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PUPIL SIZE DURING A COGNITIVE TASK AS A FUNCTION OF STATE-TRAIT ANXIETY AND STRESSFULNESS OF INSTRUCTIONS

BY

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Abstract

Pupil Size During a Cognitive Task as a Function of State-Trait Anxiety and Stressfulness of Instructions

Pupillary research has not assessed adequately the role of anxiety in pupil response during cognitive tasks. Two experiments were conducted to investigate the relationship of pupil size to anxiety and mental effort during a digit span (DS) recall task. The individual difference variables of intelligence and correctness of response were also studied.

Both studies used a time-locked procedure for presentation and recall of digits. Pupil size was monitored during an 8-number DS task in Experiment 1 and a 7-number DS task in Experiment 2. In Experiment 1, subjects were grouped on basis of Stress instructions (ego- or non ego-threatening) and Intelligence (ability on the DS Forward subscale of the WAIS). In Experiment 2, Test Anxiety Scale differences were included and the heart rate was monitored.

Results of Experiment 1 were as follows: During Input, High and Low Stress differences were noted. No baseline of pupil size was taken however, and findings had to be interpreted cautiously in view of the lack of A-state paper and pencil differences between groups. No differences were noted on the Intelligence variable. Finally, no analysis of pupil size differences for correct-incorrect trials was made as there were too few correct trials for proper analysis. Results of Experiment 2 were as follows: During Instructions, no related differences in pupil size were found, but heart rate (HR) interacted with Time in that the High Stress group showed greater HR following the threatening portion of instructions. During Input, pupil size increased over time, was larger in the High Intelligence group and larger for Correct trials, but no main effect for Stress was found. HR during Input was significantly higher for the High Stress group, but no main effects on Intelligence or Correctness of response were found, nor was there any increase over time. During Output, both pupil size and heart rate followed a similar initial pattern of decrease. Pupil size continued to decrease at a regular rate into the Rest phase. Heart rate, however, began to increase as the Output timed phase neared completion. Finally, the results of the Test Anxiety variables supported the notion that High Test Anxiety subjects demonstrated greater A-State Anxiety than did Low Test Anxiety subjects. This was supported only by the paper and pencil measure however, not by the physiological measures.

The discussion of Experiment 1 pointed out the shortcomings associated with lack of baseline measure, weakness of instructions and difficulty of task. Caution was used, therefore, in interpreting significant Stress differences in pupil size. It was more likely that pupil size was related to increased motivation rather than to increased anxiety. The discussion of Experiment 2 made reference to Kahneman, Tursky, Shapiro and Crider (1969) and these findings; presence of revised Stress instructions, task difficulty and specific measure of intelligence. It was concluded that pupil response was more sensitive than heart rate to cognitive variables. This was reached by distinguishing between Intelligence groups, correct/incorrect of trials and evidenced load increase during Input. Conversely, heart rate was more sensitive than pupil response to emotional variables, distinguishing the Stress groups during both Instructions and Input. From the pupillary data on Intelligence and Correctness it was concluded that good performance here was due to greater effort and that poor performance was due to lack of effort rather than greater task difficulty.

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Pupil Size During a Cognitive Task as a Function of State-Trait Anxiety and Stressfulness of Instructions

Interest in the metering of pupil response is probably as old as man. Certainly this concept of pupil response has been acknowledged since antiquity. Historical reports indicate that Chinese jade merchants assessed a prospective buyer's interest in a jade article by the dilation of his pupils. On a more scientific level, Fontana (1765) described pupillary dilation in response to sensory and psychological stimuli; Darwin (1873) noted a pupillary reaction in animals to emotional variables; Lowenstein (1920) claimed that pupil dilation was associated with increased intellectual attention. Thus, by 1920 the concept of pupil response to internal and external stimuli was generally understood. A renewed interest in the subject, particularly by psychologists in North America, was generated by the research in the 1960s of Eckhard Hess and associates (e.g., Hess & Polt, 1964; Hess, 1965). The number of reviews of recent literature that have appeared on the use of pupil measurements in psychology would suggest its increasing popularity (e.g., Goldwater, 1972; Hess, 1972, 1973; Janisse, 1973a, 1974a). Studies in the area have focused on such topics as cognitive activity, stress, emotional arousal, sex preferences, attitudes, interests and personality characteristics.

