relationships between autonomic arousal, capacity and allocation changes under conditions of high autonomic arousal and will be discussed later. In low levels of autonomic arousal, however, autonomic arousal and capacity are contingent upon the demands of cu rent activities.

Kahneman pointed out that the major concepts of the capacity model are the allocation policy and the evaluation of demands on the limited capacity. The allocation policy selects the activities to be performed while the evaluation of demands causes effort to be supplied as needed. In addition, an increase in the demands of an activity causes an increase in the level of autonomic arousal and this increases available capacity to attend to the activity.

However, the capacity to meet the demands of a task increases at a steadily decreasing rate (accelerates negatively) with respect to task demands. As task demands increase, the discrepancy between the capacity required and the capacity supplied increases.

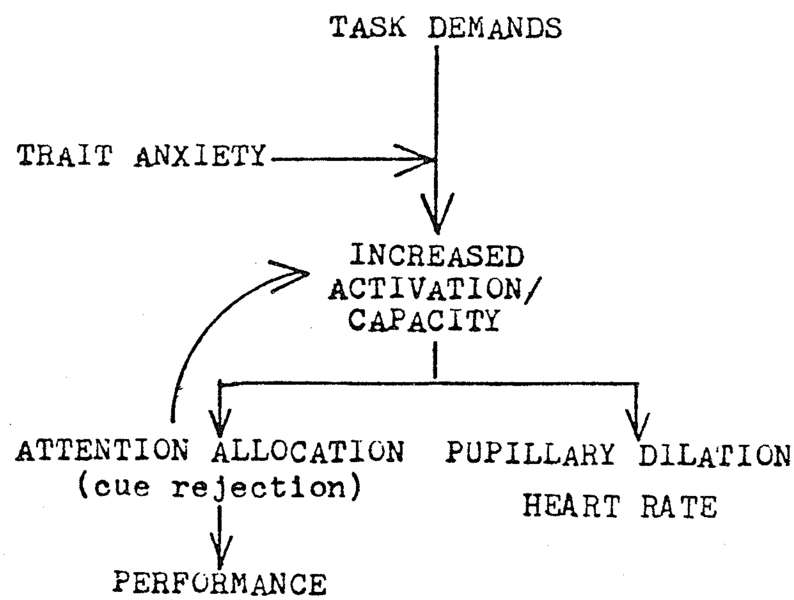
While the capacity model posits that there is a corresponding relationship between attentional demands of tasks and variations in autonomic arousal, it must be noted that "variations in autonomic arousal also affect the policy by which attention is allocated to different activities" Kahneman, 1973, p. 33). For example, variations of autonomic arousal affect task performance according to the law of Yerkes-Dodson (Yerkes and Dodson, 1908). Task performance is an inverted U-shaped function of autonomic arousal which is further modified by task complexity. Kahneman interpreted the effects of the Yerkes-Dodson law within the framework of the capacity model. According to this formulation, the performance of the underaroused subject is poor because of insufficient effort exerted on a task or a failure to evaluate the quality of performance. With respect to high autonomic arousal, a theory by Easterbrook (1959) attempts to explain the Yerkes-Dodson law. The allocation of capacity changes when autonomic arousal is high, causing performance to deteriorate with increasing autonomic arousal and to deteriorate more quickly with difficult tasks. According to Easterbrook, performing a task involves simultaneous processing of a number of cues. Some cues available to a subject are peripheral and irrelevant to task performance; other cues are central to the task. With low autonomic arousal, cue selection is poor and irrelevant cues are accepted for use. As autonomic arousal increases, however, cue selection improves, irrelevant cues are rejected first and performance improves. With additional increases there is a further reduction in cue selection until relevant cues are rejected and performance is impaired.

Assuming that a larger number of central cues are required for complex tasks, optimal performance should occur at lower levels of autonomic arousal for difficult tasks than simple tasks. Not only does high autonomic arousal affect the allocation policy so that there is an increased tendency to focus on a reduced number of cues, but, the increase of autonomic arousal impairs the discrimination of relevant from peripheral cues and thus causes a reduction in the ability to focus on relevant cues. Therefore, with a difficult task, it is expected that the number of cues utilized will be below the number required by the task and the subject will not be able to discriminate those cues that are relevant to the task.

The model suggested by Kahneman, tailored to the variables used in this study, can be conceptualized as in Figure 1A. The model suggests that pupillary responses are closely related to autonomic nervous system activity. Trait anxiety and the task demands increase autonomic arousal and capacity. This is a viscero-autonomic response manifesting an increase in state anxiety as well as autonomic nervous system activity. Capacity can be thought of as channel capacity or as the reduction of information redundancy. The amount of arousal or capacity influences the cortical attention allocation process. This process is an inferred cognitive activity which may be described by the Easterbrook hypothesis discussed previously.

The model in Figure 1A indicates that it is the arousal/capacity process that influences both performance as well as the physiological indicators. Thus, attention allocation and physiological response are both mediated by viscero-autonomic activity. Therefore, as cortical arousal increases, so will the physiological indicators.

Figure 1B presents a modification of the model which places the locus of the pupillary response in closer relation to the cortical attention allocation process. With this arrangement, the pupillary response is mediated through the attentional process and therefore does not necessarily vary dir-



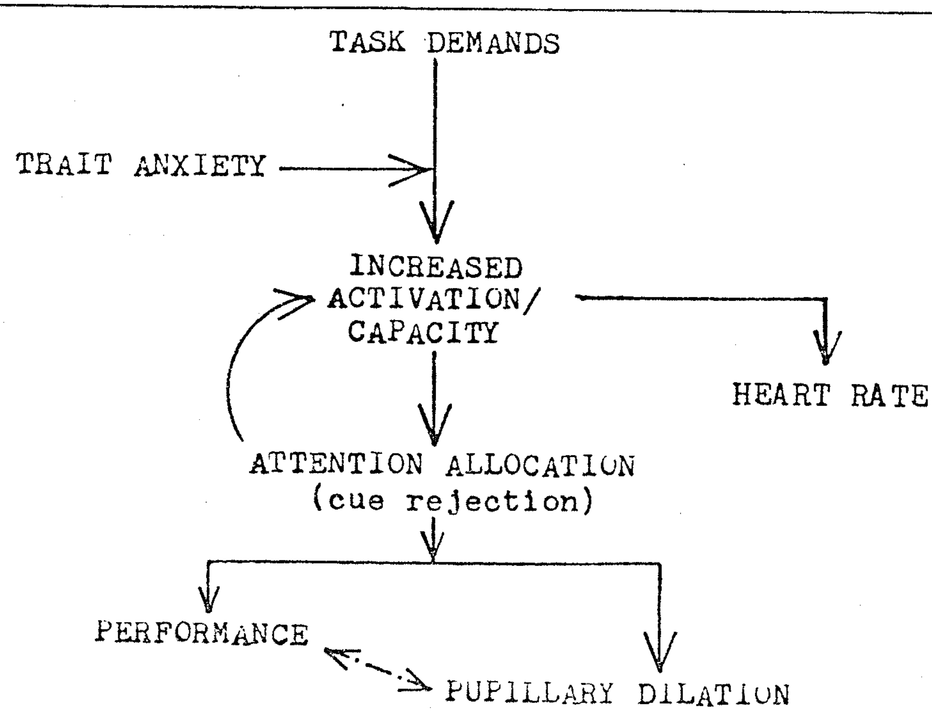


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Figure 1A.

Figure 1B.

Capacity Model suggested by Kahneman (1973) and adapted to the variables used in the present study

Modification of Model which places the locus more closely to cortical attention allocation process ectly with autonomic arousal, but as a function of the cortical processes.

A feedback mechanism from the cortical attention allocation process to the viscero-autonomic arousal/capacity process is also posited. This interplay between the two processes comprises a dual control mechanism operating on information sampling contingencies (see Pribram and McGuinness, 1975, pp. 135-136).

EYSENCK PERSONALITY INVENTORY

Eysenck's theory about the physiological bases of introversion and neuroticism may also be usefully applied in the current context as a basis for the notion that the pupillary response is a cortically mediated function which is affected by the personality dimension of introversion-extraversion.

One measure that has been used extensively and successfully to relate differential physiological responsivity to personality differences is the Eysenck Personality Inventory (EPI) (Eysenck, 1967). The Neuroticism (N) and Extraversion (E) dimensions of personality measured by the EPI are theoretically tied by Eysenck to a physiological basis. The EPI, therefore, is a measure most suitable to identifying individual differences in physiological responding.

Eysenck (1967) related neuroticism, or emotionality, to the activity of the autonomic nervous system, particularly sympathetic activity. Individual differences in emotionality are related to individual differences in autonomic activity. The physiologiacl basis of neuroticism, according to Eysenck's theory of personality, is identified with differences in the threshold of arousal of the visceral brain, i.e. the hippocampus, amygdala, cingulum, septum, and hypothalmus. Studies using GSR, muscle tension, heart rate, and other physiological measures support the notion that neurotic subjects respond more strongly to stimuli, have greater response variability and take longer to recover from the effects of stimulation.

As with Neuroticism, the Extraversion dimension is also related to nervous system activity. The degree of introversion-extraversion is related to differences in the threshold of arousal in the various parts of the ascending reticular activating system. Introverts, as defined by the EPI, are characterized by lower thresholds of cortical arousal than extraverts. Activation of the reticular activating system is related to alertness, attention and cortical arousal. The lower reaction threshold of introverts should cause greater sensitivity to sensory stimulation.

Eysenck (1967) stated that "there is ... some degree of partial independence between autonomic activation and cortical arousal; autonomic activation always leads to cortical arousal, but cortical arousal very frequently arises from types of stimulation which do not involve autonomic activation" (p. 233). Thus cortical arousal can be produced along two different pathways. Cortical arousal can occur by sensory stimulation without involving the visceral brain and there will be no autonomic activation, but possibly high cortical arousal. And, cortical arousal can also be produced by emotion. In this case the reticular formation is affected by the visceral brain activity and there will be both cortical and autonomic activity.

Since the introversion-extraversion personality dimension is related to differences in the threshold of cortical activity, differences in pupil size along this dimension would suggest that the pupillary response is related to cortical activity. It is expected that introverts, having a lower threshold of cortical arousal, would show a larger pupillary response than extraverts.

STATEMENT OF PURPOSE

The purpose of this study is to examine the relationship between pupil size and cognitive activity, and heart rate and emotional activity. The research will further investigate the physiological correlates of cognitive performance under high and low stressful conditions to be created by the instructional set and the demands of the experimental task. The variables considered are stress, trait anxiety, state anxiety, task difficulty, and intellectual ability. The literature reviewed above provided evidence that these variables, as well as the interaction of these variables, affect performance and physiological responses. This study considers the nature of the interactions of these variables in order to specify their relationships to physiological responses. The results of this study will also be discussed in terms of the proposed modifications to Kahneman's capacity model which considers the notion that the pupillary response is a cortically mediated function.

Previous studies (e.g. Kahneman, Tursky, Shapiro and Crider, 1969; Kuc, 1976) have indicated that pupillary dilation is a better measure of cognitive activity than emotional activity such as anxiety. These studies also suggested that heart rate activity is a better measure of emotional activity than cognitive activity. A further investigation of this hypothesis is warranted. One problem in this area of research is that both the pupil and heart rate seem to reflect both cognitive and emotional activity. Part of the solution consists of sorting out the interactive effects of personality and task variables on relative changes in autonomic nervous system parameters. In the study by Klorman, et al. (1975), for example, subjects responded to pictures of mutilation either with cardiac acceleration or cardiac deceleration depending on how they were previously categorized as high or low in fear of mutilation. If they had not considered the person variable, it is likely that averages over both groups would have cancelled out the effects of the stimulus on heart rate. In addition, Cattel and Scheier (1961) suggest that subjects varying in trait anxiety may produce differential state anxiety reactions, i.e. state anxiety responses for those low in trait anxiety will be different than for those scoring high in trait anxiety. This study considered whether this person variable distinguished autonomic responsivity.

Other research (e.g. Sarason, 1975; Spielberger, 1975) reveals the interactive effects of anxiety, task difficulty and intelligence on task performance. According to Spence's Drive Theory (Spence and Spence, 1966) the effect of anxiety, or drive level, on performance depends on the relative strength of correct or competing response tendencies evoked by a particular task. High anxious subjects should perform better on easy tasks, where correct responses are dominant and low anxious subjects should perform better on more difficult tasks. This is assuming that high anxiety evokes task irrevelant or competing response tendencies.

Janisse and Lee (1976), using a task involving recall of words, found that low trait anxious subjects did perform better than high trait anxious groups on a difficult task, but the high trait anxious subjects performed better than low trait anxious subjects on an easy task. The word naming task consists of naming as many words as possible beginning with a particular letter.

The question left unanswered by the Janisse and Lee (1976) study is : What are the physiological parallels to the differential performance of high and low anxious subjects to difficult and easy tasks ? Researchers have investigated the interactive effects of anxiety, task difficulty and intelligence on task performance, but what of the physiological parallels to this performance ? If performance measures differ according to the task difficulty and anxiety level of the subjects, it is expected that physiological measures should differ.

In this study, the word naming task previously described is used. This task is most appropriate for a study examining the effects of a stressor and task difficulty for a number of reasons : (1) it has been shown to be effective as a stressor that influences autonomic variables (Crooks and McNulty, 1966; Van Zoost and McNulty, 1971), (2) task difficulty may be easily manipulated by using high or low frequency initial letters, and (3) it increases in difficulty as the task progresses, without the need of interruption for additional input. The autonomic variables to be measured are pupil size and heart rate. Therefore, the three dependent measures will be the number of words named correctly, pupil size and heart rate. The independent variables will be trait anxiety (test anxiety as measured by the TAS), state anxiety (Spielberger State-Trait Anxiety Inventory), task difficulty (high and low frequency of initial letters of words), intelligence (Vocabulary subtest of the WAIS), and ego-threatening vs. non-ego-threatening instructions to insure state anxiety.

Tha manipulation of these variables will help to tease out the differential influence of cognitive vs. emotional variables on heart rate and pupil size. By manipulating both anxiety level and task difficulty we can examine whether pupil size reflects cognitive activity more than anxiety and, conversely, whether heart rate reflects anxiety more than cognitive activity.

STATEMENT OF HYPOTHESIS

If, as discussed previously, pupillary dilation reflects cognitive as opposed to emotional activity, a significant difference in pupil size with respect to task difficulty should result. If the heart rate is not sensitive to cognitive variables, no significant differences to task difficulty will appear.

Conversely, if heart rate reflects emotional as opposed to cognitive activity, a significant difference in heart rate with respect to stress instructions vs. non-stress instructions should ensue. But, if the pupil is not sensitive to emotional variables, no significant differences should occur.

METHOD

Experimental Design. There were eight between-subjects experimental conditions with 10 subjects in each condition. The independent variables were stressfulness of instructions, level of trait anxiety, level of intelligence and task difficulty. The design was a four factor mixed design with three between and one within variable. The between subjects variables were instructions (high vs. low stress), trait anxiety (high vs. low test anxiety), and intelligence (high vs. low scores on the WAIS). The within subjects variable was task difficulty (high vs. low frequency of initial letters of words). Dependent measures were pupil size, heart rate and task performance (number of words correctly named).

Subjects. The Test Anxiety Scale (TAS) (Sarason, 1957) was initially administered to 299 males in introductory psychology classes at the University of Manitoba. From the ends of the continuum of scores on this questionnaire 40 high test anxious and 40 low test anxious subjects were selected for the study. The 40 high test anxious subjects were selected from the upper 24.5% of the distribution, with the cutoff point at 23; and and the 40 low test anxious subjects were selected from the lower 22.9% of the distribution, with the cutoff point at 13. Half of each high test anxious and low test anxious group was randomly assigned to either high stress or low stress condition. There were then four groups, each consisting of 20 subjects. Each of these groups was later divided into high and low intelligence groups on the basis of a median split of the scores of each group on the Vocabulary Subtest of the Wechsler Adult Intelligence Scale (WAIS) (Wechsler, 1955). The mean scores on the Vocabulary Subtest, for low intelligence and high intelligence, respectively, in each group are as follows : low stress-low test anxious, 47.1 and 61.8; low stress-high test anxious, 44.7 and 59.4; high stress-low test anxious, 49.1.and 63.1; high stress-high test anxious, 40.4 and 53.5.

Stimuli. Tape recorded instructions were presented to the subjects (Appendix A). For the experimental task, subjects heard a recorded pulse sounding every five seconds, after which they were required to give a word which began with a certain letter. The specific letter was given 30 seconds after the pulses began. The word naming task was administered four times with four different letters - two easy and two difficult. Letters for the word naming task were selected by a survey of three dictionaries (Barnhart, 1958; Irvine, 1963; Stein, 1966). The number of pages used for words beginning with each of the 26 letters of the alphabet was calculated and rank ordered; that is, the initial letter utilizing the most pages was ranked first (most frequent), the second most pages ranked second, and so on. The rank for each letter from the three dictionaries was averaged. The letters B and M were found to occupy rank positions 6 and 7 consistently; the letters J and K were found to occupy rank positions 21 and 22 consistently. For the purposes of this study, B and M served as easy response cues, and J and K as difficult response cues. The order of presentation of letters for the experimental task was randomly varied across subjects.

Apparatus. The apparatus for recording pupil responses was a Whittaker Space Sciences Eyeview Monitor and Television Pupillometer System which provides 60 measures of pupil size per second. The pupil of the left eye was continuously monitored and the data output stored on magnetic tape for later data analysis.

A Whittaker Space Sciences Pulse Watch was used for the measurement of heart rate. Heart rate was based on the time interval between beats on a second by second basis and was later averaged over six overlapping intervals. A connector was attached to the index finger of the right hand for continuous monitoring. The heart rate data output was stored simultaneously on magnetic tape with the pupil response data.

Other Measures. The Test Anxiety Scale (TAS) (Sarason, 1957) was administered to all subjects prior to the experiment proper (Appendix B). It is an A-Trait measure which identifies those people that experience anxiety in a test-like or evaluation situation. The TAS is a most appropriate measure of trait anxiety for the purpose of the experiment since the task is a test-like situation. The use of this measure of trait anxiety specifically related to the experimental task was used to increase the probability that an A-State raaction would be obtained in this experimental situation (Endler, 1975). Spielberger (1972) also supported the notion of using a measure of trait anxiety specifically related to the experimental task, suggesting that "in general, situation specific trait anxiety measures are better predictors of elevations in A-State for a particular class of stress situations than are general A-Trait measures (p. 490)."

Similarly, a measure of intelligence was used which is directly related to the experimental task (Appendix C). The Vocabulary Subtest of the Wechsler Adult Intelligence Scale (WAIS) (Wechsler, 1955) was administered to each subject individually. The Vocabulary Subtest correlates .82 with the WAIS full-scale IQ and seems particularly suited to distinguish subjects performing a task involving recall of words.

The Self-Evaluation Questionnaire (STAI form X-1, Spielberger, Gorsuch, and Lushene, 1970) was used as a measure of A-State (Appendix D). This measure presents a number of statements which subjects use to describe their current feelings. This A-State measure was used in several ways : (1) to validate the effectiveness of the stress manipulation with respect to the A-Trait measure, (2) to investigate the relationship between state anxiety and heart rate response and the pupillary response, and (3) to examine the effects of anxiety on task performance.

Finally, the Eysenck Personality Inventory, Form A, (EPI) (Eysenck, 1967) was administered to all subjects prior to the experiment proper (Appendix E). This measure has been used to relate differential physiological responsivity to personality differences. The Neuroticism (N) and Extraversion (E) dimensions of personality measured by the EPI are theoretically tied by Eysenck to a physiological basis.