The specific focus of this paper was to investigate the relationship between pupil size, anxiety and mental effort. The roles that anxiety and mental effort played in the pupil response, particularly during cognitive tasks, were in need of clarification. The basic problem appeared to be related to the fact that the pupil response generally reflected autonomic activity (level of arousal) and that there was a parallel between the pupil response to mental effort and to anxiety. Kahneman (1973) posited that pupillary dilation during a cognitive task reflects mental effort and not simply arousal. He has attempted to clarify this issue by suggesting two factors controlling level of arousal. The first factor is stated as "the demands imposed by the activities in which the organism engages, or prepares to engage" (1973, p. 17). He postulates the possibility that pupil size is an excellent index of these demands, which may also be referred to as "mental effort". The second factor he called "miscellaneous determinants" which might include "the prevailing intensity of stimulation and the physiological effects of drugs or drive states" (Kahneman, 1973, p. 17). Some examples of these states would be anxiety, fear, anger, sexual excitement, muscular strain. These determinants might readily confound the conclusions when using a measure of arousal to gauge mental effort. Carefully controlled settings are needed, therefore, in order to minimize the incidence of miscellaneous determinants in studies attempting to measure mental effort. Kahneman has controlled for potential confounding effects, but his primary research interest has been related to investigating the "mental effort" factor via pupillary response.

His contention (Kahneman, 1973) was that changes in pupil size before, during and after a cognitive task were not due to changes in anxiety alone, but rather in mental effort. He did admit that momentary fluctuations of anxiety play a limited role in determining the pupillary dilations in a task situation. Yet it was evident that he has not pursued adequately this relationship between anxiety and mental effort in task situations nor has he noted the extent of each of their influences. It was proposed in this research to investigate the relationship of pupil size to both anxiety and mental effort during cognitive tasks. It was further noted that there has been a lack of clarity in the usage of the term anxiety in the pupil literature. This lack of clarity was also existent in the general anxiety literature (Spielberger, 1972). An attempt was made to differentiate anxiety according to the state-trait model of anxiety as part of the approach in this investigation. Furthermore, it appeared that A-trait measurement, which reflects the proneness of an individual to A-state reaction, should be such that it was highly predictive in specific situations of A-state reactions. The use of a specific type of A-trait measurement was considered in this research.

Finally, any attempt to resolve the mental effort-anxiety issue in pupillary studies must take into account the intellectual ability factor. Increase in pupil size has been related to task difficulty on cognitive tasks (e.g., Hess & Polt, 1964; Kahneman, 1973). It follows then that task difficulty would be related to an individual's ability and efficiency in dealing with the specific task given. A person who performs a specific task easily will find it requires much less effort than does someone finding that task difficult to complete. It therefore appears that the intellectual efficiency factor which relates to the specific task characteristics must be accounted for in the research design.

In this section, a selected review of the pupillometric and anxiety literature is provided. The review of the pupillometric literature discusses the neurophysiology of the pupil, methodological issues, cognition, stress and personality variables. The review of the anxiety literature covers: anxiety as a construct, anxiety and stress, and anxiety and intelligence. Finally a statement of the problem is made, followed by a statement of the hypotheses.

Neurophysiology of the Pupil Response

The mechanics of the pupil are very complex indeed and pupillary reactions can be influenced in a number of ways. Here follows a brief overview of the neurophysiology of the pupil response.

The pupil is an opening in the iris of the eye which controls the amount of light falling on the retina. The opening and closing mechanism of the pupil is controlled by two sets of muscle fibers. One set is the sphincter pupillae which contains a smooth circular band of muscle fibers around the pupil and which contracts to constrict the pupil. The other set is the radial muscles (dilator pupillae) which controls the dilation of the pupil.

The innervation of these muscles to produce constriction and dilation of the pupil is under the control of the autonomic nervous system with both the sympathetic and parasympathetic divisions involved. Lowenstein (1959) provides a brief review of the autonomic nature of the pupil response:

> The sphincter muscle of the iris is controlled by parasympathetic fibers which take their origin probably in the anterior small-celled part of the third nerve nucleus, the Westphal-Edinger nucleus. The Westphal-Edinger nucleus receives afferent impulses for pupillary constriction via the optic

> pathways. Both retinal rods and cones are recepter organs for elicitation of the pupillary light reflex. . . . The sympathetic path which innervates the dilator muscle of the pupil takes its origin from the great sympathetic centers of the ventral hypothalamus. . . . Sensory stimuli and emotions and spontaneous thoughts can thus elicit pupillary dilation via cortico-thalamic-hypothalamic connections which call the great efferent sympathetic system in the basal diencephalon into action (p. 549).

The interaction between both divisions of the autonomic nervous system represents a fairly complex neurological network, and this simple representation does not rule out other neural involvement not yet discovered.

Excitatory and inhibitory factors also play a role in the dilation of the pupil. In addition to the sympathetic pupillary dilation, the pupil can be dilated passively. The pupillary light reflex can be inhibited when the parasympathetic nucleus is inhibited and no constrictor impulses occur; thus passive dilation occurs. The paradoxical pupillary dilation is yet another mechanism for pupillary dilation to occur. This phenomenon occurs when there has been injury to the peripheral sympathetic chain and the iris has become hypersensitive to adrenergic substances (Lowenstein & Loewenfeld, 1962). Hess (1972) has reviewed several studies which discuss the hypothalamo-thalamo-cortical activity related to cortical and subcortical innervation influencing pupil change.