Procedure. Subjects were selected on the basis of scores on the TAS so that one-half of the subjects were in the upper 24.5% of scores (high A-Trait) and the other half in the lower 22.9% (low A-Trait). Subjects within each A-Trait group were randomly assigned to either a high stress condition with ego-threatening instructions or a low stress condition with reassuring, task-oriented instructions. Taped instructions were presented to both high and low stress groups. Instructions to the high stress group emphasized that the word naming test was a measure of verbal fluency, a highly accurate measure of IQ, and an efficient predictor of college success. Instructions to the low stress group emphasized that it was not important how well they did, but that they concentrate on the task.

Except for the instructions, all subjects followed the same procedure. Each subject was tested individually. Taped general instructions to all subjects explained the purpose of the experiment and the rules for completing the word naming test. Following the instructions, the subject was given a practice session with the word naming test to insure that the directions were understood.

The subject was then seated at the pupillometer and the camera focused on the pupil of his left eye. The finger connector of the pulse watch was attached to the index finger of the right hand. A baseline measure of pupil size and heart rate was taken for two minutes while the subject was not performing any task.

A tape recording of the specific instructions for the high or low stress groups was presented to the subjects immediately following the baseline measure. At the end of the instructions, the subject heard five pulses, one every five seconds. Five seconds after the fifth tone, the letter for the word naming task was presented as follows : "B as in boy". Following the letter presentation, pulses were sounded every five seconds for one minute. A word beginning with the letter "B" was to be given after every pulse. When a subject missed naming a word to two pulses in a row he was told to "relax" by the experimenter. Subjects knew from prior instructions that this was the cue to stop attempting to name words, but to remain in place at the pupillometer. A return to baseline measure of pupil size and heart rate was taken for two minutes. There was then a three minute rest period before the task was administered a second time.

Upon completion of the rest period, the camera was again focused on the pupil of the subject's left eye. The task was identical to the first task except that subjects were not given the task instructions and were given a letter, e.g., "J as in jump", after presentation of the five pulses. This procedure, including the rest periods, was repeated twice more using the letters "M as in mother" and "K as in kite". All instructions, pulses and letters were presented by tape recorder.

After the word naming task was completed, subjects were moved from the apparatus and asked to complete STAI Form X-1, a measure of state anxiety. The Vocabulary Subtest of the WAIS was then administered after which the subjects were briefed and the experimental session was completed.

RESULTS

MANIPULATION CHECKS

State Anxiety. An analysis of variance (Anova) for a 2 x 2 x 2 (STRESS X TAS X INT) factorial design was performed on the A-State self report measure to determine whether there was a significant effect due to the level of trait anxiety (TAS). Table 1 (Appendix F) contains a summary of the an lysis of variance for the A-State scores. The main effect of the level of test anxiety (TAS) was highly significant ($F(1,72) = 29.377$, $p \leq .001$) indicating that subjects included in the high test anxiety groups reported a greater degree of state anxiety ($x = 48.62$) than subjects included in the low test anxiety groups ($x = 37.92$).

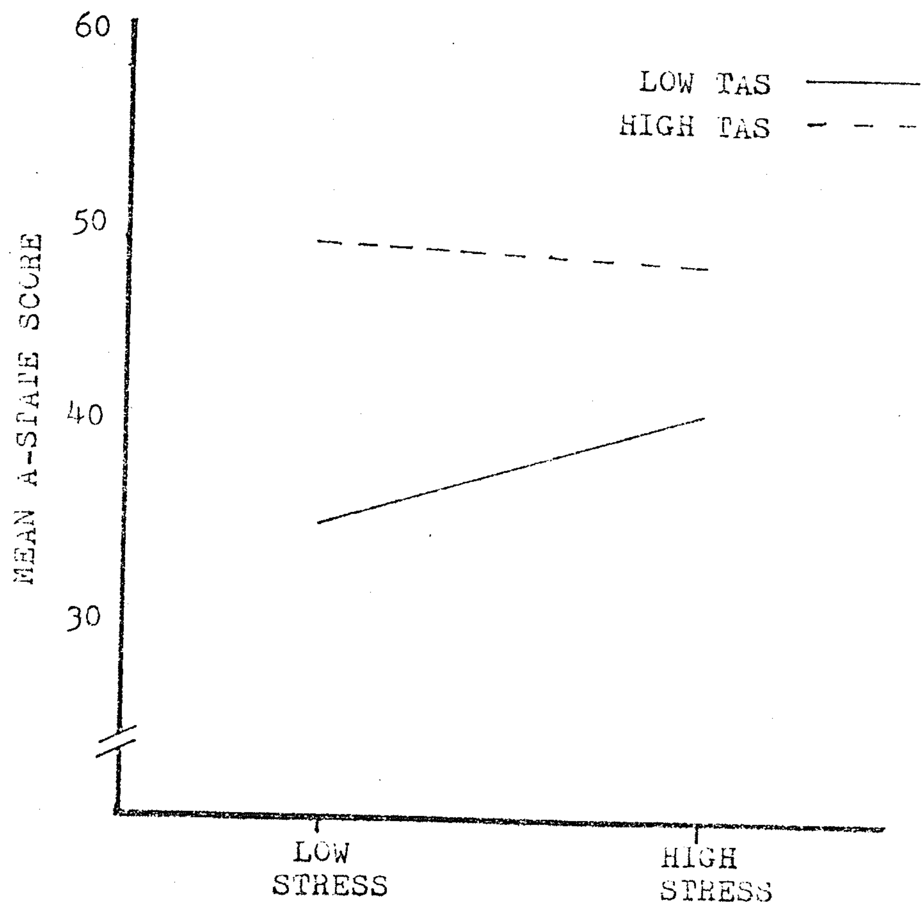
The Anova also showed that while the main effect of the stress instructions (STRESS) was not significant, the STRESS X TAS interaction was marginally significant. ($F(1,72) = 2.88$, $p \leq .094$). The high interaction effect shown in Figure 2 suggests that the high stress instructions served to raise the A-State scores across high and low stress instructions. Verifying this contention, an analysis of the simple effects of the stress instructional set (STRESS) (Table 2) revealed that the stress manipulation was significant ($F(1,72) = 4.542$, $p \leq .05$) for the low test anxious group (LTAS) while not significant for the high test anxious

Figure 2.

Significant Interaction Effect of Stress

Instructions by Test Anxiety

(STRESS X TAS) on A-State



60
50
40
30
MEAN A-STATE SCORE
LOW TAS
HIGH TAS
LOW STRESS
HIGH STRESS

group (HTAS) ($F(1,72) = 0.072$, $p > .20$). The simple effects of TAS at levels of STRESS were significant ($F(1,72) = 25.236$, $p \leq .01$ and $F(1,72) = 6.931$, $p \leq .025$) for both low (LSTRESS) and high stress (HSTRESS) groups, respectively.

The main effect for the level of intelligence (INT), as measured by scores on the Vocabulary Subtest of the WAIS, was also significant ($F(1,72) = 4.003$, $p \leq .049$). Mean A-State scores were higher for the high intelligence group (x = 45.25) than the low intelligence group (x = 41.29).

A regression analysis of TAS on A-State (using raw, continuous scores) yielded $r^2(1,78) = .258$.

<u>Pupillary Baseline.</u> An Anova for a 2 x 2 x 2 (STRESS X TAS X INT) factorial design was done on the average baseline pupil size (during the last 30 seconds of the baseline period) to determine if significant effects existed prior to the experimental stress manipulation. Table 3 contains a summary of the analysis of variance for the pupillary data. While no main effects were significant, the STRESS X TAS interaction was significant ($F(1,72) = 4.017$, $p \leq .049$). Figure 3 suggests that the low test anxious group (that would later be stressed) had a larger pupil size (x = 4.247 mm) than subjects who would later receive the low stress instructions (x = 3.815 mm). The reverse appeared to be true for those subjects in the high test anxious group, with those later receiving low stress instructions having a larger baseline pupil size (x = 3.984 mm) than those later receiving high stress instructions (x = 3.861 mm). An analysis of the simple effects of the stress instructional set verified this contention (Table 4) only for the low test anxious group (LTAS) ($F(1,72) = 4.878$ $p \leq .05$). The effect of stress for the high test anxious group was not sifnificant.

In addition, the simple effect of test anxiety in the high stress instruction group was marginally significant ($F(1,72) = 3.882$, $p \leq .10$) with the low test anxious subjects showing a greater baseline pupil size ($x = 4.246$ mm) than the high test anxious subjects ($x = 3.861$ mm).

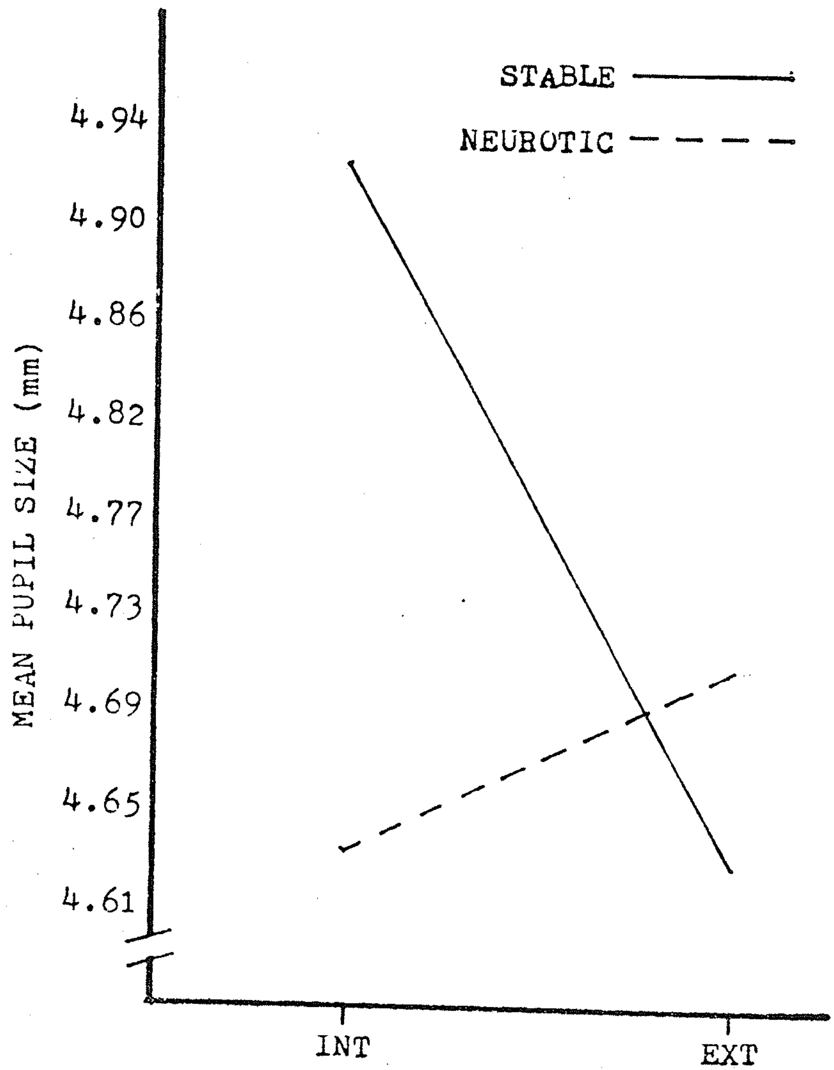
Regression of Pupillary Baselines. Regression analyses of the pupillary baseline were done on the average pupil size during performance of the experimental task. These regressions were done to determine the relationships between baseline pupil size and pupil size during task performance. The regression of the average pupillary baseline on the average pupil size during performance of the easy task (EASY) yielded a multiple R of 0.77498 ($r^2(78) = 0.6006$); the regression of the average pupillary baseline on the average pupil size during performance of the difficult task (DIFF) yielded a multiple R of 0.75764 ($r^2(78) = 0.57402$). Since such highly significant regression occurred, as well as the significant STRESS X TAS interaction on the baseline data, the pupillary baselines were used as covariates in the major analyses to be reported later.

Heart Rate Baseline. An Anova for a 2 x 2 x 2 (STRESS X TAS X INT) factorial design was done on the average heart rate response data during the last 30 seconds of the baseline period to determine if significant effects existed prior to the experimental stress manipulation. Table 5 contains a summary of the analysis of variance for the heart rate data. No effects were found significant for this baseline data. The mean baseline heart rate was 80.477 beats per minute (bpm).

Regression of Heart Rate Baseline. Regression analyses of the heart rate baseline were done on the average heart rate data during performance of the experimental task. These regressions were done to determine the relationships

Figure 3.

Significant Interaction Effect of Stress Instructions by Test Anxiety (STRESS X TAS) on Baseline Pupil Size


STABLE
NEUROTIC
4.94
4.90
4.86
4.82
4.77
4.73
4.69
4.65
4.61
MEAN PUPIL SIZE (mm)
INT
EXT

between baseline heart rate and heart rate during task performance. The regression of the average heart rate baseline on the average heart rate during performance of the easy task yielded a multiple R of 0.69859 ($r^2(78) = 0.48803$); the regression of the average heart rate baseline on the average heart rate during performance of the difficult task yielded a multiple R of 0.66940 ($r^2(78) = 0.44809$). The presence of these highly significant regressions warranted the use of the heart rate baseline as a covariate in the major analyses reported later.

PERFORMANCE

The performance measure was the number of words (WORDS) produced by subjects during the experimental period. Performance for the easy task (EASY) was the mean number of words produced for the two easy letters (B, M) and performance for the difficult task (DIFF) was the mean number of words produced for the two difficult letters (J, K). An Anova was performed on the number of words produced to determine the effects of the independent variables on performance. Analysis was done on a 2 x 2 x 2 X 2 (STRESS X TAS X INT X WORDS) mixed design with repeated measures on the last variable. A summary table of the Anova will be found in Table 6.

The main effect of task difficulty (WORD) was highly significant ($\underline{F}(1,72) = 634.53$, $\underline{p} = .000$), clearly showing that performance was better for the easy task (x = 10.1 words) than the difficult task (x = 4.39 words).

A second order interaction (STRESS X TAS X WORDS) was also found to be highly significant ($\underline{F}(1,72) = 11.89$, $\underline{p} = .001$). An analysis of the simple simple effects and simple interaction effects (Table 7) revealed a number of significant factors that did not appear as significant in the tests of main effects.

The analysis of the simple interaction effects revealed that the stress instructional set by test anxiety interaction was marginally significant for the easy word (STRESS X TAS at EASY) ($\underline{F}(1,44) = 3.394$, $\underline{p} \leq .10$) and difficult word (STRESS X TAS at DIFF) ($\underline{F}(1,44) = 3.084$, $\underline{p} \leq .10$) conditions.

The simple interaction effect of stress instructions by test anxiety for the easy task is depicted in Figure 4. This figure suggests that low test anxious subjects performed better under the low stress instructions ($x = 10.675$ words) than the high stress instructions ($x = 9.925$ words). The reverse occurred for high test anxious subjects. High test anxious subjects appeared to do better under the high stress conditions ($x = 10.325$ words) than the low stress conditions ($x = 9.475$ words).

Figure 5 depicts the simple interaction effect of stress instructions by test anxiety for the difficult task. The figure suggests that the high test anxious subjects performed better under the low stress instructions ($x = 4.5$ words) than the high stress instructions ($x = 3.475$ words). Also, note that the low test anxious subjects appeared to perform better under the high stress instructions ($x = 5.05$ words) than the low stress instructions ($x = 4.55$ words).

Comparison of Figure 4 with Figure 5 raises the possibility that the stress instructions have opposite effects at the different levels of task difficulty. In fact, the simple interaction of the stress instructional set by task difficulty (STRESS X WORDS) was marginally significant for the low test anxious group ($\underline{F}(1,72) = 3.805$, $\underline{p} \leq .10$), and significant for the high test anxious group ($\underline{F}(1,72) = 8.562$, $\underline{p} \leq .005$). For the

Figure 4.

Significant Simple Interaction Effect

of STRESS X TAS for the

Easy Word Condition

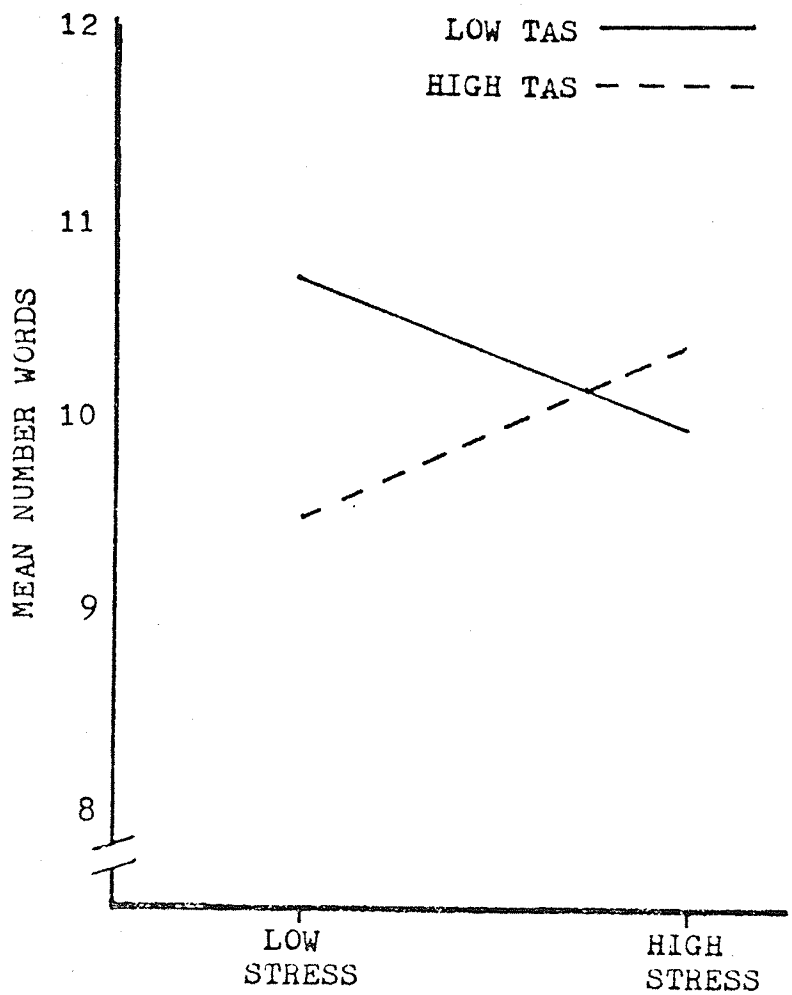
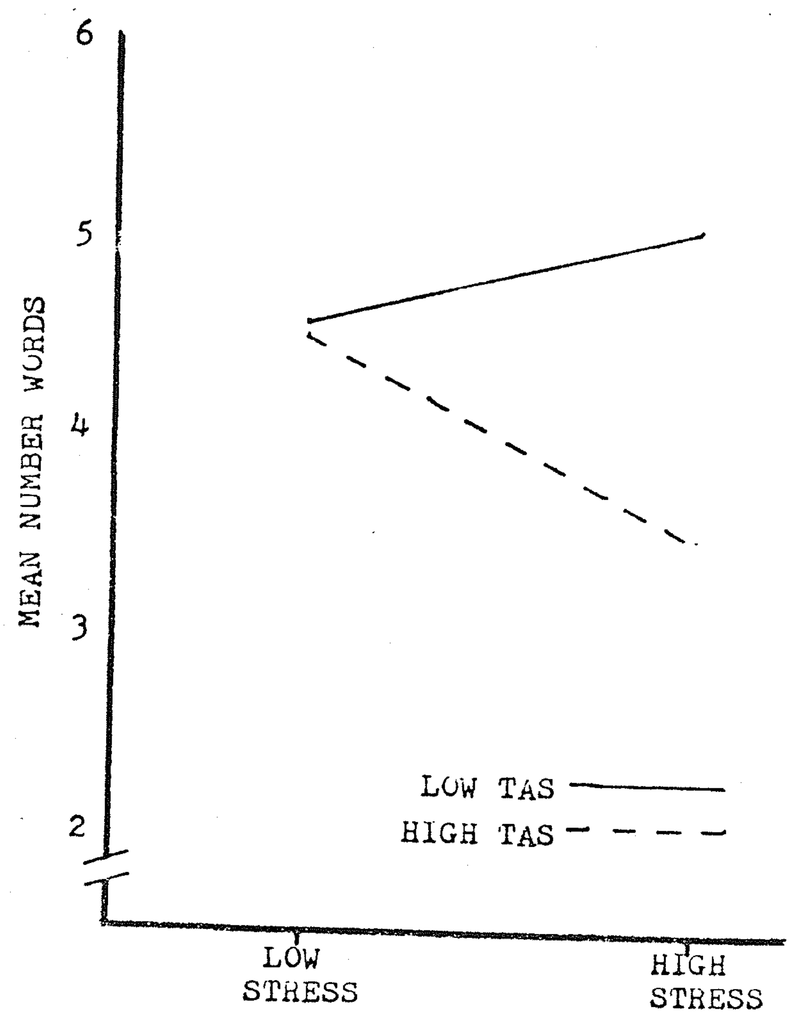

LOW TAS
HIGH TAS
12
11
10
9
8
MEAN NUMBER WORDS
LOW STRESS
HIGH STRESS

Figure 5.

Significant Simple Interaction Effect

of STRESS X TAS for the

Difficult Word Condition


6
5
4
3
2
MEAN NUMBER WORDS
LOW TAS
HIGH TAS
LOW STRESS
HIGH STRESS

low test anxious group, the effect of stress appeared to impair performance in the easy word condition and improve performance in the difficult word condition. For the high test anxious group, the effect of stress appeared to improve performance in the easy word condition and impair performance in the difficult word condition.

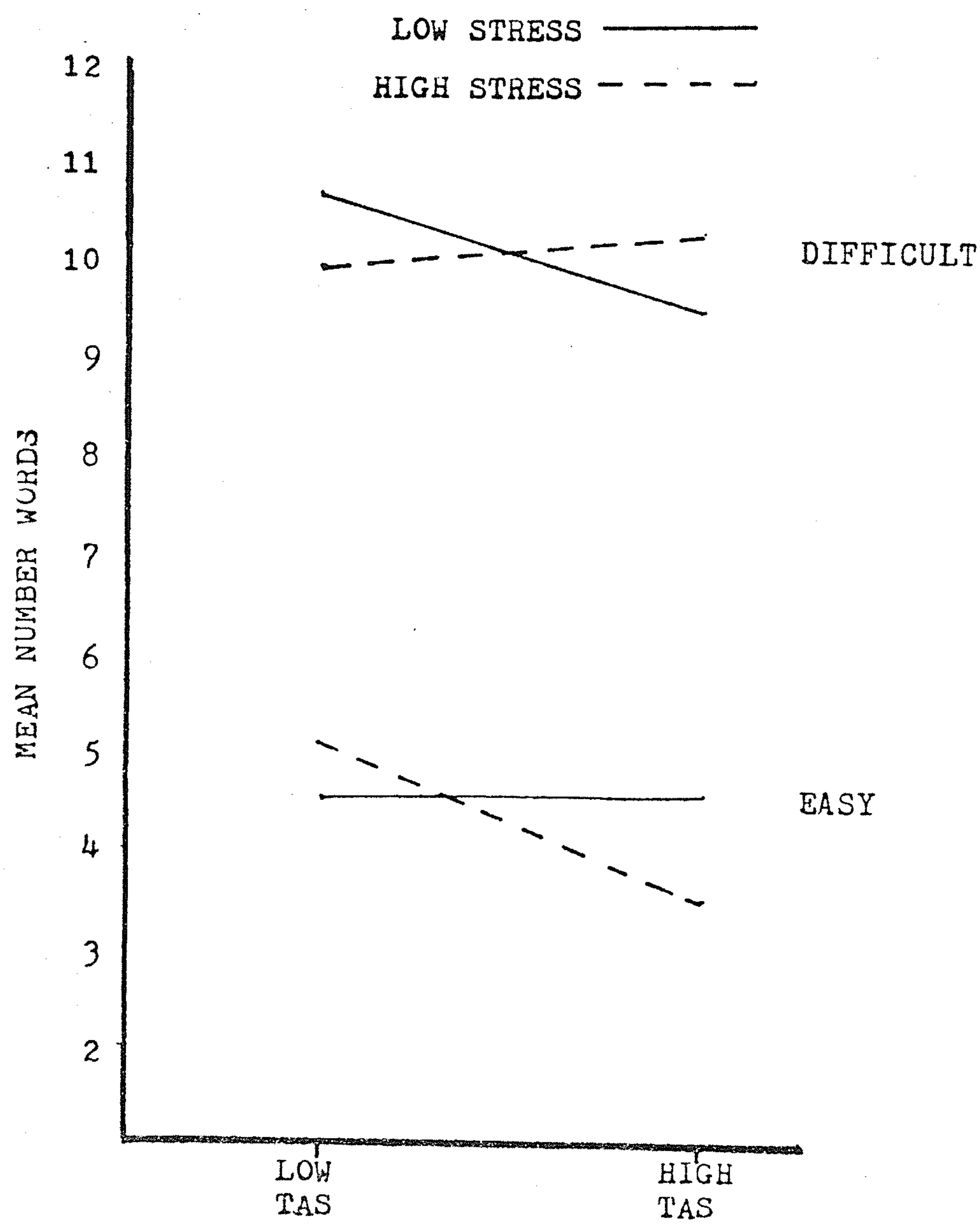
In order to clarify the meaning of these interactions, analyses of the simple simple effects of the stress instructional set (STRESS) were performed. These analyses revealed that stress was a marginally significant factor in only one of four experimental conditions: for high test anxious subjects in the difficult word condition (STRESS at HTAS/DIFF) ($F(1,144) = 2.786$, $p \leq .10$). Thus, the credibility of the above suppositions about the effects of the stress instructional set must be considered cautiously.

Finally, the simple interaction effect of level of test anxiety by level of word difficulty was found to be significant for the high stress group (TAS X WORD at HSTRESS) ($F(1,72) = 9.50$, $p \leq .005$), and marginally significant for the low stress group (TAS X WORD at LSTRESS) ($F(1,72) = 3.221$, $p \leq .10$). These interactions are depicted in Figure 6. Analysis of the simple simple effects of test anxiety at each combination of stress instructions and task difficulty revealed that test anxiety was a significant factor in two out of four experimental conditions : (1) for the low stress group in the easy word condition (TAS at LSTRESS/EASY) ($F(1,144) = 3.819$, $p \leq .10$), and (2) for the high stress group in the difficult word condition (TAS at HSTRESS/DIFF) ($F(1,144) = 6.578$, $p \leq .025$).

The marginally significant simple effect of test anxiety for the low stress group in the easy word condition in shown in Figure 6. The figure

Figure 6.

Significant Simple Interaction Effects
of TAS X WORDS for the Low Stress and
High Stress Conditions



LOW STRESS
HIGH STRESS
12
11
10
9
8
7
6
5
4
3
2
MEAN NUMBER WORDS
DIFFICULT
EASY
LOW TAS
HIGH TAS

shows that low test anxious subjects (x = 10.675 words) performed better than high test anxious subjects (x = 9.475 words) in the easy word condition. The figure also shows the simple effect of test anxiety for the high stress group in the difficult word condition. It can be seen that the low test anxious subjects (x = 5.05 words) performed better than the high test anxious subjects (x = 3.475 words) in the difficult word condition.

PUPILLARY RESPONSE

A univariate analysis of covariance (Ancova) was performed on the mean pupil size during the experimental period to determine the effects of the independent variables on the pupillary response. The experimental period was defined as that time during which subjects were successfully performing the required task. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X TAS X INT X WORDS) mixed design with repeated measures on the last variable. Baseline pupil size was used as the covariate for reasons discussed previously. Table 8 contains a summary of the analysis of covariance for the pupillary data.

There were no significant main effects, nor interaction effects, for any of the variables. The main effect for the within subjects variable of task difficulty (WORDS), however, was highly significant ($\underline{F}(1,72) = 10.93$, $\underline{p} \leq .001$). The significant main effect of task difficulty indicates that pupil size during the difficult task (DIFF) (x = 4.736 mm) was larger than during the easy task (EASY) (x = 4.649 mm).

HEART RATE RESPONSE

A univariate Ancova was performed on the mean heart rate during the experimental period to determine the effect of the independent variables on the heart rate response. As with the pupillary response, the experimental period was defined as that time during which the subjects were successfully performing the required task. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X TAS X INT X WORDS) mixed design with repeated measures on the last variable. Baseline heart rate was used as a covariate for reasons discussed previously. Table 9 contains a summary of the analysis of covariance for the heart rate data.

The main effect of the stress instructional set was highly significant ($\underline{F}(1,71) = 5.14$, $\underline{p} \leq .025$) indicating that subjects in the low stress condition ($x = 87.9456$ bpm) had a slower heart rate than subjects in the high stress condition ($x = 91.2601$ bpm).

The Ancova also showed that the interaction between level of test anxiety and intelligence (TAS X INT) was highly significant ($\underline{F}(1,71) = 7.17$, $\underline{p} \leq .005$). The significant interaction effect shown in Figure 7 suggests that the mean heart rate was lower for the more intelligent subjects (HINT) of the high test anxious group ($x = 87.459$ bpm) than for the less intelligent subjects (LINT) ($x = 91.759$ bpm). For the low test anxious group, mean heart rate was lower for the less intelligent subject ($x = 88.496$) than the more intelligent subjects ($x = 92.765$). An analysis of the simple effects of test anxiety at the different levels of intelligence provided no significant effects either.

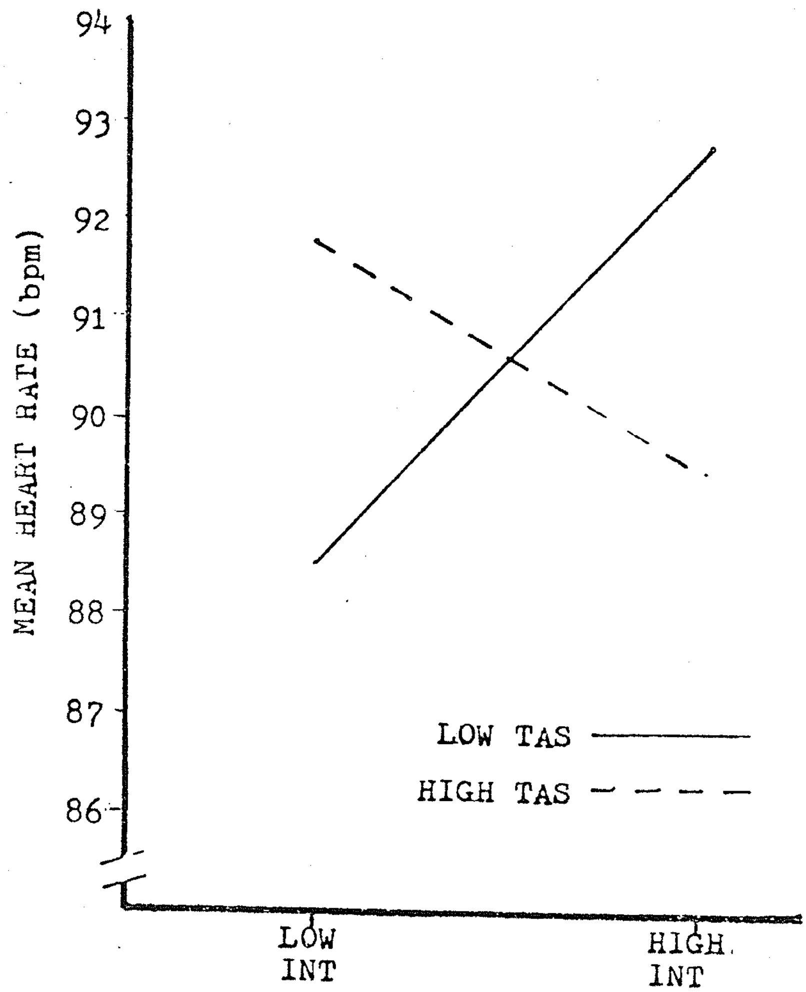
The Ancova also showed that although there was not a significant main effect for task difficulty, there was a significant second order interaction (TAS X INT X WORDS) ($\underline{F}(1,72) = 6.51$, $\underline{p} \leq .013$). The analysis of the simple simple effects and simple interaction effects of the TAS X

Figure 7.

Significant Interaction Effect of

Test Anxiety by Intelligence

(TAS X INT) on Heart Rate


94
93
92
91
90
89
88
87
86
MEAN HEART RATE (bpm)
LOW TAS
HIGH TAS
LOW INT
HIGH INT

INT X WORDS interaction is presented in Table 11.

Firstly, the analysis of the simple interaction effects of task difficulty by test anxiety were marginally significant for the high intelligence group (WORDS X TAS at HINT) ($F(1,72) = 3.487$, $p \leq .10$) and the low intelligence group (WORDS X TAS at LINT) ($F(1,72) = 3.025$, $p \leq .10$). The simple interaction effects of task difficulty by intelligence were significant for the high test anxious (WORD X INT at HTAS) subjects ($F(1,72) = 4.631$, $p \leq .05$), but not significant for the low test anxious (LTAS) subjects. The analysis of the simple simple effects of task difficulty, however, indicated significance only for the high intelligence subjects in the high test anxious group (WORD at HTAS/HINT). Even then, the level of significance was only marginal ($F(1,72) = 2.839$, $p \leq .10$). Figure 8, which depicts the above interactions and simple effects, shows that heart rate was higher for the high intelligence subjects in the high test anxiety group at the easy task ($x = 88.896$ bpm) than the difficult task ($x = 86.023$ bpm).

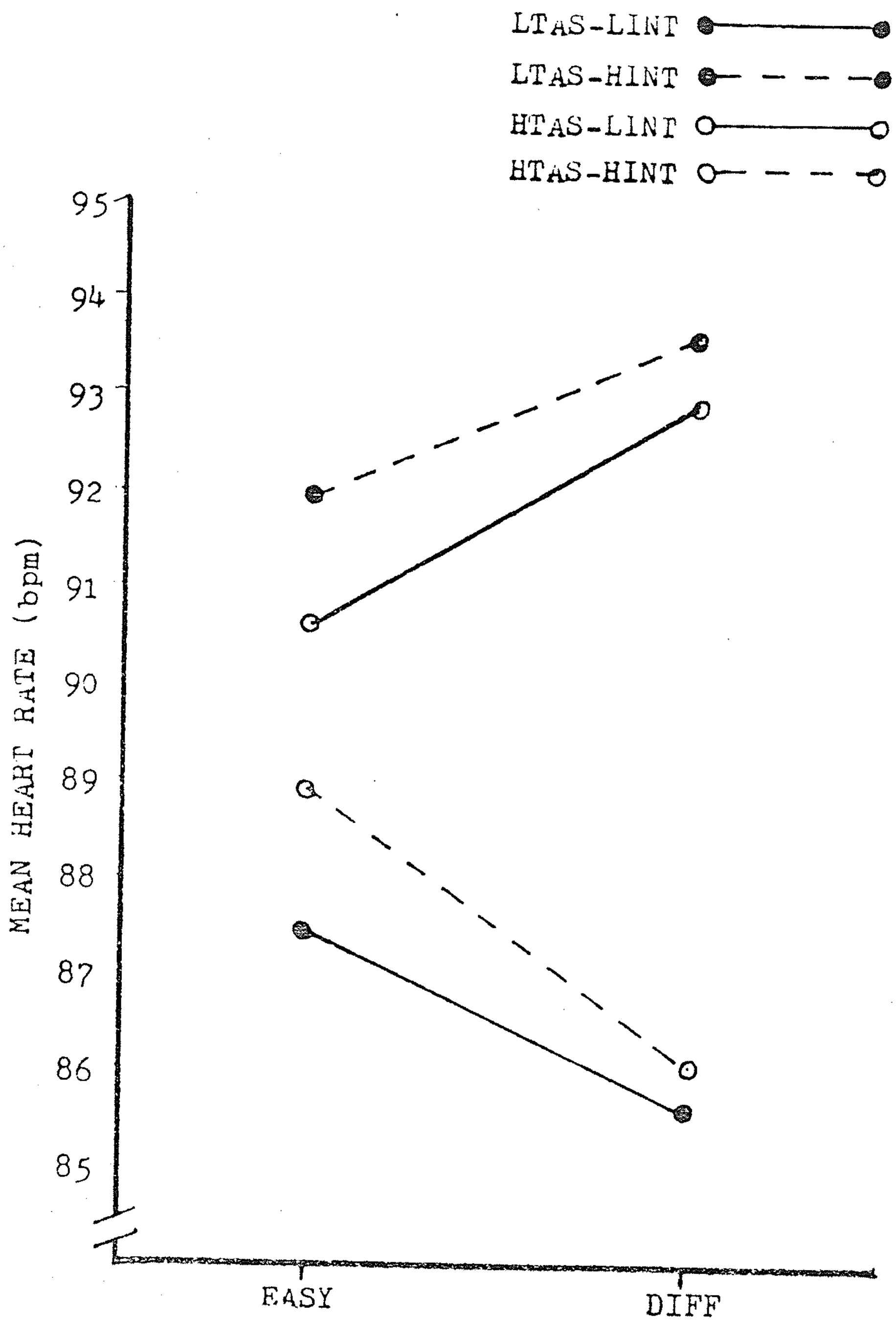
The simple interaction effects of test anxiety by intelligence were significant for the difficult task (TAS X INT at DIFF) ($F(1,143) = 12.115$, $p \leq .001$), but not significant for the easy task.

The simple interaction effect of intelligence by test anxiety for the difficult task is shown in Figure 9. The simple simple effect of intelligence was significant for both the low test anxious (INT at LTAS/DIFF) ($F(1,143) = 7.009$, $p \leq .01$) and the high test anxious (INT at HTAS/DIFF) ($F(1,143) = 5.175$, $p \leq .025$) groups. In the low test anxious group, mean heart rate was faster for the more intelligent subjects

Figure 8.