To summarize briefly, pupillary constriction can be accounted for in at least four ways: parasympathetic impulses, loss of sympathetic innervation, decrease of central inhibition of the Westphal-Edinger nucleus (either functionally or organically) and cholinergic substances. By the same token, pupillary dilation can be accounted for by three processes: sympathetic innervation, inhibition of the Westphal-Edinger nucleus and paradoxical pupillary dilation.

Methodological Issues in Pupillometric Research

Because the pupil response is directly related to the activity of the autonomic nervous system, the pupil reflects many of the properties associated with other indirect autonomic measures (e.g., E.E.G., E.C.G., G.S.R.). The pupil response, however, is observable visually and is thus unique as an index of physiological activity. Brief mention will be made of those problems often encountered which are specific to pupillometry. A more detailed discussion of methodological issues can be found elsewhere (e.g., Goldwater, 1972; Janisse, 1974b; Loewenfeld, 1966; Woodmansee, 1966).

In pupillary research, the light reflex effect is the most common source of interference. When the eye is open, pupil size is affected by changes in the level of illumination and by shading patterns. The latter phenomenon is particularly significant when using pictorial stimuli because pupil size changes due to "contrast effects" can be appreciable as the point of gaze of a subject changes (e.g., Woodmansee, 1966). Janisse (1974b) suggests that to avoid this effect, visual stimuli should be avoided where possible. If it is necessary to use visual stimuli, then selection criteria should be based on those stimuli of minimal contrast and be line drawings, words, numbers or other simple lined symbols. The key to reducing the light reflex effect is to provide a constant brightness level across the subject's visual field while still providing an effective focus area.

The near-vision reflex effect is another specific problem. Upon viewing a near object, even under controlled lighting conditions, there is a tendency for the pupil to constrict over time. The phenomenon coincides with convergence of the eyes and accommodation of the lens to viewing near objects. This effect increases with age due to the need of an older person to compensate for loss of accommodation. In order to control for this variable, Woodmansee (1966) suggests selecting subjects under 30 years of age and increasing the viewing distance for more comfortable focusing; generally, three or four meters is an acceptable viewing distance. The effect is enhanced by lengthy stimulus presentation which suggests that such procedures include brief rest periods to reduce the occurrence of the phenomenon.

A final issue to be touched upon is that of high pupillary variability. The pupil has been referred to as a "noisy" system that is in a constant state of flux. This motion is often referred to as "pupillary unrest" or "hippus", and appears to be related to many other ongoing functions of the organism (Lowenstein, Feinberg & Loewenfeld, 1963). Woodmansee (1966) noted that one percent pupil size change can occur from second to second, and that the change over several seconds can be as high as ten to twenty percent. This type of uncontrolled variability can decrease test-retest reliability and thus subject research findings to cautious interpretation.

Some procedures to minimize this type of variance have been suggested. Hakerem and Sutton (1964) suggest using a repeated measures design to average out the pupillary fluctuations. Using eight or more trials per subject might be another way to average out the variability (Woodmansee, 1966). A possible drawback in using the averaging technique to improve data reliability is that the spontaneous movements of the pupil may provide a further index of psychological activation (Lowenstein, Feinberg & Loewenfeld, 1963). The type of technique a researcher decides upon will be dependent upon the kinds of information most pertinent to the topic being investigated.

To summarize, the problems unique to the pupil as an index of physiological activity are the light reflex effect, the near-vision effect and high pupil variability. It is usually possible to institute controls to counteract these problem effects during pupillary experiments. The pupil also exhibits many properties of other autonomic indices: e.g., response habituation (Lowenstein & Loewenfeld, 1962), parasympathetic rebound (Rubin, 1964), arousal decrement (Woodmansee, 1966), and "law of initial value" effect (Dureman & Scholander, 1962). In the light of the foregoing, it is important for the pupil researcher to account for the many possible confounders by carefully controlled experimentation.

Pupillary Response and Mental Activity

The relationship between the pupillary response and mental activity was noted as long as 50 years ago by German psychologists (c.f. Hess, 1965). Lowenstein (1920) wrote that pupil dilation could be found with every increase in attention by intellectual processes of every kind. This past decade has seen a renewed interest for psychologists as a result of the work of Hess and Polt (1964).

Kahneman (1973) saw the pupil response measurement as a useful indicator of mental effort. He found this measurement sensitive to both "between-task" variation of effort (a variety of cognitive tasks) and "within-task" changes in effort (related to changes in "load", reaching solutions, rehearsal fluctuations).

Beginning with Hess and Polt (1964) there is an array of research findings to support this contention. They studied pupil size in relation to mental activity during simple problem solving. They presented five subjects each with four multiplication problems of increasing difficulty. The problems were presented orally as the subject fixed his gaze on a control slide. Typically, the pupils of each subject showed a gradual increase in diameter, reached a maximum dilation immediately before an answer was given, then reverted to the previous control size. Pupil changes were not only correlated with the presentation of problems but the size of the pupil also increased with the difficulty level of the problem. Daly (Note 1) obtained similar results controlling for age and intelligence.

Schaefer, Ferguson, Klein and Rawson (1968) also studied the pupil response during mental activities. They monitored the pupil size of 40 subjects continuously during a series of intellectual tasks. One of the findings was that pupil diameter reliably increased (approximately 30%) during tasks involving number memory, multiplication and word definition. Dilation was greater for novel or more difficult tasks. They also found that if subjects kept cogitating on a problem after answering, the pupil dilation persisted.

Similar findings were reported by Bradshaw (1967) who used both cartoon and anagram material. His findings indicated that subjects responded with greater pupillary dilation on incomprehensible cartoon drawings than on those drawings a person could understand. This pattern was repeated when subjects were shown novel material as compared to repeated familiar stimuli. Another finding was that with solved single solution anagram problems, subjects' pupil dilation reached a peak at the moment of verbalized solution after which the pupil rapidly constricted. On the other hand, insoluble problems caused subjects to maintain a relative dilation beyond that of the solved problem and the abstract geometric control stimuli.

Kahneman and Beatty (1966) observed similar kinds of pupil size changes during a short-term memory task as those occurring during problem-solving tasks. The pupil dilated steadily during the listening phase and constricted during the report phase. A string of digits was presented at a steady rate for immediate recall and the subject's report was paced at the same rate. Rate of change was related as a function of task difficulty, that is, more cognitive effort is involved in rehearsing the digits during the loading phases than during the unloading phases. Beatty and Kahneman (1966) noted greater pupil dilations when subjects recalled a well-learned telephone number (long term memory) than when required to recall a string of seven digits (short term memory). They suggested that greater cognitive loading is required for long term memory than for short term memory. However, Janisse (Note 2) suggested that other factors, such as emotional arousal, might have been associated with recall of familiar telephone numbers, thus enhancing dilation.

Effects of grouping on the pupil response in a short term memory task has also been studied (Kahneman, Onuska & Wolman, 1968). Strings of nine digits were presented for immediate recall either at a consistent one-per-second rate or in groups of three digits separated by a pause. Under the monotone presentation pupils dilated at a steady rate, but in the grouped condition pupil dilation and constriction waves were noted during the pauses. At the end of the grouped presentation, there was a steep rise in dilation. The authors interpreted this as a large effort required to pull the three groups of digits together at the end.

Kahneman, Peavler and Onuska (1968) reported two studies designed to assess the effects of verbalization and incentive on pupil response to mental effort. Pupil size measurements were obtained during performance on a short-term memory task and a digit-transformation task. Their findings indicated that task difficulty was the single most powerful variable influencing pupil response in both experiments.

Using pupil diameter, heart rate and skin resistence as dependent measures during a paced digit-transformation task, Kahneman, Tursky, Shapiro and Crider (1969) observed similar response patterns among the three measures, with the pupil data being the most consistent. The peak response in each measure was ordered as a function of task difficulty. The authors suggested that the time-locked aspect of the task served to provide a better procedure to compare the other physiological measures with pupil response than to use the more traditional unstructured time procedures.

Kahneman and Wright (1971) investigated changes of pupil size and rehearsal strategies in a short-term memory task. They expected and found that total recall produces more pupil dilation than partial recall. The position taken was that it takes more mental effort to deal with the total recall material in a serial learning situation. Wright and Kahneman (1971) found similar results using a sentence retention task.

In essence, what Kahneman and his associates have worked towards in their series of studies was a demonstration that the pupil response is a reliable indicator of mental effort. In a recent review, Kahneman (1973) discussed the measurement of effort by arousal. In his model, he saw two sets of factors controlling the level of arousal. In the first, level of arousal may reflect what the subject is doing and the amount of effort he is investing. In the second, it may indicate what is happening to the subject and the amount of stress due to drugs or drive. If one controls for the "miscellaneous effects", then one can interpret pupillary dilation during a cognitive task as autonomic measure of the amount of effort or "mental effort" being expended on the task. By using pupil response as a measure of processing load in a variety of carefully controlled experiments, they have demonstrated that there are reliable changes in pupil size as a function of task difficulty and that these changes are also related to other physiological measures.