Non-significant Simple Simple Effects

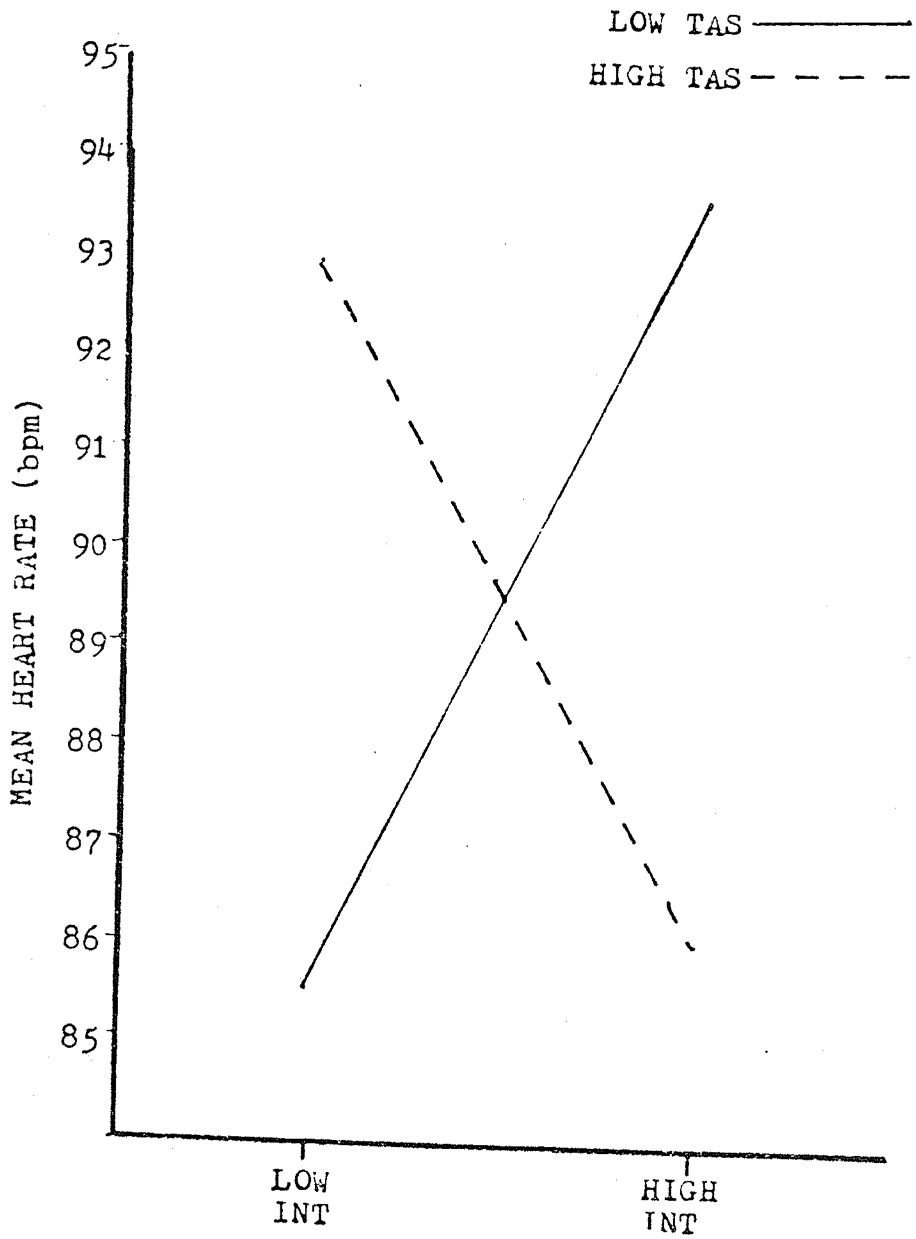
of WORDS at each level of TAS X INT



LTAS-LINT
LTAS-HINT
HTAS-LINT
HTAS-HINT
95
94
93
92
91
90
89
88
87
86
85
MEAN HEART RATE (bpm)
EASY
DIFF

Figure 9.

Significant Simple Interaction Effect
of Intelligence by Test Anxiety
(TAS X INT) for the Difficult Task



LOW TAS
HIGH TAS
95
94
93
92
91
90
89
88
87
86
85
MEAN HEART RATE (bpm)
LOW INT
HIGH INT

(x = 93.580 bpm) than the less intelligent subjects (x = 85.557 bpm). The reverse occurred for the high test anxious group : mean heart rate was higher for the less intelligent subjects (x = 92.917 bpm) than the more intelligent subjects (x = 86.023 bpm).

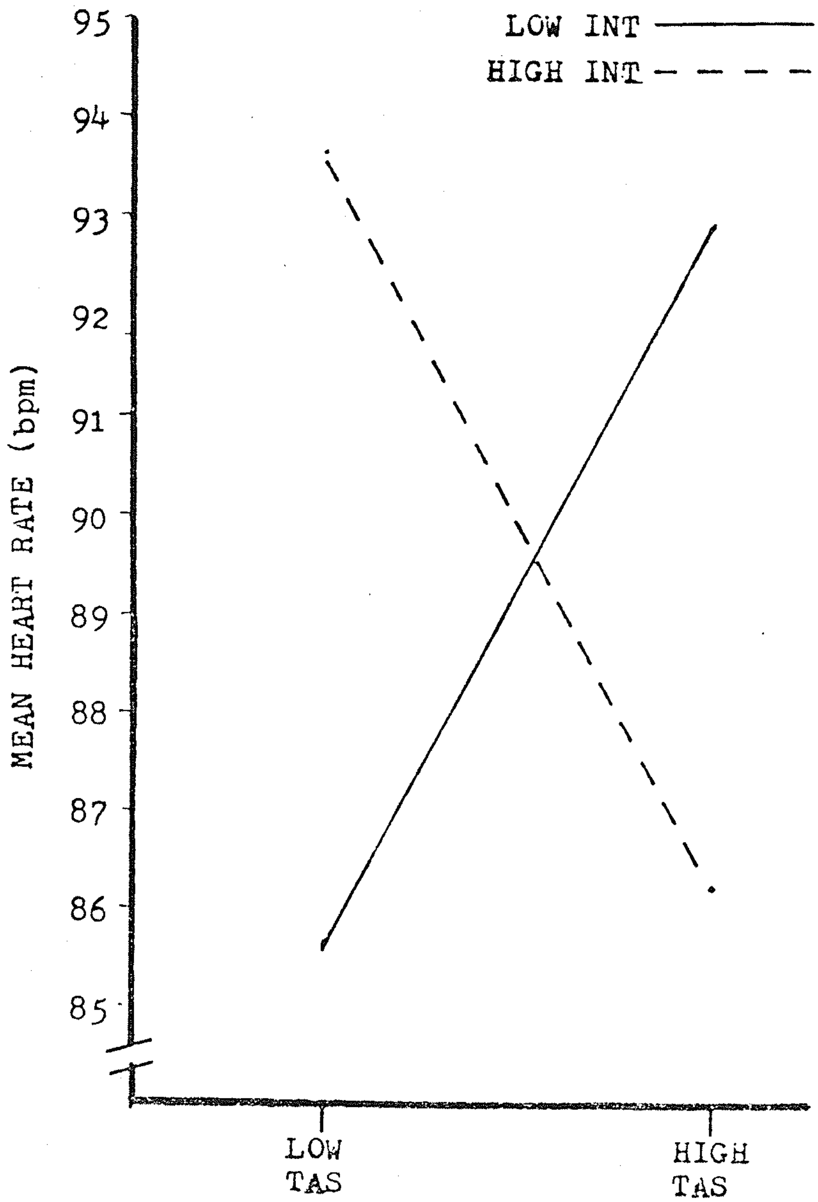
Finally, the simple simple effect of test anxiety was significant, in the difficult task only, for both the low intelligence (TAS at LINT/DIFF) ($F(1,143) = 5.899$, $p \leq .025$) and the high intelligence (TAS at HINT/DIFF) ($F(1,143) = 6.219$, $p \leq .025$) groups. Figure 10 shows that mean heart rate was faster for the low intelligence subjects in the high test anxious group (x = 92.917 bpm) than subjects in the low test anxious group (x = 85.557 bpm). For the high intelligence subjects, however, mean heart rate was faster for subjects in the low test anxious group (x = 93.58 bpm) than subjects in the high test anxious group (x = 86.023 bpm).

MULTIVARIATE ANALYSIS OF PUPILLARY AND HEART RATE RELATIONSHIPS

A multivariate analysis of covariance (Mancova) was performed to assess the effects of the experimental factors on the package of physiological measures. The physiological measures were mean pupil size and mean heart rate during the experimental period. In addition, a discriminant analysis was performed in order to determine the relative importance of the physiological measures vis-a-vis the independent variables. Analysis was done for a 2 X 2 X 2 X 2 (STRESS X TAS X INT X WORDS) mixed design with repeated measures on the last variable. Baseline pupil size and baseline heart rate were used as covariates for reasons discussed previously. A regression parallelism test was performed ($F(28,110) = 1.3279$, $p \leq .1519$) which indicated that the interaction of the covariates with

Figure 10.

Significant Simple Simple Effects
of Test Anxiety for Low and High
Intelligence Groups on the
Difficult Task


LOW INT
HIGH INT
95
94
93
92
91
90
89
88
87
86
85
MEAN HEART RATE (bpm)
LOW TAS
HIGH TAS

the between subjects factors was not significant. Table 12 contains a summary of the Mancova on the combined physiological variables.

The multivariate analysis revealed that the main effect of the stress instructional set was significant ($\underline{F}(2,69) = 3.9922$, $\underline{p} \leq .0229$). Multivariate centroids calculated for the two stress groups indicated that subjects in the high stress group had a greater composite physiological response (centroid = 15.27) than subjects in the low stress group (centroid = 14.64). Examination of the standardized discriminant weights (sdw) revealed that the effect of stress was due to both the pupillary and heart rate measures. However, it should be noted that the heart rate measure (sdw = .8605) was almost twice as important as the pupillary measure (sdw = .4857) with respect to the stress manipulation, i.e. the heart rate measure received a weight nearly twice as heavy as the pupillary measure.

The Mancova also demonstrated that the interaction between level of test anxiety and intelligence (TAS X INT) was significant ($\underline{F}(2,69) = 3.7463$, $\underline{p} \leq .0286$). Multivariate centroids for the interaction were calculated and are presented in Table 13. The interaction effect, shown in Figure 11, suggests that the composite physiological response for the low intelligence group was lower for the low test anxious subjects than for the high test anxious subjects. For the high intelligence group, however, the composite physiological response was higher for the low test anxious subjects than for high test anxious subjects.

In addition, it appears that level of test anxiety functions to increase physiological responding for the low intelligence subjects, but decreases physiological responding for the high intelligence subjects.

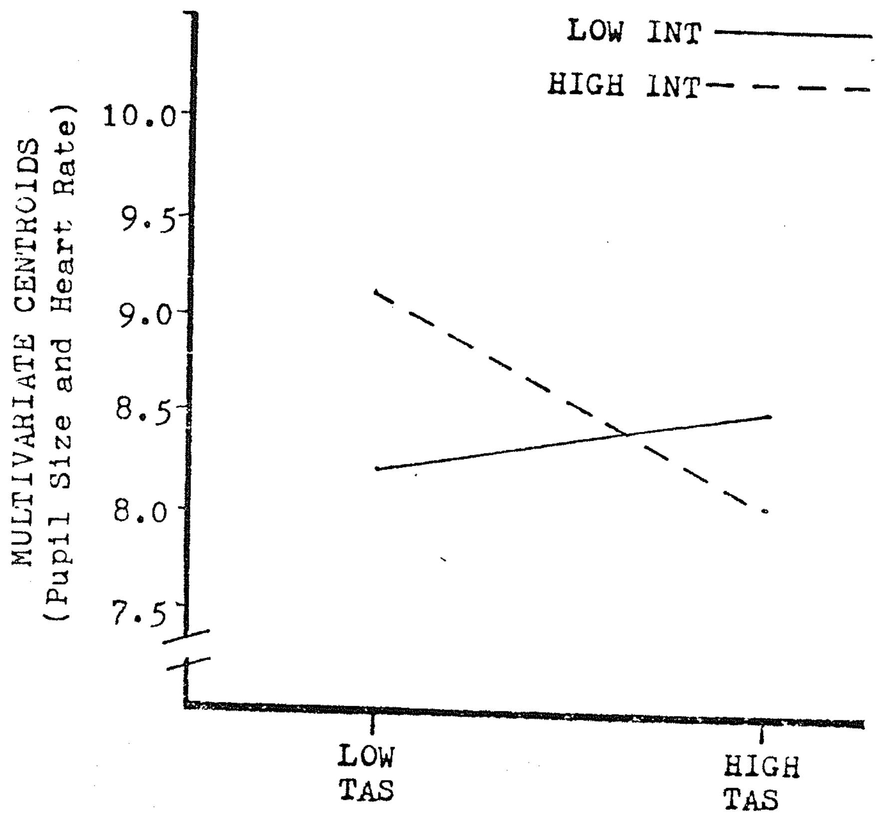
Figure 11.

Significant Multivariate Interaction

Effect of Test Anxiety by Intelligence

(TAS X INT) on the

physiological composite


LOW INT
HIGH INT
MULTIVARIATE CENTROIDS
(Pupil Size and Heart Rate)
10.0
9.5
9.0
8.5
8.0
7.5
LOW TAS
HIGH TAS

Examination of the standardized discriminant weights indicated that the test anxiety by intelligence interaction was almost entirely due to differences in the heart rate response (sdw - .9940) rather than the pupillary response (sdw = -.1412).

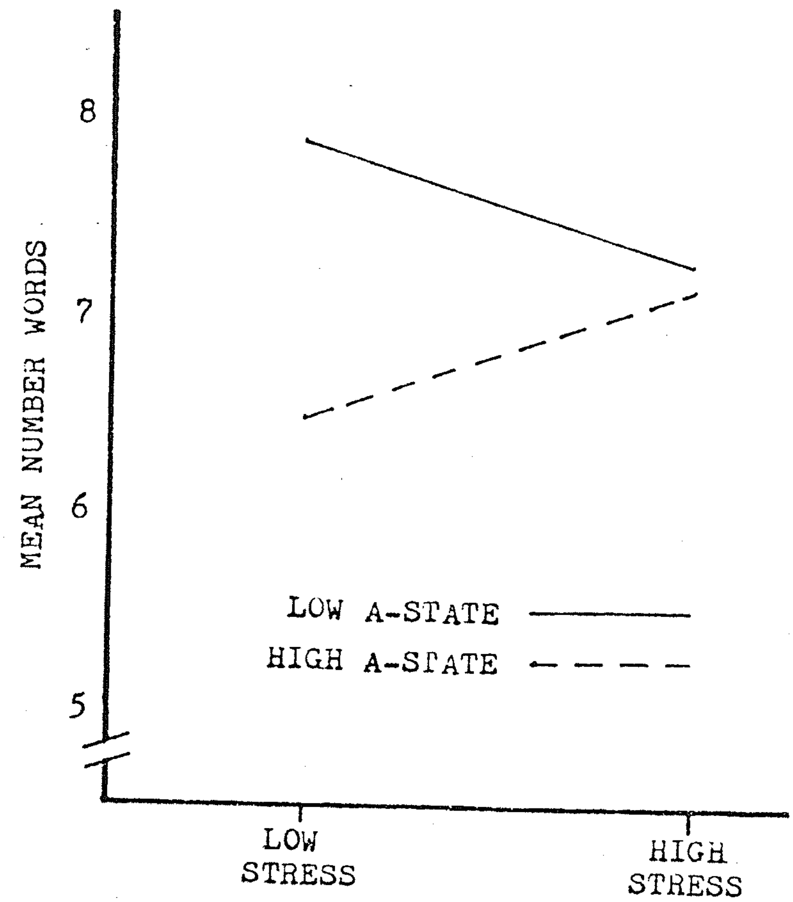
The main effect of the task difficulty factor (WORD) was also significant ($F(2,71) = 5.4058$, $p \leq .0066$). Multivariate centroids were calculated for the two levels of task difficulty and indicated that the composite physiological response was greater for the difficult task (centroid = 19.496) than the easy task (centroid = 19.126). Visual examination of the discriminant function coefficients indicated that the effect of task difficulty was almost entirely due to the pupillary response (sdw = .9976) rather than the heart rate response (sdw = .0580).

Finally, the Mancova showed that a second order interaction (TAS X INT X WORDS) was significant ($F(2,271) = 3.3229$, $p \leq .0418$). The multivariate centroids were calculated for each group in the interaction (Table 14) and are depicted in Figure 12. The figure, remarkably similar to Figure 8, suggests that the important variables in the interaction were test anxiety and intelligence, rather than task difficulty. For example, it appears that the composite physiological response of the low test anxious group is greater for subjects of higher intelligence than those of lower intelligence. The reverse occurs for subjects in the high test anxious group : composite physiological response is greater for the low intellignece subject than the high intelligence subjects.

With respect to test anxiety, Figure 12 suggests that an increase in test anxiety is related to increased physiological responding for the low intelligence subjects and decreased physiological responding for the high intelligence subjects.

Figure 12.

Significant Multivariate Interaction
Effect of Test Anxiety by Intelligence
by Task Difficulty (TAS X INT X WORDS)
on the physiological composite



8
7
6
5
MEAN NUMBER WORDS
LOW A-STATE
HIGH A-STATE
LOW STRESS
HIGH STRESS

ANALYSIS UNDER A-STATE

Previous analysis indicated that the main effect of test anxiety level on A-State was significant and that test anxiety accounted for 25% of the variance in A-State measures (r^2 (1,78) = .258). Nevertheless, the performance, pupillary and heart rate measures were also analyzed using A-State as an independent variable in place of the trait anxiety measure (TAS). Subjects were divided by a median split on the basis of their scores on the A-State measure. The median scores for each of the stress-intelligence groups are as follows : low stress-high intelligence, 41; low stress-low intelligence, 37; high stress-high intelligence, 41; high stress-low intelligence, 44. Note, however, that analyses using A-State are based on unequal cell sizes. The group structure for these analyses are presented in Table 15.

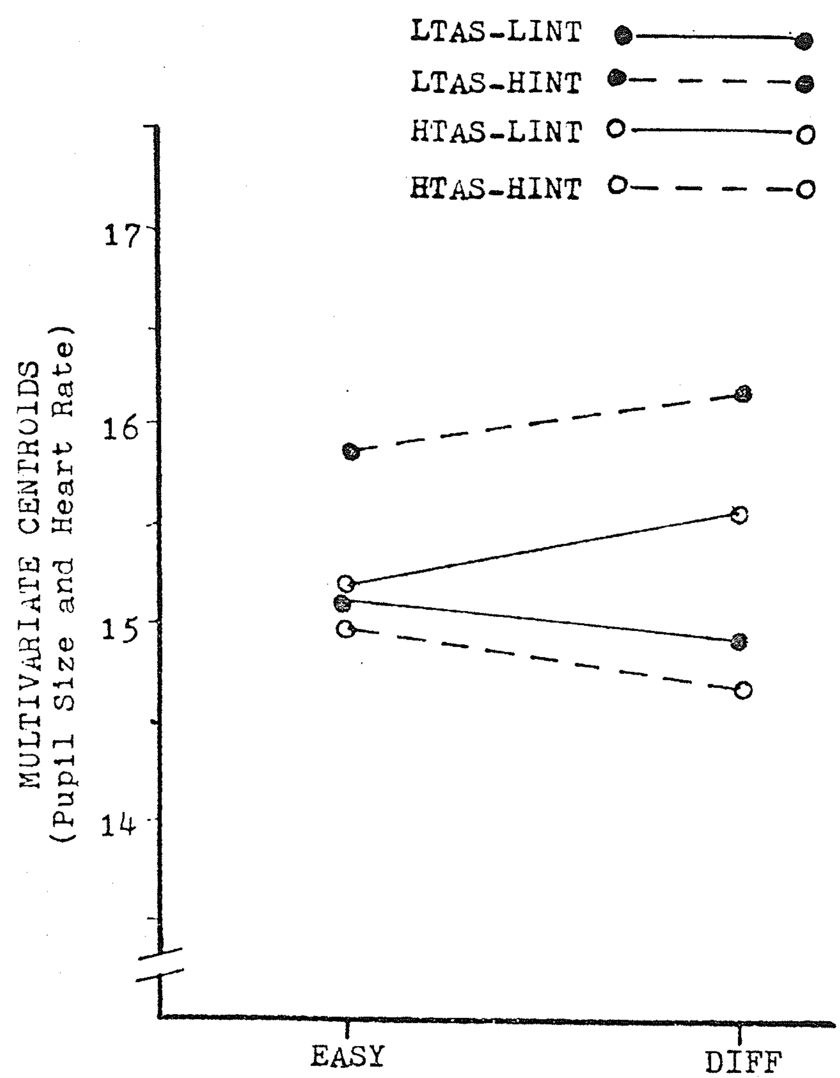
PERFORMANCE WITH A-STATE

A univariate Anova was performed on the number of words produced to determine the effects of the independent variables on performance. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X INT X A-STATE X WORDS) mixed design with repeated measures on the last variable. A summary table of the Anova will be found in Table 16.