Another independent line of research has demonstrated a consistent response during imagery tasks. Paivio and Simpson (1966) sought to find the relationship between word abstractness, word pleasantness and pupil size during an imagery task. When the subjects attempted to generate mental images to stimulus words their pupils dilated, dilation being greater to abstract than to concrete words. They suggested that the greater arousal was associated with attempts to image abstract words. Simpson and Paivio (1966) also studied changes in pupil size during an imagery task, but in this study they did not have subjects make a motor response to indicate task completion. The study showed similar but attenuated dilation effects when the key press response was eliminated. Simpson (Note 3) clearly showed that pupil dilation is enhanced when an overt motor response indicates task completion. Other experimenters have also noted that pupil response is enhanced when verbalization is required (e.g., Harkerem & Sutton, 1966; Bernick & Overlander, 1968). Simpson and Paivio (1968) looked at both verbal and manual indications of cognitive task fulfillment and found that greater dilation occurs during the imagery task than during the control period, but only under conditions involving an overt public response.

Some studies have shown latency of response more sensitive than pupil dilation. Simpson, Molloy, Hale and Climan (1968) studied latency and magnitude of pupil response during an imagery task. They were not able to differentiate word difficulty using degree of pupil dilation, but they were able to measure difficulty by latency to responses. Colman and Paivio (1969) also found that the latency measure is a more sensitive index than magnitude of pupil response. Kuc (Note 4) obtained similar results when using MMPI statements of varying degrees of ambiguity.

Simpson and Hale (1969) noted that an arbitrary motor response during a decision-making task had only a minor effect on pupil response, but pupil size was greatly increased when the motor response was associated with decision-making. This finding suggested that there is a cumulative effect in arousal level when the response is associated with the task, the pupil response being enhanced. In another study, Simpson and Climan (1971) examined pupil response and EMG changes during an imagery task. They noted that the involvement of the motor response has definite effects on the pupil response pattern, but that these results may indicate that some other characteristic of responding, in addition to muscle activity contributes to greater pupil size. In conclusion, it appears that the work of Paivio and his associates is closely related to Kahneman's position. Paivio (1973) reasons that the pupillary dilation during imagery tasks is for the most part determined by arousal due to decision-making process. Janisse (Note 5) points out that Paivio's decisional processing may explain differences between the experimental and control groups in the overt response conditions, but it does not explain differences between abstract and concrete experimental tasks. It may be that the larger pupil size, when one has an abstract image, is a reflection of greater difficulty of deciding than would be necessary for a concrete image. This explanation would be in agreement with Kahneman, Peavler and Onuska's (1968) data which indicate that the difficulty of the task is of more importance in determining dilation than is the nature of the response.

In summary, the research in this area has generally supported the notion of the pupil response being a reliable indicator of "mental effort". The major thrust of this research has been undertaken by Kahneman (1973) and Paivio (1973) and their respective associates. Most of the studies reported have been interested in the mental effort aspect and have tried to control for other factors which could confound the data. The results, besides showing the pupil as a measure of mental effort in general, have also shown this effect to support both "between" and "within" task differences.

Pupillary Response and Stress

Pupillary response to cognitive activity or mental effort has been fairly well documented in various settings and on various types of tasks. Two conclusions are noted: first, pupillary dilation has been observed to peak at different levels on different types of trials which reflect the mental effort required by these tasks; second, within trial variations of pupil size change represents the processing load imposed by the task. Kahneman and his co-workers have generally attempted to validate the pupil response as a measure of mental effort and have directed their energies to the study of attention and processing load. Kahneman (1973) has referred to the potential of the mental effort being confounded by other variables, for example, anxiety. He has not, however, studied these potential effects directly.

Carver (1971) and Johnson (1971) have suggested that anxiety during a mental task might be related to the level of task difficulty. Peavler (1974) undertook to test for the possibility of anxiety influencing pupil response during a cognitive task of differing levels of difficulty. He presented subjects with digit strings of various lengths (5, 9, 13 digits) for immediate recall and gave them instructions as to the nature and difficulty of the strings. He found the characteristic pupil response pattern of previous research, except that with the 13 digit string pupil size levels off after the ninth second. He concludes that "presumed anxiety associated with information overload is not characterized by additional dilation resulting from momentary emotional states" (p.565). His instructions regarding the longer digit strings may, however, have been interpreted by the subjects as indicating a lack of necessity to try very hard. If so, this would have reduced the likelihood of an anxiety arousing component. Some indication of related measures of anxiety would have been helpful to resolve this issue.

Other studies have included a more direct manipulation of a stressor variable. Adams (1969) investigated changes in pupil size under conditions of anxiety and stress. She selected subjects on the basis of the IPAT Anxiety Scale and, in counterbalanced order, exposed them to stressful noise and to a cognitive task with incentives. She did not find differences between anxiety groups. Significant differences between pupil size measured during stressful noise period and during cognitive task period were noted only when the stress preceded the task. She suggested that the pupil can differentiate short term affective states. Two factors may have confounded the results of this study: first, the subjects could terminate noise at will, thus reducing the stress factor; second, the subjects were given incentives to the cognitive task performance which might have reduced the aversive aspect of the auditory stimuli when it followed the incentive task. Incentive manipulations increased motivation enhancing pupil response. Kahneman and Peavler (1969) demonstrated that greater pupil dilation occurred in subjects when motivated by five cent rewards for correct responses during association learning tasks than when motivated by one cent rewards. It appeared that greater effort was expended to solve the more profitable problems.

Nunnally, Knott, Duchnoski and Parker (1967) as part of a larger experiment presented subjects with various noise tones (64.2, 74.2, 84.2 and 94.2 decibels). There were no differences in pupil dilation to the first three tones, but these three differed significantly from the 94.2 db tone during which tone the greatest dilation occurred. The authors explained their findings by suggesting that an increase in muscle tension resulted from the very loud tone. Patrick (Note 6) devised a study in which he presented noise levels ranging from 73 db to 96 db during a visual scanning task. Greater dilation was observed during auditory stimulation, but the increase was not linearly related to the noise levels.

Other types of stress have also influenced pupil response. Simpson and Molloy (1971) used audience presence as a stressor and found increased pupil size for high audience anxious subjects as compared to low anxious subjects. Polt (1970) gave subjects arithmetical problems to solve and threatened some of them with electric shock for every incorrect response. Those threatened showed greater pupil size than those not threatened. Arima and Wilson (1972) found the largest maximum pupil diameter resulted from exposure to a Stroop Color Test rather than to other more congruous word lists; however, the results were not statistically significant. High anxious subjects responded with greater pupil dilation on the first eight trials to the incongruous list than the other two congruous lists. Low anxious subjects responded with a smaller pupil dilation on the first four blocks. It seemed that with continual responding, habituation occurred and anxiety was reduced. Furthermore, there may have been a confounding of results by using coloured stimuli, resulting in high individual variability. Miller (1966) found colour slides rated as more emotional and evoked greater pupil dilation than neutral gray slides. Bouma (1962) also demonstrated that, other things being equal, the wavelength of a light stimulus can influence pupil size.

Various methods to induce anxiety have been tried in different experimental situations with varying degrees of success. Increase of aversive auditory stimulation has shown increased pupil size. Threat of shock has also produced greater pupil size than a no threat condition and a social stressor indicated pupil size differences. While the Color Test had limited results as a stressor, these results are confounded by the inherent problem associated with visual presentation. Increasing the list lengths for recall did not indicate presence of an anxiety component, however, no other measures were used to substantiate whether or not anxiety was present. It appears, therefore, that various types of stressors do influence pupil response and a need is indicated to account for such influences on pupil response.

Pupillary Response and Personality

A number of studies have investigated pupil activity as a function of paper and pencil measures of anxiety and related constructs. The results have been generally positive in demonstrating a relationship between pupil size and various personality dimensions under varying conditions.

Simpson and Molloy (1971) had high and low audience anxious subjects perform a short-term memory and digit-transformation task under conditions of audience stress. They found larger pupil sizes for high anxious subjects than for low anxious ones throughout the experimental session. During the pause before responding, high anxious subjects maintained a continuously high pupil size, while the low anxious subjects exhibited a decrease in pupil size over the six second pause. The explanation given was that high anxious subjects responded with greater pupil size during the session because they were functioning at higher arousal levels under a stressful situation.

Arima and Wilson (1972) investigated the effects of level of anxiety (MAS) and stress (Stroop Color Word Test) on pupil response. Low anxious subjects responded with situational anxiety showing a pupil size increase during the Stroop task. The high anxious subjects initially had a large pupil size, but pupil size decreased after the first eight trials. Because the sample was small, the authors cautioned against over-generalization of the results. Adams (1969) failed to find differences between high and low scorers on the IPAT Anxiety Scale. These results may have been confounded by the type of task and the instructions.

Eysenck (1967) suggested that there was a relationship between neuroticism and autonomic lability. A number of researchers have looked at neuroticism scores and have noted a relationship between pupil size and neuroticism. Francis (1969) obtained Eysenck Personality Inventory (EPI) (1967) scores on subjects and observed changes (covert response) in pupil size in response to emotionally loaded stimuli. He also recorded overt response of eye movements, blinking and lid closing as dependent measures. High pupillary responders (covert responses) scored high on both extraversion and neuroticism scales, although only the latter scores were significant. Francis also found that low overt responders had significantly higher neuroticism scores than high responders, the latter having slightly higher, but non-significant, extraversion scores. There appeared to be a tendency to have greater pupil dilation in relationship to neuroticism; low scorers on neuroticism tended to make more overt responses. It seemed that subjects adopted different ways to cope with anxiety-provoking stimuli. The low neuroticism scorer closed his eyes or looked away to reduce anxiety, but the high neuroticism scorer did not appear to employ this approach.