The main effect of level of state anxiety (A-STATE) was significant ($\underline{F}(1,72) = 4.64$, $\underline{p} \leq .035$) showing that performance was better for low A-State subjects ($x = 7.572$) than high A-State subjects ($x = 6.784$). The interaction between stress instructional set and level of state anxiety (STRESS X A-STATE) was marginally significant ($\underline{F}(1,72) = 3.13$, $\underline{p} \leq .081$). Figure 13, which depicts the STRESS X A-STATE

Figure 13.

Significant Interaction Effect of Stress Instructions by State Anxiety (STRESS X A-State) on Mean Number Words Produced


LTAS-LINT
LTAS-HINT
HTAS-LINT
HTAS-HINT
MULTIVARIATE CENTROIDS
(Pupil Size and Heart Rate)
17
16
15
14
EASY
DIFF

interaction, serves to clarify the meaning of the A-State main effect. It appears, from the figure, that the effect of state anxiety was significant only in the low stress condition. Analyses of the simple effects of state anxiety at each stress instructional set were performed (Table 17) to verify this contention. As expected, the simple effect of state anxiety was significant in the low stress condition (A-STATE at LSTRESS) ($F(1,72) = 3.989$, $p \leq .05$) verifying that performance was better for the low state anxious subject ($x = 7.875$ words) than the high state anxious subject ($x = 6.441$ words). The simple effect of state anxiety was not significant in the high stress condition (A-STATE at HSTRESS) ($F(1,72) = .038$, $p > .10$).

Although Figure 13 suggests that stress facilitated performance for the high state anxious subjects and impaired performance for the low state anxious subjects, the simple effects of stress instruction were not significant.

The Anova also showed that the main effect of task difficulty (WORD) was highly significant ($F(1,72) = 532.25$, $p \leq .0001$), clearly showing that performance was better for the easy task ($x = 10.1$ words) than the difficult task ($x = 4.39$ words). In addition, an interaction between task difficulty and level of intelligence appeared which was marginally significant (INT X WORD) ($F(1,72) = 2.96$, $p \leq .09$). Analyses of the simple effects of intelligence at both the easy and difficult tasks (INT at EASY and INT at DIFF) were not significant (Table 18).

The second order interaction (STRESS X INT X WORDS) was also found to be significant ($F(1,72) = 6.01$, $p \leq .017$). The analyses of the simple simple effects and simple interaction effects is presented in Table 19.

The analyses of the simple interaction effects revealed that the stress instructional set by intelligence interaction was significant for the easy word condition (STRESS X INT at EASY) ($F(1,144)$, = 6.999, $p \leq .01$). In order to clarify the meaning of this interaction, analysis of the simple simple effects of the stress instructional set were performed. These analyses indicated that stress was a significant factor only for the low intelligence subjects in the easy task (STRESS at LINT/EASY) ($F(1,144) = 4.604$, $p \leq .05$). Performance was better for subjects in the high stress condition (x = 10.74 words) than in the low stress condition (x = 9.42 words). The simple simple effect of intelligence was also found to be significant in the high stress-easy task combination (INT at HSTRESS/EASY) ($F(1,144) = 4.812$, $p \leq .05$), revealing the surprising result that subjects in the low intelligence group (x = 10.74 words) performed better than subjects in the high intelligence group (x = 9.41 words).

Two other simple interaction effects were found to be significant : (1) the effect of stress instructional set by task difficulty for the low intelligence group (STRESS X WORD at LINT) ($F(1,72) = 4.673$, $p \leq .05$), and (2) the effect of intelligence by task difficulty for the high stress condition (INT X WORD at HSTRESS) ($F(1,72) = 9.141$, $p \leq .005$). The simple simple effects of task difficulty were highly significant in all conditions and are reported in Table 19.

PUPILLARY RESPONSE WITH A-STATE

A univariate Ancova was performed on the mean pupil size during the experimental period to determine the effects of the independent variables on the pupillary response. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X INT X A-STATE X WORDS) mixed design with repeated measures on the last variable. Baseline pupil size was used as a covariate for reasons discussed previously. A summary table of the Ancova will be found in Table 20.

There were no significant main effects, nor interaction effects, for any of the between subjects variables. The main effect for the within subjects variable of task difficulty (WORDS), however, was highly significant ($\underline{F}(1,72) = 11.14$, $\underline{p} \leq .001$). The significant main effect of task difficulty indicates that pupil size during the difficult task ($x = 4.736$ mm) was larger than during the easy task ($x = 4.649$ mm).

HEART RATE RESPONSE WITH A-STATE

A univariate Ancova was performed on the mean heart rate during the experimental period to determine the effects of the independent variables on the heart rate response. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X INT X A-STATE X WORDS) mixed design with repeated measures on the last variable. Baseline heart rate was used as a covariate for reasons discussed previously. Table 21 contains a summary of the analysis of covariance for the heart rate data.

The main effect of the stress instructional set was found to be significant ($\underline{F}(1,71) = 4.62$, $\underline{p} \leq .035$) indicating that subjects in the low stress condition ($x = 87.9456$ bpm) had a slower heart rate than subjects in the high stress condition ($x = 91.2601$ bpm). No other effects reached significance.

MULTIVARIATE ANALYSIS OF PUPILLARY AND HEART RATE RELATIONSHIPS ON A-STATE

A multivariate analysis of covariance (Mancova) was performed to assess the effects of the experimental factors on the package of physiological measures. The physiological measures were mean pupil size and mean heart rate during the experimental period. In addition, a discriminant analysis was performed in order to determine the relative importance of the physiological measures vis-a-vis the independent variables. Analysis was done for a 2 X 2 X 2 X 2 (STRESS X INT X STATE X WORDS) mixed design with repeated measures on the last variable. Baseline pupil size and baseline heart rate were used as covariates for reasons discussed previously. A regression parallelism test was performed ($\underline{F}(28,110) = .8693$, $\underline{p} \leq .6555$) which indicated that the interaction of the covariates with the between subjects factors was not significant. Table 22 contains a summary of the Mancova on the combined physiological variables.

The multivariate analysis revealed that the main effect of the stress instructional set was significant ($\underline{F}(2,69) = 3.9318$, $\underline{p} \leq .0242$). Multivariate centroids calculated for the two stress groups indicated that subjects in the high stress group had a greater composite physiological response (centroid = 15.56) than subjects in the low stress group (centroid = 14.92). Examination of the standardized discriminant weights (sdw) revealed that the effect of stress was due to both the pupillary and heart rate measures. However, it should be noted that the heart rate measure (sdw = .8707) was almost twice as important as the pupillary measure (sdw = .5072) with respect to the stress manipulations, i.e. the heart rate measure received a weight nearly twice as heavy as the pupillary measure. No other between subjects factors were significant.

The main effect of the task difficulty factor (WORD) was also significant ($F(2,71) = 5.7625$, $p \leq .0048$). Multivariate centroids were calculated for the two levels of task difficulty and indicated that the composite physiological response was greater for the difficult task (centroid = 20.115) than the easy task (centroid = 19.733). Visual examination of the discriminant function coefficient indicated that the effect of task difficulty was almost entirely due to the pupillary response (sdw = .9978) rather than the heart rate response (sdw = .0624). There were no significant interactions with the factor of task difficulty.

EYSENCK PERSONALITY INVENTORY

A secondary hypothesis of this research concerned the use of the Neuroticism (N) and Extraversion (E) dimensions of the Eysenck Personality Inventory (EPI) with respect to subjects' performance, pupillary response and heart rate. Subjects were divided by a median split on the basis of their scores on the Neuroticism dimension as well as the Extraversion dimension. The median for the Neuroticism dimension was 11.5 and the median for the Extraversion dimension was 13.6. Note that the analyses using EPI measures are based on unequal cell sizes. The group structure for these analyses are presented in Table 23.

PERFORMANCE

A univariate Anova was performed on the number of words produced to determine the effects of the independent variables on performance. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X E X N X WORDS) mixed design with repeated measures on the last variable. A summary of the Anova will be found in Table 24.

The main effects for extraversion and neuroticism were not signigicant. However, the stress instructional set by neuroticism by task difficulty interaction (STRESS X N X WORDS) was significant ($\underline{F}(1,72) = 6.26$, $\underline{p} \leq .015$). Analyses of the simple effects of stress and the simple effects of neuroticism were performed in order to determine if these factors were operating at any level of stress or task difficulty. The only (marginally) significant effect resulting from the analyses was neuroticism at the high-stress difficult word condition (N at HSTRESS/DIFF) ($\underline{F}(1,144) = 3.605$, $\underline{p} \leq .10$) where stables ($x = 4.86$ words) performed better than neurotics ($x = 3.67$ words). A summary of the simple effects is presented in Table 25.

PUPILLARY RESPONSE

A univariate Ancova was performed on the mean pupil size during the experimental period to determine the effects of the independent variables on the pupillary response. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X E X N X WORDS) mixed design with repeated measures on the last variable. A summary table of the Ancova will be found in Table 26.

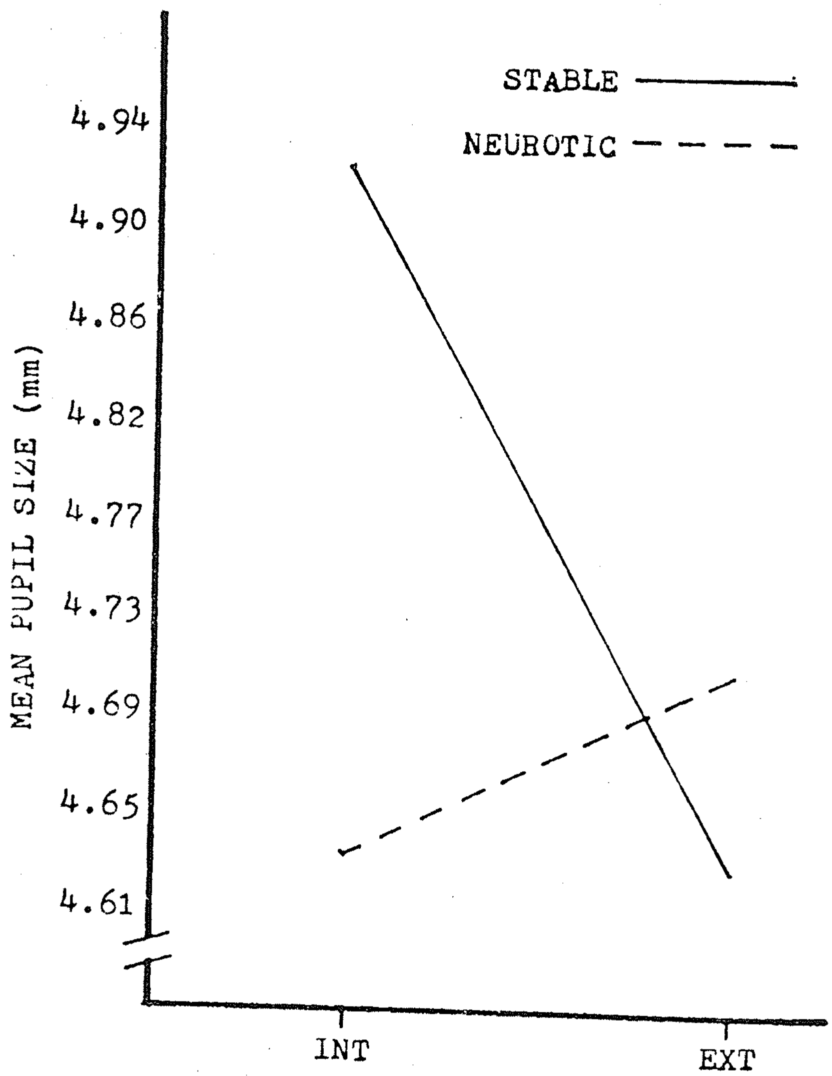
The main effects for neuroticism and extraversion were not significant. However, the extraversion by neuroticism interaction (E X N) was significant ($\underline{F}(1,71) = 4.84$, $\underline{p} \leq .031$). The significant interaction, depicted in Figure 14, suggests that pupil size is larger for the introverted-stable subjects ($x = 4.957$ mm) than the extroverted-stable subjects ($x = 4.631$ mm). For the neurotic subjects, introverts appear to have a smaller pupillary response ($\bar{x}$ = 4.626 mm) than the extroverted subjects ($\bar{x}$ = 4.697 mm). An analysis of the simple effects of the Extraversion dimension (Table 27) indicated that the Extraversion dimension was only marginally significant for the stables (E at STAB) (F (1,71) = 3.541, $p \leq .10$) and not significant for neurotics.

HEART RATE RESPONSE

A univariate Ancova was performed on the mean heart rate during the experimental period to determine the effects of the independent variables on the heart rate response. Analysis was done on a 2 X 2 X 2 X 2 (STRESS X E X N WORDS) mixed design with repeated maasures on the last variable. A summary table of the Anova will be found in Table 28. Neither the neuroticism nor extraversion dimensions were found to be significant.

Figure 14.

Significant Extraversion by Neuroticism Interaction (E X N) on Mean Pupil Size


STABLE
NEUROTIC
4.94
4.90
4.86
4.82
4.77
4.73
4.69
4.65
4.61
MEAN PUPIL SIZE (mm)
INT
EXT

DISCUSSION

The primary purpose of this experiment was to examine the differential influence of "cognitive" and "emotional" variables on heart rate and pupil size. Specifically, the theoretical notion of interest was that the pupillary response is cortically mediated and, therefore, will reflect cognitive activity to a greater extent than emotional activity. A corresponding idea was that heart rate reflects visceral, autonomic nervous system activity and is therefore more strongly related to emotional responsivity than to cognitive activity.

The theoretical propositions were operationalized in this study as follows : the pupillary response would be affected primarily by level of task difficulty since task difficulty was considered a manipulation of cortically mediated activity. The heart rate response, however, would be affected primarily by the level of stress instructional set since level of stress was considered a manipulation of autonomically mediated activity. Conversely, the theoretical propositions imply that pupil size should be only secondarily affected by the stress manipulation while the heart rate should be only secondarily affected by task difficulty.

The results of this experiment provide convincing evidence that the pupillary response is cortically mediated while heart rate is autonomically mediated. The discussion to follow will show how the findings of this experiment lead directly to verification of the proposition and present the rationale behind the theoretical expectations.

MANIPULATION CHECKS

A series of manipulation checks were performed in order to determine how some of the variables were operating within the experiment. One of the questions considered important for proper interpretation of the result was the influence of the stress instructional set, level of trait anxiety and level of intelligence on state anxiety during the experiment. First, subjects in the high test anxious group reported greater state anxiety both in the low stress and high stress conditions. This result was as expected and assured that the factor of test anxiety was, in fact, providing differential levels of anxiety during the experiment.

The stress manipulation, however, did not work in the expected direction, i.e. the stress manipulation served to increase the reported level of state anxiety for low test anxious subjects only. The high test anxious subjects maintained a high level of state anxiety across both low and high stress instructions. It was expected that the high test anxious subjects would show a much greater anxiety reaction to the high stress instructions that the low stress instructions. Either the experimental setting itself and the nature of the experimental task served to arouse anxiety, or, the low stress instructions failed to reduce or hold down the anxiety responses of the highly test anxious subjects. Possibly a ceiling effect occured in that any type of test situation is very arousing to high test anxious subjects. The fact that the stress by test anxiety interaction was not as expected bears upon the outcome of the performance analysis. Also bearing upon the performance outcome is the finding that subjects in the high intelligence group reported greater state anxiety than those in the low intelligence group. These implications will be investigated further in the appropriate section of this discussion.

The second manipulation check was the analysis of the pupillary baseline. Supposedly, measures taken before presentation of the stress instructions should not differentiate among subjects who will later be divided into low and high stress groups. It might be expected, though, that subjects in the high test anxiety group would reflect their personality characteristics by showing a larger pupil size than low test anxious subjects. If there are significant effects in the baseline measure, the possibility of experimenter bias must be considered. Nevertheless, caution must be taken to determine the effects on the data gathered in the experimental period.

Significant effects were found in the pupillary baseline of the present experiment. While no main effects were significant, the stress by test anxiety interaction was significant. For subjects in the low test anxious group, those who would later be given high stress instructions had a larger pupil size than those who would receive low stress instructions. (Figure 2). Therefore, it is conceivable that the experiment biased those subjects who would later be in the high stress group. It is unlikely, however, that the experimenter would bias subjects in this direction for several reasons : (1) Since the experiment posited different predictions for pupil size vs. heart rate, the experimenter could not intentionally influence one of the dependent measures to the exclusion of the other. Heart rate baseline was not significant with respect to later stress manipulation. (2) Based on the hypothesis of this study, the experimenter would more likely want to keep the pupil size of "later-to-be-stressed" subjects as low as possible. (3) If anything, the experimenter would be more likely to bias the high test anxious subjedts, since later significance during the experimental period could more easily be explained away as an artifact. That is, subjects scoring high in test anxiety had a larger pupil size during the experimental period because they had a larger pupillary baseline.

Paradoxically, the presence of the significant pupillary baseline effect serves to strengthen, rather than weaken the experimental results. The baseline effect would have worked against the hypothesis that the pupillary response would not be affected by stress factors during performance.

The simple effect of test anxiety in the high stress group was marginally significant for the pupillary baseline (Figure 2). The low test anxious subjects had a larger pupillary baseline than the high test anxious group. This baseline effect also would have worked against the hypothesis that the pupillary response during performance would not be affected by level of test anxiety.

In order to control for these significant pupillary baseline effects, and because the relationship between baseline pupil size and pupil size during task performance was very high, the pupillary baselines were used as covariates in the analysis of experimental data.

The third manipulation check, analysis of the heart rate baseline, did not differentiate among subjects on the independent variables. Nevertheless, regression analysis indicated that there was a strong relationship between baseline heart rate and heart rate during performance. Therefore, the heart rate baselines were used as covariates in the analysis of the data obtained during the experimental task.

PUPILLARY AND HEART RATE ACTIVITY

The analysis of pupillary and heart rate activity proceeded in several steps. First, univariate analyses were done in order to consider the effects of the independent variables on each of the physiological measures independently. Then a multivariate analysis was done in order to consider the effects of the independent variables on the composite of the physiological responses and, more importantly, to determine the relative importance of each physiological measure via discriminant analyses. A set of analyses were done using test anxiety as one of the independent variables, and another set which substituted state anxiety for test anxiety.

Both univariate analyses of the pupillary response showed that level of task difficulty was a highly significant factor. Subjects were seen to have a significantly larger pupil size while performing a difficult task than while performing an easy task. None of the other factors in the analyses predicted pupil size (i.e. neither stress, intelligence, test anxiety nor state anxiety were significant).

The results of these univariate analyses of the pupillary response are offered as the first piece of evidence that the pupillary response reflects cognitive activity to a greater degree than emotional activity. Two of the experimental hypotheses are verified : (1) pupil size was larger for the difficult task than for the easy task, indicating that pupil size reflects mental effort, and (2) no significant differences occurred with respect to high stress and low stress instructions, indicating that pupil size is not a sensitive measure of emotional variables. Additionally, pupil size was not a discriminator of levels of test anxiety nor state anxiety, which further supports the notion that the pupillary response is a weak measure of emotional variables.

The univariate analyses of the heart rate data, however, painted a different picture. Both analysis with trait anxiety and state anxiety showed that level of stress was a highly significant factor while task difficulty was not related to heart rate.* Subjects in the high stress condition had a faster rate than subjects on the low stress condition. Other effects found to be significant involved the interaction between test anxiety and intelligence.

The results of the univariate analyses of the heart rate response are offered as the next piece of evidence : heart rate reflects emotional activity to a greater degree than cognitive activity. Two of the experimental hypotheses are verified again : (1) no significant differences occurred with respect to task difficulty, indicating that heart rate is not a sensitive measure of cognitive activity; and (2) a significant difference in heart rate was found with respect to high and low stress instructions, indicating that heart rate response reflects emotional activity.

The results of the multivariate analyses confirm the implications of the univariate findings by allowing one to compare the relative importance of each physiological variable on the significant effects. There was a significant effect of stress on the multivariate physiological composite which indicates that there is a greater overall physiological response to high stress as opposed to low stress. The discriminant analysis, however, showed that the heart rate measure was almost twice as important as the pupillary measure in accounting for statistical significance. Again, we see that the significant effect of stress instructions is due to heart rate response primarily, while pupillary response is only a secondary source of the significant variation.

* A marginally significant ($p \leq .10$) simple effect of task difficulty for high test anxious-high intelligence subjects was found. However, this evidence is not taken an disruptive of the argument being presented since heart rate was slower for the difficult task.

The outcome of the multivariate analysis is seen as the third piece of evidence : heart rate is the discriminating measure of the stress manipulation while pupillary response is considerably less sensitive. The implication is that the heart rate response reflects emotional activity. Conversely, the pupillary response is not a strong indicator of emotional activity.

There was also a significant effect of task difficulty on the multivariate physiological composite which showed that there was a greater overall physiological response to the difficult task as opposed to the easy task. The discriminant analysis confirmed that the effect of task difficulty was almost entirely due to the pupillary response. The contribution of the heart rate response was trivial. The evidence gleaned from comparisons of the univariate analyses is further supported by the discriminant analysis : the significant effect of task difficulty is due to pupillary response primarily, while heart rate response is only a negligible source of the significant variation.

The weights of the discriminant function, then, are seen as the fourth piece of evidence : pupillary response is the discriminating measure of task difficulty while heart rate is a poor discriminator. This implies that the pupillary response reflects cognitive activity, and conversely, that the haart rate response is not a sensitive measure of cognitive activity.

All the evidence, taken together, leads to a single conclusion. The pupillary response is a better measure of cognitive activity than heart rate and can be considered a choice measure of cortically mediated activity. On the other hand, the heart rate response is a better measure of emotional activity or autonomically mediated activity.

TAS BY INTELLIGENCE INTERACTION ON HEART RATE

A surprising outcome of this experiment was the significant TAS by Intelligence interaction on heart rate. Generally, it would be expected that heart rate would be greater for high test anxious subjects across all levels of intelligence. However, the results of this experiment show that of those in the high intelligence group, low test anxious subjects have a faster heart rate (Figure 10) on the difficult task. Conversely, of the low intelligence subjects, the high test anxious group has a faster heart rate.

This result may seem paradoxical, However, a framework will be suggested by which we may be able to begin to explain the results. The argument takes the form that heart rate acceleration is related to mechanisms for coping. Aside from the "intake-rejection" hypothesis of Lacey (Lacey, Kagan, Lacey and Moss, 1963; Lacey and Lacey, 1970; Lacey and Lacey, 1974), other researchers have discussed the relationships between personality variables and heart rate activity. Lykken, Macindoe and Tellegen (1972), for example, found that low anxiety subjects showed a heart rate response to warning of shock which was twice as large as that produced by high anxious subjects. They suggested that this heart rate acceleration was an adaptive mechanism used more efficiently by low anxious subjects to reduce vulnerability to a noxious stimulus.

Research comparing the physiological responses of psychopaths to non-psychopaths revealed that psychopaths had a greater heart rate response prior to shock (Hare and Craigen, 1974) and prior to an aversive, intense tone (Hare, Frazelle and Cox, 1978). These results were interpreted as evidence that cardiac activity reflects the operation of an active, efficient coping mechanism. Schalling (1976) also found that psychopaths had higher pain tolerance than non-psychopaths along with a greater heart rate increase. Pain tolerance was found to be positively correlated with heart rate increase.

Obrist (1976) and his colleagues (Obrist, Gaebelein, Teller, Langer, Grigiolo, Light and McCubbin, 1978) have recently begun to examine the relationships between coping styles and heart rate activity. In three experiments concerned with the passive/active coping dimension, it was found that "providing a subject with an opportunity to cope actively is more apt to initiate and then perpetuate sympathetic influences on the heart" (Obrist, 1976, p. 100). The impact of the three experiments was to indicate that active coping results in greater heart rate activity than passive coping.

Considering the findings of the research reported above, it appears that a relationship may exist between personality factors and heart rate. More specifically, this relationship may be mediated by the coping style (active vs. passive) of personality sub-types. With respect to this experiment, there is some evidence to suggest that intelligence level may be indicative of coping style. In a longitudinal study of intellectual development (Sontag, Baker and Nelson, 1955; Sontag, Baker and Nelson, 1958), characterized children with increasing mental development as independent, aggressive, self-initiating, competitive and good problem-solvers. Children with decreasing IQ were characterized as dependent, passive and conforming.

Accepting the premise that the high intelligence subjects were more likely to engage in active coping processes, it is possible to begin to interpret the test anxiety by intelligence interaction on heart rate. The results showed a significant effect of intelligence for low test anxious subjects in which the high intelligence group had a larger heart rate response than the low intelligence group. We might hypothesize, in line with the research cited, that subjects in the high intelligence group are involved in more active coping and therefore have a faster heart rate. Within the high intelligence group, low test anxious subjects showed a faster heart rate than high test anxious subjects. This too, may be accounted for by the active coping processes of the low test anxious subjects.

However, subjects in the low intellignece, high test anxious group also showed a fast heart rate. This result does not fit the coping style framework being suggested. An explanation of this result, though, might be related to the specific attributes of this group, e. g. lower intelligent, high anxious subjects have had to learn effective coping techniques in order to counteract the factors impairing their performance.

The above discussion is purely conjecture, but several important questions are raised. How do the coping styles of subjects at different levels of intelligence affect performance and physiological response ? Are scores on paper and pencil measures of anxiety affected by the subjects' coping strategies ? If so, how might the construct of anxiety be defined and developed to account for the paradoxical findings of the studies reviewed ? The present experiment was not designed to answer these questions nor test the adequacy of the suggested framework of explanation.

EYSENCK PERSONALITY INVENTORY

As presented in the Introduction, Eysenck's (1967) theory about the physiological basis of introversion and neuroticism may be usefully applied to the notion that the pupillary response is a cortically mediated function which is affected by the personality dimension of introversion-extraversion.

Eysenck related introversion-extroversion to differences in the threshold of cortical arousal. Introverts are characterized by lower thresholds of cortical arousal than extroverts.

Since the introversion-extroversion personality dimension is related to differences in the threshold of cortical activity, differences in pupil size along this dimension would suggest that the pupillary response is related to cortical activity. It is expected that introverts, having a lower threshold of cortical arousal, would show a larger pupillary response than extroverts.

The results of this experiment offer some support for this contention. The Ancova on the pupillary response revealed significant extraversion by neuroticism interaction. The analysis of the simple effects of the Extraversion dimension indicated that the degree of extraversion was marginally significant (and only for subjects classified as stables), introverts had a larger pupil size than extroverts. Two reasons for failure to reach significance present themselves immediately : (1) cell sizes in the analysis were grossly unequal, and (2) there was a large number of subjects who might more correctly be classified as ambiverts.

Other research, however, provides stronger evidence of the extraversion-pupil size relationship. Stelmack and Mandelzys (1975) examined pupillary responses of extraverts and introverts to affective and taboo words. Their results generally showed that introverts yielded the largest pupil size and the largest magnitude in change of pupil size from prestimulus levels. The authors related their results to Eysenck's hypothesized relationship between extraversion and cortical arousal, i.e. introverts are characterized by higher levels of arousal. Dumoff and Janisse (1976) and Boddicker (1972) also found pupil size to be larger for introverts.

PERFORMANCE

The results of the performance analyses were generally supportive of the predictions from Spence's Drive Theory (Spence, 1958; Spence and Spence, 1966) as well as the extension of this theory by Spielberger (1966). To recapitulate, drive theory predicts that high anxious subjects will perform better than low anxious subjects on an easy task because correct response tendencies are dominant. On a difficult task, competing (incorrect) response tendencies are dominant, and low anxious subjects will perform better than high anxious subjects. Spielberger's extension of drive theory accounts for the interaction of intelligence and anxiety as it affects performance. Basically, the difficulty of a task for a particular subject depends upon the intelligence or ability of that subject.

The research evidence (e.g. Sarason, 1961; Spielberger and Smith, 1966) indicates that these effects on performance occur only when an adequate stressor has been applied to insure that anxiety is aroused in subjects. In the present experiment, task performance under the high stress condition was consistent with expectations. On the easy task, high test anxious subjects (x = 10.325 words) performed better than low test anxious subjects (x = 9.925 words). On the difficult task, low test anxious subjects (x = 5.05 words) performed better than high test anxious subjects (x = 3.475 words).

Statistical analysis, however, showed that the effect for the easy task was not significant. Two reasons are forwarded as explanations of the failure of this effect to reach significance : (1) a failure of the stress manipulation to maximize state anxiety differences between high and low test anxious subjects, and (2) the level of difficulty of the easy task was not great enough to discriminate between groups.

Probably both reasons contributed to the failure of the test anxiety effect to reach significance. In the first case, it was mentioned previously that the stress manipulation did not affect A-State in the expected direction, i.e., the A-State scores of high test anxious subjects were not affected while the scores of low test anxious subjects were significantly increased by high stress instructions. Therefore, the differences in state anxiety between low and high test anxious subjects were relatively smaller (although significant) in the high stress condition than the low stress condition (Figure 1). This suggests that the differences in state anxiety under high stress were not large enough to produce a significant effect. The stress instructions may have been so strong as to motivate the low test anxious subjects to perform better than they might have under more neutral instructions.

The second reason suggested for the failure to obtain a significant performance effect concerns the level of difficulty of the task. The task may have been so easy that ceiling effects were being reached which did not allow for discrimination between groups. In particular, subjects in the low test anxious group were motivated by stress instructions to perform an easy task and therefore produced scores too high to allow for a significant effect.

Subjects were originally selected on the basis of differences in TAS scores in order to increase the probability that an A-State reaction would be obtained in the experiment. Both Endler (1975) and Spielberger (1972) supported the notion of using a measure of trait anxiety specifically related to the experimental task. Spielberger (1972) suggested that "in general, situation specific trait anxiety measures are better predictors of elevations in A-State for a particular class of stress situations than are general A-Trait measures" (p. 490). We have seen that subjects in the high test anxious groups, in fact, reported a higher level of state anxiety than subjects in the low test anxious group. Additionally, Spielberger and Smith (1966) and Sarason (1961; 1972) have presented evidence implying that the predictions of drive theory will occur only when subjects are experiencing anxiety during the experimental task. It would seem, therefore, that if subjects were divided on the basis of A-State scores rather than TAS, the performance effects predicted by drive theory would be displayed. The analysis, however, did not verify this assumption. The effect of state anxiety on performance was not significant in the high stress condition.

Performance effects came out as expected when subjects were divided on the basis of TAS, but not when divided on the basis of A-State scores. Some of the low test anxious subjects reported greater A-State scores than their high test anxious counterparts. Nevertheless, their performance scores did not fit theoretical predictions. Apparently, the state anxiety measures by the Self-Evaluation Questionnaire (STAI Form X-1, Spielberger, Gorsuch and Lushene, 1970) is not the most appropriate measure of that anxiety experienced by subjects scoring high on the TAS. Just as a situation-specific measure of A-Trait will increase the probability of an A-State reaction, perhaps a trait-specific measure of A-State is required to validate the effectiveness of experimental manipulation.

The low stress instructions presented to subjects were actually a combination reassuring and task-orienting condition as described by Sarason, (1972). While no predictions had been forwarded, it might have been expected that high test anxious subjects would perform better than low test anxious subjects. In fact, in Sarason's (1972) study, high test anxious subjects were found to perform better than low test anxious subjects when given reassuring or task-orienting instructions. In the present experiment, however, the low stress instructions were not anxiety-allaying to the high test anxious subjects, but were anxiety-allaying to the low test anxious subjects. Still, the more highly anxious subjects would be expected to perform better on the easy task if we were to invoke drive theory predictions. Nevertheless, the results of the performance analysis under low stress instructions (although marginally significant) indicated that low test anxious subjects performed better than high test anxious subjects in the easy task (10.67 words vs. 9.47 words).

A discussion by Sarason provides a clue to the apparent anomoly in the results of the present experiment. Sarason (1972) suggested that "high and low test anxious individuals may differ most importantly in the meanings they attach to performance cues" (p. 387). Under high anxiety, the high test anxious could not make profitable use of the task-orienting cues. Low test anxious subjects, however, made use of the cues and therefore performed well.

PHYSIOLOGICAL RESPONSE, TAS, AND PERFORMANCE

One of the objectives of this experiment was to investigate the physiological parallels to the differential performance of high and low test anxious subjects to difficult and easy tasks. The interactive effects of test anxiety and task difficulty have been discussed. What has not been discussed is whether the pupillary response tracks the test anxiety by task difficulty interaction on performance.

In a recent review of the literature on the relationship between pupil size and anxiety, Janisse (1976) concluded that "...ample evidence is reported associating pupillary dilation with state anxiety; however, differences in pupil size reflecting various levels of trait anxiety have not been consistently reported" (p. 42). Arima and Wilson (1972) and Kuc and Janisse (1976), for example, reported no significant main effect between their high and low anxious groups in pupil size. Hicks and Azamtarrahian (1977), however, presented some evidence offering "...support for the speculation that there is a positive correlation between pupil size and scores on situation specific measures of trait anxiety" (p. 5).

The evidence for the relationship between test anxiety and test performance has been reviewed. The dynamics of this relationship have been elucidated a number of ways (Mandler, 1975; Sarason, 1975; Spielberger, Anton and Bedell, 1976; Wine, 1971), but the thrust of the explanations point in the same direction. The high test anxious subject produces competing and interfering responses which can disrupt performance. Attention is divided between task relevant cues necessary for optimal performance and self-centered, interfering cues (e.g. worry), that are irrelevant to and impair performance on a test. Low test anxious subjects, on the other hand, attend only to task relevant cues.

Hicks and Azamtarrahian (1977) speculated that high test anxious subjects "expend greater levels of mental effort during the performance of a test" (p. 3) than low test anxious subjects because they are attending to both task relevant and task irrelevant cues. These differences in "mental effort" should be reflected in differential pupil size; high test anxious subjects should have a larger pupil size than low test anxious subjects. Unfortunately, this conception blurs the attempt to provide a distinction between pupillary activity as a response to cognitive vs. emotional variables. For example, if the pupillary response reflects autonomic arousal associated with anxiety, we would expect pupil size to be larger for higher levels of autonomic arousal, regardless of task performance. High test anxious subjects should always have a larger pupil size than low test anxious subjects. This is exactly the same prediction forwarded by Hicks and Azamtarrahian (1977) for their formulation.

An alternative refinement of the relationship between performance and test anxiety rests on the assumption that the pupillary response reflects cognitive activity and is cortically mediated. A speculation that might be entertained is that a cortically mediated pupillary response is an index of task relevant cognitive activity. Kuc (1976), incidentally, discussed how the pupillary response was related to correct responses on a mental task. Specifically, then, low anxious subjects will perform better than high anxious subjects on a difficult task and will, concomitantly, have a larger pupil size than high anxious subjects.

In order to support either of the above notions relating performance, test anxiety and pupil size, it would be necessary to demonstrate a significant difference in the pupillary response with respect to the test anxiety variable. To support the Hicks et al position, high test anxious subjects must have a significantly larger pupil size than low test anxious subjects. To support the second formulatuon, low test anxious subjects must have a significantly larger pupil size than high test anxious subjects in situations where their performance is significantly better. Unfortunately, the results of the analysis of the pupillary response with respect to levels of test anxiety do not support either of the above notions. Test anxiety was not found to be significantly related to pupillary response. The nature of the experimental task and the form of the data analysis, however, were not really appropriate to test the idea that the pupillary response indexed task relevant activity. In this experiment, the data analyzed consisted of pupillary response only during task relevant performance for all groups. Once subjects stopped performing correctly they were instructed to stop doing the task. An appropriate test would have to consider incorrect performance as well as correct performance.

IN DEFENSE OF A MODIFIED MODEL

One of the purposes of this study was to consider a modification of the capacity model of Kahneman (1973). As mentioned previously, the model of Kahneman (depicted in Figure 1A) indicates that it is the arousal/capacity process that influences both performance as well as the physiological indicators. A modification of this model has been presented (depicted in Figure 1B) which places the locus of the pupillary response in closer relation to the cortical attention allocation process.

It is the model depicted in Figure 1B that is offered as the rationale underlying the results of the present experiment. The model considered that accurate use of information was related to the ability to maintain focus on the relevant cues. Focus here refers to the lability of attention allocation to the relevant cues. Pupillary response is related to the allocation of attention to central task cues and maintenance of attention to the task, a cortical process.

The writer believes that the modified model more adequately describes the relationship of the pupillary response to cognitive activity for the following reasons :

PSYCHOLOGICAL EVIDENCE

1. The Kahneman model implies that attention allocation and physiological responses are both mediated by viscero-autonomic activity. The model

predicts that an increase in activity of the viscero-autonomic system would be related to an increase in cortical arousal, and, concomitantly, an increase in the physiological indicators. Therefore, we would expect a high correlation between performance (as an indicator of cognitive activity) and heart rate activity. However, a very low correlation ($r = .05$) between performance and heart rate was obtained in this study. This suggests that there is some degree of independence between the attention allocation process and the physiological indicators.

2. Kahneman's model does not offer immediate insight into the differential values of the pupillary response vs. heart rate response as measures of cognitive activity, He mentions "directional fractionation" as the reason for the inadequacy of the heart rate response as a measure of mental effort (Kahneman, 1973). However, it would seem that by varying the demands of a task, while holding the type of cognitive processing required by the task constant, the directional fractionation issue would be controlled. If so, we should expect that heart rate would vary with cognitive activity, either directly or inversely. The evidence form this study showed that the heart rate was not significantly related to the level of difficulty of the task. Since the task was constant in terms of the type of cognitive processing required we cannot assume that heart rate changes are related to the effort required to meet the demands of a cognitive task, i.e., variations in physiological autonomic activity may not be directly related or highly correlated with variations in cognitive activity.

3. If there is a strong association between viscero-autonomic activity as it affects both attention allocation and physiological responses (as suggested by Figure 1A), we would expect the correlation between the pupillary

response and the heart rate response to be strong and both to be highly correlated with performance. However, the evidence of this study points to a fairly weak correlation between the two physiological indicators (r = .006) as well as the aforementioned weak correlation between heart rate and performance.

4. The modified model offers some insight into the differential values of the pupillary response vs. heart rate response as measures of cognitive activity. The pupillary response is more directly related to cortical processes while the heart rate response is not. The evidence of this study showed that the pupillary response was significantly related to the level of difficulty of the task. Discriminant analysis indicated that the contribution of heart rate activity to this significant result was trivial. This supports the assumption of the modified model that the pupillary and heart rate responses are mediated through different mechanisms.

5. Since the heart rate response was significantly related to stress manipulations while the pupillary response was not, it is proposed that the heart rate response is directly mediated by viscero-autonomic activity. Discriminant analysis indicated that stress did play a role in the pupillary response, however. This effect is represented in the model by a feedback mechanism from the cortical attention allocation process to the viscero-autonomic arousal/capacity process.