Francis and Kelly (1969) presented religious words to subjects with and without religious ties. They found that subjects with religious ties responded more to the stimuli than those with none. Further analysis of the data, using EPI Neuroticism scores, indicated a relationship between neuroticism and pupil response tendency. For the Roman Catholic group, there was a relationship between high neuroticism scores and pupil dilation, and a relationship between low neuroticism scores and pupil constriction. They interpreted these results to mean that lists of religious words are appropriate to distinguish between high and low neuroticism scores among Roman Catholics. Liakos and Crisp (1971) found a significant correlation between anxiety scores, neuroticism scores and "static" pupil size in normal subjects, but not in subjects classified as "neurotic".

Kuc (Note 4) selected introverts and extraverts based on the EPI scores and presented university students with MMPI statements of high and low ambiguity over repeated sessions. He found that there was a significant habituation effect for all subjects over repeated testings, but there were no significant main effects for ambiguity or extraversion. The mean raw score pupil size of the introvert tended to be larger than that of the extravert. This tendency was reversed when utilizing proportional change scores for comparisons of experimental and control slide effects. It would appear that extraverts responded with greater variability from base level than introverts. Probably the fact that introverts had larger pupil sizes would tend to reduce the likelihood of greater variability. It may be that introverts see everything as serious or interesting while the interest of extraverts changes often over time. This idea is based on the fact that introverts tend to be more stable in behavior and more socially withdrawn while extraverts tend to be socially outgoing and somewhat impulsive.

Stelmack and Mendelzys (1975) studied extraversion and the pupil response to affective and taboo words. They found that introverts showed larger average pupil size under all conditions and had the greatest magnitude of change in pupil size from pre-stimulus level. These findings appeared to be in agreement with those of Kuc (Note 4) and supported Eysenck's general hypothesis that introverts have a higher level of cortical arousal as compared to extraverts. Boddicker (1972) reported results in which neither neuroticism nor extraversion were significantly related to the pupil response to neutral, positive and negative stimuli.

Studies employing the Repression-Sensitization Scale (R-S) (Byrne, 1961) have had mixed results. Fredricks (1970) studied R-S and the pupil response to pleasant and unpleasant stimuli. He found that sensitizers showed greater pupil dilation to pleasant stimuli. He explained his results by stating that repressors are "defensive and non-emotional", while sensitizers are "non-defensive and emotional". Another study (Good & Levin, 1970) noted only a slight trend for sensitizers to dilate more than repressors across neutral, aversive and sexual pictorial stimuli. The within-subject variance was of such a magnitude, however, that this trend must be considered due to chance variation. They did find that all subjects dilated significantly more to all of the sexual and aversive stimuli than to the emotionally neutral stimuli. The authors suggested that the stimuli categorization was too gross for the effective delineation of anxiety-provoking cues for the individual. Likewise, Tanck and Robbins (1970) failed to find a relationship between R-S and pupillary responsiveness.

Pupillary responsiveness among addicts and non-addicts has been investigated to some degree. Altman, Bernick and Mintz (1972) had addicts and non-addicts listen to and think about words, some of which were double-entendre addict argot. They found pupil size following presentation of non-argot words to be larger than for argot words, for both addicts and non-addicts. The authors felt that more cognitive effort was needed to deal with unfamiliar non-argot words as compared to familiar argot words. It was also felt possible that subjects were more suspicious about the non-argot words because they did not fit into their sub-cultural group expectations and thus were more anxiety arousing. Bernick, Altman and Mintz (1972) measured pupil response during verbalization of visually presented words among addicts in treatment. Subjects took slightly longer to respond to drug words than to control words. Pupil response to drug words was positively correlated to scores on the Language of Addiction Scale and negatively correlated to the Acceptability for Psychotherapy Scale. Further, pupil response to sex words correlated negatively with the MMPI-MF Scale.

A moderate degree of success has been achieved by relating differences in pupil size to personality factors, therefore the pupil measure may have reasonable index potential. The audience anxiety scale and the extraversion m easure both have indicated positive results. The repression-sensitization scale has thus far failed to demonstrate enough consistency to justify predictive statements, but the neuroticism scale has promise for future research designs. The general A-trait measures discussed have not shown more than a weak relationship to pupil size, thus caution needs to be exercised in the conclusions until more research has been done. It may be that the approach to investigating a relationship among pupil size and anxiety variables must take a more focused and specific approach. The following sections will look at this point and discuss the anxiety construct in more detail.