PHYSIOLOGICAL EVIDENCE

6. Finally, some mention might be made of the physiological evidence that the pupillary response is cortically mediated. Descending fibers from the cortex to the Edinger-Westphal nucleus appear to be associated with pupillary response. Stimulation of these descending occipitomesencephalic

fibers which synapse at the Edinger-Westphal nucleus results in pupillary contraction. In addition, when a state of consciousness exists, impulses from the corticothalamohypothalmic pathway inhibit impulses from the Edinger-Westphal nucleus resulting in a tendency to pupillary dilation. On the other hand, in states of sleep, fatigue or unconsciousness, decreased inhibitory impulses to the Edinger-Westphal nucleus from the cortex and reticular activating system results in an increased tendency to pupillary constriction (Zinn, 1972).

Therefore, it appears that impulses from the cortex play an important role in the pupillary response along with the influence of the autonomic nervous system. As stated by Hess (1972) :

> ...we must also remember that it has never been proved that the autonomic nervous system alone influences the contraction and dilation of the pupil. The anatomical basis of the total innervation of the pupil have not yet been delineated fully, so that we cannot categorically discount the possiblilty of extraautonomic influences in pupillary behavior (p. 499).

Physiological evidence (Gellhorn, 1970; Lowenstein and Loewenfeld, 1962) has indicated the importance of the thalamus and hypothalamus to the pupillary response. Destruction of the thalamus or hypothalamus, for example, causes a reduction in pupillary dilation. On the other hand, decorticated animals, sensitive to autonomic functions, show maximal pupillary dilation (Lowenstein and Loewenfeld, 1962). Liberman (1965) has interpreted this evidence to suggest that subcortical structures are responsible for the execution of pupillary responses, but the cortex is responsible for the regulation of those responses. Other researchers (Shaknovich, 1956; Smirnov, reported in Sokolov, 1959) have related differential pupillary activity to stimulation or damage of particular cortical areas. Hess (1972) stated that "it should be emphasized that the iris is constantly influenced by sympathetic, parasympathetic and supranuclear cortical mechanisms" (p. 500).

Lowenstein and Loewenfeld (1962) emphasized the importance of supranuclear inhibition on the Edinger-Westphal nucleus as it affects pupillary movement. "Cortico-thalamo-hypothalamic impulses, elicited by sensory and emotional stimuli, and by physiological processes such as spontaneous thoughts and emotions, converge upon the oculomotor nucleus and prevent it from sending constrictor impulses to the pupillary sphincter" (p. 246). Inhibiting impulses reach the Edinger-Westphal nucleus both by direct afferent connections in the reticular formation and from higher brain centers.

Other physiological evidence (Wang, Lu, and Lau, 1932; Ward and Reed, 1946) has shown that pupillary dilations can be elicited from cortical stimulation. Wang, et al (1932) reported that pupillary dilation persisted even after section of both cervical sympathetic chains. However, when the sympathetic chains were left intact and the parasympathetic nerves (oculomotor nerve) to the pupil was sectioned, the pupil did not dilate to stimulation of the motor cortex. This result suggests that pupillary dilation is due to inhibition of the tone of the parasympathetic neurons to the pupil. Ward and Reed (1946) found pupillary dilations to stimulation of the frontal cortex; but their results indicated a less important contribution of the oculomotor nerve while the major influence on pupillary dilation was through the sympathetic system. Nevertheless, it was also found that stimulation of the hypothalamus did not produce dilation of a sympathectomized pupil. This result then suggests the importance of inhibition by the oculomotor nucleus or some other mechanism mediating a dilation response from the cortex.

CONCLUDING STATEMENT

As an empirical study, the purpose of this research was to test the role of the pupillary response as a measure of cognitive activity. I believe this experiment has provided strong and consistent evidence bearing upon the relationship between pupillary response and cognitive activity. The response of the pupil was marked against heart rate response, a well known measure of emotional reactance. Through comparisons between pupillary and heart rate data, the major hypotheses were supported : pupillary response reflected cognitive activity, while the heart rate response more adequately reflected emotional activity.

The expectation that the pupil reflected cognitive activity led to the idea that the pupillary response was cortically mediated. Some theoretical rationale for this notion was required, and so, the capacity model by Kahneman (1973) was presented and modified to account for pupillary response which was more directly related to cortical attention allocation processes than viscero-autonomic nervous system influences. This model seemed more consistent with empirical expectations and a discussion of its merits was presented.

Part of the discussion of the model included evidence from the physiological literature which supported the notion of a relationship between cortical functions and the pupil. The data of the experiment in relation to the expectations of the model also supported the idea of cortical mediation of the pupillary response. The fact that evidence from two separate disciplines can be used to address the same question and point to the same conclusions is encouraging. Probably more exciting, though, is that the approach and procedure used in this research shows that the theories and methods of the science of psychology can be brought to bear on what is more likely to be seen as a neurophysiological issue.

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Appendix A

General Instructions

The purpose of this experiment is to study physiological responses to a mental task. The physiological responses which we will be measuring are the changes in pupil size and pulse rate. There will be four separate tasks in which you are to name as many words beginning with a certain letter of the alphabet which I will describe at the time of the task. You are to attempt to name as many words as you can at the rate of one every five seconds.

You will hear a tone every five seconds. Upon hearing the tone, you are to respond by naming one word. For example, if I tell you to name as many words as you can beginning with the letter 'S', wait until you hear the first tone and respond with a word such as 'sugar', then wait for the second tone and respond with another word beginning with 'S' such as 'sweater', and so on until you are told to stop. There will be a time limit of 60 seconds.

The experiment will follow the following procedure: First, you will be seated at the pupillometer and adjustments will be made so that you are comfortable. A measure will be taken of your pupil size while you are relaxing and not performing any task. Then you will do one of the four tasks which were mentioned before for 60 seconds. After this first task has been completed there will be a rest period. You will then do one of the remaining tasks, followed by a rest period, and so on, until you have completed all four tasks.

Once you have been seated at the pupillometer and the apparatus has been adjusted:

1. Look straight ahead at the chart on the far wall in front of you.
2. Keep your forehead on the forehead bar and try not to move your head.
3. Keep your eyes open and try not to blink.

Are there any questions? If so, please ask them now before the apparatus is adjusted.

Now let us practice the word naming task.

Following these instructions you will hear a recorded tone every five seconds. After each tone you will be required to give a word which must begin with a certain letter. Do not use proper names or plurals and try not to repear any word you have previously given. Remember, the words must always begin with the same letter. The specific letter will be given to you 30 seconds after the tones begin. If you fail to answer any tone, please try and continue the task. Are the any questions?

Instructions for Low Stress Condition

In this experiment I am interested in finding out something about the way the pupil responds when we are concentrating. Generally, researchers have found that our pupils change when we are doing something that involves our concentration — like on trying to solve an arithmetic problem or when reading a book and trying to remember its contents. Eventually, I am interested in finding out exactly how our pupils change when we are concentrating on something that becomes rather difficult. So, I am going to give you something to do that will involve your concentration on words that begin with a certain letter of the alphabet.

This session, here today, is really to help me to determine the level of difficuly of the word naming task that I am thinking of using in a experiment. Based on the results I get now, adjustments will be made in the task before it is used in the experiment.

So, you will be a big help to me if you just try to concentrate on what you are asked to do. I think that the word naming task will get to be quite difficult, but I am not concerned with how well you do, since I don't know how well you can even be expected to do; but I am interested that you try to concentrate and try to do your best.

Following these instructions you will hear a recorded tone every five seconds. After each tone you will be required to give a word which must begin with a certain letter. Do not use proper names or plurals and try not to repeat any word you have previously given. Remember, the words must always begin with the same letter. The specific letter will be given to you

30 seconds after the tones begin. If you fail to answer any tone, please try and continue the task. When you have missed two tones in a row, or have made two consecutive errors, I will tell you to relax. Also, when the time limit expires I will tell you to relax.

When I tell you to relax, do not move your head from the apparatus. Just stop doing the task and relax. In this phase of the experiment, a measure of your pupil size will be taken for a period of two minutes while you are relaxing. Try not to move your head and look toward the chart on the wall. Remember, a letter will be given to you 30 seconds after the tones begin.

Instructions for High Stress Condition

This study is investigating the relationship between deviant response styles and intellectual efficiency. You have been selected for this study on the basis of the test responses you made on the Test Anxiety Scale questionnaire of a previous experiment.

It has been found that deviant responses on these tests are related to intellectual efficiency and subsequent academic performance. Moreover, the pupil response on certain kinds of tasks has been found to be an excellent measure of intellectual efficiency. Later comparisons of your total grade point average will also be made.

During this test you will be required to name as many words as you can beginning with a certain letter of the alphabet.

Following these instructions you will hear a recorded tone every five seconds. After each tone you will be required to give a word which must begin with a certain letter. Do not use proper names or plurals and try not to repeat any word you have previously given. Remember, the words must always begin with the same letter. The specific letter will be given to you 30 seconds after the tones begin. If you fail to answer any tone, please try and continue the task. When you have missed two tones in a row, or have made two consecutive errors, I will tell you to relax. Also, when the time limit expires I will tell you to relax.

When I tell you to relax, do not move your head from the apparatus. Just stop doing the task and relax. In this phase of the experiment, a measure of your pupil size will be taken for a period of two minutes while you are relaxing. Try not to move your head and look toward the chart on the wall. Remember, a letter will be given to you 30 seconds after the tones begin.

Appendix B

Student Attitude Scale

Indicate on the accompanying IBM answer sheet whether or not each statement is true or false as it applies to you.

1. While taking an important exam I find myself thinking of how much brighter the other students are than I am.

2. If I were to take an intelligence test, I would worry a great deal before taking it.

3. If I knew I was going to take an intelligence test, I would feel confident and relaxed, beforehand.

4. While taking an important examination I perspire a great deal.

5. During course examination I find myself thinking of things unrelated to the actual course material.

6. I get to feel very panicky when I have to take a surprise exam.

7. During tests I find myself thinking of the consequences of failing.

8. After important tests I am frequently so tense that my stomach gets upset.

9. I freeze up on things like intelligence tests and final exams.

10. Getting a good grade on one test doesn't seem to increase my confidence on the second.

11. I sometimes feel my heart beating very fast during important tests.

12. After taking a test I always feel I could have done better than I actually did.

13. I usually get depressed after taking a test.

14. I have an uneasy, upset feeling before taking a final examination.

15. When taking a test my emotional feelings do not interfere with my performance.

16. During a course examination I frequently get so nervous that I forget facts I really know.

17. I seem to defeat myself while working on important tests.

18. The harder I work at taking a test or studying for one, the more confused I get.

19. As soon as an exam is over I try to stop worrying about it, but I just can't.

20. During exams I sometimes wonder if I'II ever get through college.

21. I would rather write a paper than take an examination for my grade in a course.

22. I wish examinations did not bother me so much.

23. I think I could do much better on tests if I could take them alone and not feel pressured by a time limit.

24. Thinking about the grade I may get in a course interferes with my studying and my performance on tests.

25. If examinations could be done away with I think I would actually learn more.

26. On exams I take the attitude, "If I don't know it now there's no point worrying about it."

27. I really don't see why some people get so upset about tests.

28. Thoughts of doing poorly interfere with my performance on tests.

29. I don't study any harder for final exams than for the rest of my course work.

30. Even when I'm well prepared for a test, I feel very anxious about it.

31. I don't enjoy eating before an important test.

32. Before an important examination I find my hands or arms trembling.

33. I seldom feel the need for "cramming" before an exam.

34. The University ought to recognize that some students are more nervous than others about tests and that this affects their performance.

35. It seems to me that examination periods ought not to be made the tense situations which they are.

36. I start feeling very uneasy just before getting a test paper back.

37. I dread courses where the professor has the habit of giving "pop" quizzes.

Appendix C

	SCORE 2, 1 or 0	6. VOCABULARY
1. Bed		
2. Ship		
3. Penny		
4. Winter		
5. Repair		
6. Breakfast		
7. Fabric		
8. Slice		
9. Assemble		
0. Conceal		
1. Enormous		
2. Hasten		
3. Sentence		
4. Regulate		
5. Commence		
. Ponder		
. Cavern		
. Designate		
. Domestic		
. Consume		
. Terminate		
. Obstruct		
. Remorse		
. Sanctuary		
. Matchless		
. Reluctant		
. Calamity		
. Fortitude		
. Tranquil		
. Edifice		
. Compassion		
. Tangible		
Perimeter		
Audacious		
Ominous		
Tirade		
Encumber		
Plagiarize		
Impale		
Travesty		

Appendix D

SELF-EVALUATION QUESTIONNAIRE

Developed by C. D. Spielberger, R. L. Gorsuch and R. Lushene

STAI FORM X-1

NAME ______________________________ DATE ____________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then blacken in the appropriate circle to the right of the statement to indicate how you *feel* right now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I am regretful	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel rested	1	2	3	4
9. I feel anxious	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel "high strung"	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel over-excited and "rattled"	1	2	3	4
19. I feel joyful	1	2	3	4
20. I feel pleasant	1	2	3	4

SELF-EVALUATION QUESTIONNAIRE

STAI FORM X-2

NAME ______________________________ DATE ______________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then blacken in the appropriate circle to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	①	②	③	④
22. I tire quickly	①	②	③	④
23. I feel like crying	①	②	③	④
24. I wish I could be as happy as others seem to be	①	②	③	④
25. I am losing out on things because I can't make up my mind soon enough	①	②	③	④
26. I feel rested	①	②	③	④
27. I am "calm, cool, and collected"	①	②	③	④
28. I feel that difficulties are piling up so that I cannot overcome them	①	②	③	④
29. I worry too much over something that really doesn't matter	①	②	③	④
30. I am happy	①	②	③	④
31. I am inclined to take things hard	①	②	③	④
32. I lack self-confidence	①	②	③	④
33. I feel secure	①	②	③	④
34. I try to avoid facing a crisis or difficulty	①	②	③	④
35. I feel blue	①	②	③	④
36. I am content	①	②	③	④
37. Some unimportant thought runs through my mind and bothers me	①	②	③	④
38. I take disappointments so keenly that I can't put them out of my mind	①	②	③	④
39. I am a steady person	①	②	③	④
40. I get in a state of tension or turmoil as I think over my recent concerns and [illegible]	①	②	③	④

Appendix E

E N L

- Do you often long for excitement? . . . . Yes No
- Do you often need understanding friends to cheer you up? . . . . Yes No
- Are you usually carefree? . . . . Yes No
- Do you find it very hard to take no for an answer? . . . Yes No
- Do you stop and think things over before doing anything? . . . . Yes No
- If you say you will do something do you always keep your promise, no matter how inconvenient it might be to do so? . . . . Yes No
- Does your mood often go up and down? . . . . Yes No
- Do you generally do and say things quickly without stopping to think? . . . . Yes No
- Do you ever feel "just miserable" for no good reason? Yes No
- Would you do almost anything for a dare? . . . . Yes No
- Do you suddenly feel shy when you want to talk to an attractive stranger? . . . . Yes No
- Once in a while do you lose your temper and get angry? . . . . Yes No
- Do you often do things on the spur of the moment? . . . Yes No
- Do you often worry about things you should not have done or said? . . . . Yes No
- Generally do you prefer reading to meeting people? . . Yes No
- Are your feelings rather easily hurt? . . . . Yes No
- Do you like going out a lot? . . . . Yes No
- Do you occasionally have thoughts and ideas that you would not like other people to know about? . . . . Yes No
- Are you sometimes bubbling over with energy and sometimes very sluggish? . . . . Yes No
- Do you prefer to have few but special friends? . . . . . Yes No
- Do you daydream a lot? . . . . Yes No
- When people shout at you, do you shout back? . . . . . . Yes No
- Are you often troubled about feelings of guilt? . . . . . . Yes No
- Are all your habits good and desirable ones? . . . . . . Yes No
- Can you usually let yourself go and enjoy yourself a lot at a gay party? . . . . Yes No
- Would you call yourself tense or "highly-strung"? . . . Yes No
- Do other people think of you as being very lively? . . . Yes No
- After you have done something important, do you often come away feeling you could have done better? . . . . . Yes No
- Are you mostly quiet when you are with other people? Yes No
- Do you sometimes gossip? . . . . Yes No

31. Do ideas run through your head so that you cannot sleep? . . . . Yes No
32. If there is something you want to know about, would you rather look it up in a book than talk to someone about it? . . . . Yes No
33. Do you get palpitations or thumping in your heart? . . . Yes No
34. Do you like the kind of work that you need to pay close attention to? . . . . Yes No
35. Do you get attacks of shaking or trembling? . . . . Yes No
36. Would you always declare everything at the customs, even if you knew that you could never be found out? . . Yes No
37. Do you hate being with a crowd who play jokes on one another? . . . . Yes No
38. Are you an irritable person? . . . . Yes No
39. Do you like doing things in which you have to act quickly? . . . . Yes No
40. Do you worry about awful things that might happen? . . Yes No
41. Are you slow and unhurried in the way you move? . . . Yes No
42. Have you ever been late for an appointment or work? . Yes No
43. Do you have many nightmares? . . . . Yes No
44. Do you like talking to people so much that you would never miss a chance of talking to a stranger? . . . . . . Yes No
45. Are you troubled by aches and pains? . . . . Yes No
46. Would you be very unhappy if you could not see lots of people most of the time? . . . . Yes No
47. Would you call yourself a nervous person? . . . . Yes No
48. Of all the people you know are there some whom you definitely do not like? . . . . Yes No
49. Would you say you were fairly self-confident? . . . . . . Yes No
50. Are you easily hurt when people find fault with you or your work? . . . . Yes No
51. Do you find it hard to really enjoy yourself at a lively party? . . . . Yes No
52. Are you troubled with feelings of inferiority? . . . . . . Yes No
53. Can you easily get some life into a rather dull party? . Yes No
54. Do you sometimes talk about things you know nothing about? . . . . Yes No
55. Do you worry about your health? . . . . Yes No
56. Do you like playing pranks on others? . . . . Yes No
57. Do you suffer from sleeplessness? . . . . Yes No

PLEASE CHECK TO SEE THAT YOU HAVE ANSWERED ALL THE QUESTIONS.

Appendix F

Table 1

Analysis of Variance of A-State Scores

Source of Variation	df	MS	F	p≤
A (STRESS)	1	135.20	1.73	.19
B (TAS)	1	2289.80	29.37	.00
C (INT)	1	312.05	4.00	.05
AB	1	224.45	2.88	.09
AC	1	20.00	.25	.61
BC	1	57.80	.74	.39
ABC	1	26.45	.34	.56
ERROR	72	77.94		
TOTAL	79	109.84		

TAS = Test Anxiety

INT = Intelligence

Table 2

Test of Simple Effects for STRESS X TAS

Interaction of A-State Scores

Source of Variation	df	MS	F	p≤
STRESS at LTAS	1	354.02	4.54	.05
STRESS at HTAS	1	5.62	.07	NS
TAS at LSTRESS	1	1974.02	25.32	.01
TAS at HSTRESS	1	540.22	6.93	.025
Error	72	77.94		

LTAS = Low Test Anxiety

HTAS = High Test Anxiety

LSTRESS = Low Stress

HSTRESS = High Stress

Table 3

Analysis of Variance of Pupillary Baseline Data

Source of Variation	df	MS	F	p≤
A (STRESS)	1	272.51	1.25	.59
B (TAS)	1	133.02	.61	.43
C (INT)	1	7.24	.03	.85
AB	1	873.53	4.01	.05
AC	1	80.16	.37	.54
BC	1	.48	.00	.96
ABC	1	383.98	1.76	.18
Error	72	217.48		
Total	79	220.37		

TAS = Test Anxiety

INT = Intelligence

Table 4

Test of Simple Effects for STRESS X TAS

Interaction of Pupillary Baseline Data

Source of Variation	df	MS	F	p≤
STRESS at LTAS	1	1060.90	4.87	.05
STRESS at HTAS	1	85.16	.39	NS
TAS at LSTRESS	1	162.41	.74	NS
TAS at HSTRESS	1	844.20	3.88	.10
Error	72	217.48		

LTAS = Low Test Anxiety

HTAS = High Test Anxiety

LSTRESS = Low Stress

HSTRESS = High Stress

Table 5

Analysis of Variance of Heart Rate Data

Source of Variation	df	MS	F	p≤
A (STRESS)	1	72.60	.31	.57
B (TAS)	1	570.94	2.49	.12
C (INT)	1	46.41	.20	.65
AB	1	56.29	.24	.62
AC	1	38.40	.16	.68
BC	1	21.67	.09	.76
ABC	1	4.64	.02	.88
Error	72	229.28		
Total	79	219.23		

TAS = Test Anxiety

INT = Intelligence

Table 6

Analysis of Variance of Number of Words Produced (Performance)

Source of Variation	df	MS	F	p≤
A (STRESS)	1	.45	.08	.77
B (TAS)	1	14.70	2.68	.11
C (INT)	1	10.76	1.96	.16
AB	1	.01	.00	.96
AC	1	3.75	.68	.41
BC	1	.26	.05	.82
ABC	1	1.13	.21	.65
Error1	72	5.49		
D (WORDS)	1	1302.42	634.53	.00
AD	1	.97	.48	.49
BD	1	1.70	.83	.36
CD	1	.82	.40	.52
ABD	1	24.41	11.89	.001
ACD	1	2.89	1.41	.24
BCD	1	5.07	2.47	.12
ABCD	1	.01	.00	.97
Error2	72	2.05		

TAS = Test Anxiety

INT = Intelligence

WORDS = Task Difficulty

Table 7

Test of Simple Interaction Effects and Simple Simple Effects of STRESS X TAS X WORDS Interaction on Number of Words Produced (Performance)

Source of Variation	df	MS	F	p≤
STRESS X TAS at EASY	1	12.80	3.39	.10
STRESS at LTAS/EASY	1	5.62	1.49	NS
STRESS at LTAS/DIFF	1	2.50	.66	NS
STRESS at HTAS/EASY	1	7.22	1.91	NS
STRESS at HTAS/DIFF	1	10.50	2.78	.10
TAS at LSTRESS/EASY	1	14.40	3.82	.10
TAS at LSTRESS/DIFF	1	.02	.01	NS
TAS at HSTRESS/EASY	1	1.60	.42	NS
TAS at HSTRESS/DIFF	1	26.80	6.57	.025
Error1	144	3.77		
STRESS X WORDS at LTAS	1	7.81	3.80	.10
STRESS X WORDS at HTAS	1	17.57	8.56	.005
TAS X WORDS at HSTRESS	1	19.50	9.50	.005
TAS X WORDS at LSTRESS	1	6.61	3.22	.10
Error2	72	2.05		

TAS = Test Anxiety

WORDS = Task Difficulty

LTAS = Low Test Anxiety

LSTRESS = Low Stress

EASY = Easy Task

INT = Intelligence

HTAS = High Test Anxiety

HSTRESS = High Stress

DIFF = Difficult Task

Table 8

Analysis of Covariance of Pupillary Response Data

Source of Variation	df	MS	F	p≤
A (STRESS)	1	327.85	2.08	.15
B (TAS)	1	76.77	.49	.48
C (INT)	1	47.85	.30	.58
AB	1	16.49	.10	.74
AC	1	58.43	.37	.54
BC	1	14.19	.09	.76
ABC	1	298.33	1.90	.17
Error1	71	157.39		
D (WORDS)	1	170.76	10.93	.001
AD	1	36.64	2.35	.13
BD	1	3.86	.25	.62
CD	1	8.10	.52	.47
ABD	1	9.02	.58	.45
ACD	1	31.39	2.01	.16
BCD	1	3.15	.20	.65
ABCD	1	.66	.04	.83
Error2	72	15.62		

TAS = Test Anxiety

INT = Intelligence

WORDS = Task Difficulty

Table 9

Analysis of Covariance of Heart Rate Data

Source of Variation	df	MS	F	p≤
A (STRESS)	1	798.59	5.14	.025
B (TAS)	1	.02	.00	.99
C (INT)	1	38.69	.25	.61
AB	1	85.83	.55	.46
AC	1	24.93	.16	.69
BC	1	1115.34	7.17	.005
ABC	1	13.78	.09	.76
Error1	71	155.47		
D (WORDS)	1	1.61	.06	.81
AD	1	.01	.00	.98
BD	1	.23	.01	.92
CD	1	7.06	.24	.62
ABD	1	42.97	1.48	.22
ACD	1	.00	.00	.99
BCD	1	189.14	6.51	.013
ABCD	1	23.29	.80	.37
Error2	72	29.07		

TAS = Test Anxiety

INT = Intelligence

WORDS = Task Difficulty

Table 10

Test of Simple Effects of TAS X Intelligence

Interaction on Heart Rate

Source of Variation	df	MS	F	p≤
INT at LTAS	1	182.24	1.17	NS
INT at HTAS	1	184.79	1.19	NS
TAS at LINT	1	106.62	.68	NS
TAS at HINT	1	281.64	1.81	NS
Error	71	155.48		

TAS = Test Anxiety

INT = Intelligence

LTAS = Low Test Anxiety

HTAS = High Test Anxiety

LINT = Low Intelligence

HINT = High Intelligence

Table 11

Test of Simple Interaction Effects and Simple Simple Effects of TAS X Intelligence X Task Difficulty Interaction on Heart Rate Data

Source of Variation	df	MS	F	p≤
TAS X INT at EASY	1	193.36	2.10	NS
TAS X INT at DIFF	1	1112.54	12.11	.001
TAS at LINT/EASY	1	99.98	1.09	NS
TAS at LINT/DIFF	1	541.69	5.89	.025
TAS at HINT/EASY	1	93.27	1.01	NS
TAS at HINT/DIFF	1	571.08	6.22	.025
INT at LTAS/EASY	1	203.85	2.22	NS
INT at LTAS/DIFF	1	643.66	7.01	.01
INT at HTAS/EASY	1	29.03	.31	NS
INT at HTAS/DIFF	1	475.27	5.17	.025
Error1	143	91.83		
TAS X WORDS at HINT	1	101.38	3.48	.10
TAS X WORDS at LINT	1	87.96	3.02	.10
INT X WORDS at LTAS	1	61.50	2.11	NS
INT X WORDS at HTAS	1	134.64	4.63	.05
WORDS at LTAS/LINT	1	35.26	1.21	NS
WORDS at LTAS/HINT	1	26.56	.91	NS
WORDS at HTAS/LINT	1	53.68	1.84	NS
WORDS at HTAS/HINT	1	82.54	2.84	.10
Error2	72	29.07		

TAS = Test Anxiety

INT = Intelligence

WORDS = Task Difficulty

LTAS = Low Test Anxiety

LINT = Low Intelligence

EASY = Easy Task

HTAS = High Test Anxiety

HINT = High Intelligence

DIFF = Difficult Task

Table 12

Multivariate Analysis of Covariance

on the Physiological Composite

Source of Variation	df	F	p≤
A (STRESS)	2,69	3.99	.023
B (TAS)	2,69	.30	.74
C (INT)	2,69	.31	.72
AB	2,69	.09	.90
AC	2,69	.34	.71
BC	2,69	3.74	.028
ABC	2,69	.90	.40
D (WORDS)	2,71	5.40	.006
AD	2,71	1.15	.32
BD	2,71	.12	.88
CD	2,71	.37	.69
ABD	2,71	1.02	.36
ACD	2,71	.99	.37
BCD	2,71	3.32	.04
ABCD	2,71	.41	.66

TAS = Test Anxiety

INT = Intelligence

WORDS = Task Difficulty

Table 13

Multivariate Centroids for the Test Anxiety by Intelligence Interaction

	LOW INTELLIGENCE	HIGH INTELLIGENCE
LOW TEST ANXIETY	8.19	9.11
HIGH TEST ANXIETY	8.50	8.05

Table 14

Multivariate Centroids for the Test Anxiety by Intelligence by Task Difficulty Interaction

		EASY TASK	HARD TASK
LTAS	LINT	15.08	14.93
	HINT	15.87	16.17
HTAS	LINT	15.15	15.52
	HINT	14.95	14.67

LTAS = Low Test Anxiety
HTAS = High Test Anxiety

LINT = Low Intelligence
HINT = High Intelligence

Table 15

Group Structure of Analyses
with A-State Measures

STRUCTURE			COUNT
LOW STRESS	LOW INT	L STATE	11
		H STATE	6
	HIGH INT	L STATE	12
		H STATE	11
HIGH STRESS	LOW INT	L STATE	10
		H STATE	12
	HIGH INT	L STATE	7
		H STATE	11

LOW INT = Low Intelligence

HIGH INT = High Intelligence

L STATE = Low State Anxiety

H STATE = High State Anxiety

Table 16

Analysis of Variance of Number of Wrods Produced

(Performance) with A-State Scores

Source of Variation	df	MS	F	p≤
A (STRESS)	1	.05	.01	.91
B (INT)	1	2.00	.40	.53
C (A-STATE)	1	23.37	4.64	.035
AB	1	11.16	2.22	.14
AC	1	15.75	3.13	.08
BC	1	6.41	1.27	.26
ABC	1	.15	.03	.86
Error1	72	5.04		
D (WORDS)	1	1189.82	532.25	.000
AD	1	.75	.34	.56
BD	1	6.61	2.96	.09
CD	1	.22	.10	.75
ABD	1	13.43	6.01	.017
ACD	1	.23	.10	.74
BCD	1	.61	.27	.60
ABCD	1	.38	.17	.68
Error2	72	2.24		

INT = Intelligence

Table 17

Test of the Simple Effects of the Stress by A-State Interaction on Number of Words Produced (Performance)

Source of Variation	df	MS	F	p≤
A-STATE at LSTRESS	1	20.09	3.99	.05
A-STATE at HSTRESS	1	.19	.03	NS
STRESS at Low A-STATE	1	3.60	.71	NS
STRESS at High A-STATE	1	4.59	.91	NS
Error	72	5.03		

LSTRESS = Low Stress

HSTRESS = High Stress

Table 18

Test of Simple Effects for the Intelligence by Task Difficulty Interaction on Number of Words Produced (Performance) with A-State Scores

Source of Variation	df	MS	F	p≤
INT at EASY	1	.70	.19	NS
INT at DIFF	1	8.43	2.31	NS
Error1	144	3.63		
WORDS at LINT	1	710.72	317.93	.001
WORDS at HINT	1	554.19	247.91	.001
Error2	72	2.23		

INT = Intelligence

LINT = Low Intelligence

HINT = High Intelligence

WORDS = Task Difficulty

EASY = Easy Task

DIFF = Difficult Task

Table 19

Test of Simple Interaction Effects and Simple Simple Effects for the Stress y Intelligence by Task Difficulty Interaction on Number of Words Produced (Performance) with A-State Scores

Source of Variation	df	MS	F	p≤
STRESS X INT at EASY	1	25.44	6.99	.01
STRESS X INT at DIFF	1	-.40	-.11	NS
STRESS at LINT/EASY	1	16.74	4.60	.05
STRESS at LINT/HARD	1	.23	.06	NS
STRESS at HINT/EASY	1	9.32	2.56	NS
STRESS at HINT/DIFF	1	.02	.01	NS
INT at LSTRESS/EASY	1	8.87	2.44	NS
INT at LSTRESS/DIFF	1	3.48	.95	NS
INT at HSTRESS/EASY	1	17.49	4.81	.05
INT at HSTRESS/DIFF	1	4.88	1.34	NS
Error1	144	3.63		
STRESS X WORDS at LINT	1	10.44	4.63	.05
STRESS X WORDS at HINT	1	4.19	1.87	NS
INT X WORDS at LSTRESS	1	.62	.27	NS
INT X WORDS at HSTRESS	1	20.43	9.14	.005
WORDS at LSTRESS/LINT	1	238.69	106.79	.001
WORDS at LSTRESS/HINT	1	367.80	164.56	.001
WORDS at HSTRESS/LINT	1	504.91	225.91	.001
WORDS at HSTRESS/HINT	1	202.50	90.60	.001
Error2	72	2.23		

INT = Intelligence

WORDS = Task Difficulty

LSTRESS = Low Stress

HSTRESS = High Stress

EASY = Easy Task

DIFF = Difficult Task

LINT = Low Intelligence

HINT = High Intelligence

Table 20

Analysis of Covariance of Pupillary Response Data with A-State Scores

Source of Variation	df	MS	F	p≤
A (STRESS)	1	195.11	1.28	.26
B (INT)	1	41.52	.27	.60
C (A-STATE)	1	355.76	2.33	.13
AB	1	.69	.00	.94
AC	1	42.35	.28	.60
BC	1	21.95	.14	.70
ABC	1	275.69	1.80	.18
Error1	71	152.90		
D (WORDS)	1	163.45	11.14	.001
AD	1	29.69	2.02	.16
BD	1	18.98	1.29	.26
CD	1	.18	.01	.91
ABD	1	15.71	1.07	.30
ACD	1	40.28	2.75	.10
BCD	1	20.11	1.37	.24
ABCD	1	12.44	.85	.36
Error2	72	14.66		

INT = Intelligence

WORDS = Task Difficulty

Table 21

Analysis of Covariance of Heart Rate Data

with A-State Scores

Source of Variation	df	MS	F	p≤
A (STRESS)	1	764.57	4.62	.035
B (INT)	1	57.12	.35	.56
C (A-STATE)	1	32.83	.20	.65
AB	1	.49	.00	.95
AC	1	189.97	1.15	.28
BC	1	246.80	1.49	.22
ABC	1	59.73	.36	.55
Error1	71	165.46		
D (WORDS)	1	.54	.02	.89
AD	1	.02	.00	.97
BD	1	.29	.01	.92
CD	1	28.82	.94	.33
ABD	1	48.62	1.59	.21
ACD	1	22.52	.74	.39
BCD	1	7.05	.23	.63
ABCD	1	49.91	1.64	.20
Error2	72	30.52		

INT = Intelligence

WORDS = Task Difficulty

Table 22

Multivariate Analysis of Covariance on the

Physiological Composite with A-State Scores

Source of Variation	df	F	p≤
A (STRESS)	2,69	3.93	.02
B (INT)	2,69	.62	.53
C (A-STATE)	2,69	1.53	.22
AB	2,69	.01	.98
AC	2,69	.79	.45
BC	2,69	.72	.48
ABC	2,69	.99	.37
D (WORDS)	2,71	5.76	.005
AD	2,71	1.23	.29
BD	2,71	.91	.40
CD	2,71	.76	.47
ABD	2,71	1.13	.33
ACD	2,71	1.93	.15
BCD	2,71	.79	.45
ABCD	2,71	1.23	.29

INT = Intelligence

WORDS = Task Difficulty

Table 23

Group Structure of Analyses

with EPI Measures

STRUCTURE			COUNT
LOW STRESS	INTROVERT	NEUROTIC	13
		STABLE	3
	EXTRAVERT	NEUROTIC	7
		STABLE	17
HIGH STRESS	INTROVERT	NEUROTIC	12
		STABLE	11
	EXTRAVERT	NEUROTIC	8
		STABLE	9

Table 24

Analysis of Variance of Number of Words Produced (Performance) with EPI Measures

Source of Variation	df	MS	F	p≤
A (STRESS)	1	.30	.05	.81
B (EXTRA)	1	3.98	.71	.40
C (NEUR)	1	4.16	.75	.39
AB	1	3.84	.69	.41
AC	1	1.15	.21	.65
BC	1	5.24	.94	.33
ABC	1	1.41	.25	.61
Error1	72	5.58		
D (WORDS)	1	1040.25	465.14	.000
AD	1	.99	.44	.50
BD	1	.90	.40	.52
CD	1	.04	.02	.88
ABD	1	4.77	2.14	.14
ACD	1	13.99	6.26	.015
BCD	1	.05	.03	.87
ABCD	1	.02	.01	.91
Error2	72	2.23		

EXTRA = Extraversion

NEUR = Neuroticism

WORDS = Task Difficulty

Table 25

Test of Simple Effects of Stress by Neuroticism

by Task Difficulty on Number

of Words Produced (Performance)

Source of Variation	df	MS	F	p≤
NEUR at LSTRESS/EASY	1	7.74	1.98	NS
NEUR at LSTRESS/DIFF	1	2.85	.73	NS
NEUR at HSTRESS/EASY	1	.05	.01	NS
NEUR at HSTRESS/DIFF	1	14.09	3.60	.10
STRESS at STAB/EASY	1	.40	.10	NS
STRESS at STAB/DIFF	1	6.10	1.56	NS
STRESS at N/EASY	1	5.67	1.45	NS
STRESS at N/DIFF	1	8.83	2.26	NS
Error	144	3.90		

NEUR = Neuroticism

STAB = Stables

N = Neurotics

LSTRESS = Low Stress

HSTRESS = High Stress

EASY = Easy Task

DIFF = Difficult Task

Table 26

Analysis of Variance of Oupillary Response Data

with EPI Measures

Source of Variation	df	MS	F	p≤
A (STRESS)	1	65.29	.45	.50
B (EXTRA)	1	284.87	1.96	.16
C (NEUR)	1	307.34	2.12	.15
AB	1	349.46	2.41	.12
AC	1	193.56	1.33	.25
BC	1	702.62	4.84	.031
ABC	1	53.93	.37	.54
Error1	71	145.07		
D (WORDS)	1	121.40	8.12	.006
AD	1	10.37	.69	.40
BD	1	7.77	.52	.47
CD	1	8.72	.58	.44
ABD	1	31.48	2.11	.15
ACD	1	.18	.01	.91
BCD	1	.01	.00	.98
ABCD	1	43.25	2.89	.093
Error2	72	14.95		

EXTRA = Extraversion

NEUR = Neuroticism

WORDS = Task Difficulty

Table 27

Test of Simple Effects of Extraversion by

Neuroticism Interaction on Pupillary Response Data

Source of Variation	df	MS	F	p≤
EXTRA at STAB	1	513.72	3.54	.10
EXTRA at N	1	26.99	.18	NS
NEUR at E	1	23.90	.16	NS
NEUR at I	1	558.01	3.84	.10
Error	71	145.08		

EXTRA = Extraversion

E = Extraverts

I = Introverts

NEUR = Neuroticism

STAB = Stables

N = Neurotics

Table 28

Analysis of Variance of Heart Rate Data

with EPI Measures

Source of Variation	df	MS	F	p≤
A (STRESS)	1	719.27	4.19	.044
B (EXTRA)	1	.55	.00	.95
C (NEUR)	1	.73	.00	.94
AB	1	52.43	.31	.58
AC	1	12.55	.07	.78
BC	1	51.23	.30	.58
ABC	1	2.33	.01	.90
Error1	71	171.47		
D (WORDS)	1	.45	.01	.90
AD	1	1.17	.04	.85
BD	1	24.30	.75	.39
CD	1	10.77	.33	.56
ABD	1	3.20	.10	.75
ACD	1	.24	.01	.93
BCD	1	.18	.01	.94
ABCD	1	.33	.01	.92
Error2	72	32.29		

EXTRA = Extraversion

NEUR = Neuroticism

WORDS = Task Difficulty