Anxiety as a Construct

From the previous sections it is apparent that the role of anxiety in the pupil response requires further clarification. One is not quite clear what the concept of anxiety means to the pupil investigator. Its meaning is also in doubt when reviewing the general field of anxiety literature (cf. Spielberger, 1966, 1972). Spielberger (1966) suggested that much of the ambiguity and semantic confusion associated with the concept of anxiety has resulted from the more or less indiscriminate use of the term to refer to related but very different constructs, namely, trait and state anxiety.

In a more recent publication Spielberger (1972) attempted to bring the concept of anxiety into some order and provide a conceptual framework, the better to understand this construct. He has put forth a theory of anxiety that attempts to posit a relationship between three different, but related, anxiety concepts: state anxiety (A-state), trait anxiety (A-trait), and anxiety as an emotional process. Anxiety as a state is characterized by subjective, consciously perceived, feelings of apprehension and tension, accompanied by or associated with activation or arousal of the autonomic nervous system. A-state anxiety is related to Freud's (1936) concept of anxiety and encompasses Krause's (1961) discussion of transitory anxiety. Anxiety as a trait appears to be more of a behavioral disposition in an individual which makes him prone to perceiving an array of objectively non-dangerous circumstances as threatening and thus respond to these situations with greater A-state reactions than would be expected. It appears that a subject must perceive the situation as threatening to respond with A-state reaction, and the intensity of the reaction will depend upon the degree of threat perceived. Finally, the theory of anxiety as a complex process is Spielberger's attempt to bring together the concepts of stress, threat, A-state, A-trait, cognitive appraisal and reappraisal, psychological defences and various classes of coping and avoidance behaviors that occur as a reaction to elevation of A-state. He states:

> 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 defensive maneuvers 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).

The differentiation of anxiety into various components may be beneficial in this attempt to relate the construct of anxiety to pupil response. Further, it will provide a better basis to evaluate the effect of anxiety in more specific terms. The next section will provide a clearer understanding of the relationship between A-state and A-trait in a variety of experimental settings.

Anxiety and Stress

This section deals with the relationship of A-state and A-trait as measured in different situations. A differentiation between a general A-trait measure and a specific A-trait measure is made. The benefits associated with the use of specific A-trait measures in research are discussed, with particular reference made to the Test Anxiety Scale (TAS) (Sarason, 1960).

A number of researchers have reviewed the relationship of state-trait variables under all types of conditions (e.g., Spielberger, 1966, 1972; Spence & Spence, 1966; Sarason, 1960). Many studies have dealt with the reaction which subjects, divided according to A-trait scale scores, have shown when confronted with situations involving personal threat or stress. Generally, the stress of ego-threat has been created by instructions which suggest that the subject is failing or doing poorly at some task or that the task is a measure of intellectual ability. The assumption and general findings have been that high-anxious people would be more sensitive to the stress condition than subjects low on anxiety measures. Saracon (1960) commented "that high anxious subjects have been found to be more self-depreciative, more self-preoccupied and generally less content with themselves than subjects lower on the distribution of anxiety scores" (p. 405). Not all research results (e.g., Cox & Sarason, 1954; Farber & Spence, 1956; Taylor, 1958) have been consistent with this assumption and general findings, however the bulk of the research has been more consistent and supportive of this.

Another finding also consistent with the general assumption has been that subjects who differ on A-trait measures do not differ in their performance when tested under neutral or non-threatening conditions. Spielberger (1972) commented that A-trait does not influence A-state intensity to all stressors. He pointed out that high A-trait subjects tend to respond to psychological threats to self-esteem more readily than they might to physical danger. Katkin (1965) and Hodges and Spielberger (1966) found that A-trait levels as measured by the Taylor Manifest Anxiety Scale (MAS) (Taylor, 1953) did not differentiate between conditions of threat of electric shock, but A-state reactions increased both on self-reports and on physiological measures. It is likely that the cognitive set is different for the different types of threat situations. Physical threat is a more tangible set and associated with a specific kind of danger; on the other hand, an ego-threat is less tangible and has greater associative meaning potential.

Hodges and Spielberger (1966) administered the Fear of Shock Questionnaire (FSQ) to subjects two months prior to the experiment. They found that when they threatened them with shock during the experiment, those subjects who reported greater fear of shock showed greater A-state reaction than subjects who did not respond positively. Students' scores from the FSQ and the AACL-Today (Affect Adjective Checklist, Zuckerman, 1960, 1965) indicated significant correlations to heart rate under threat of electric shock; the general measure of A-trait (MAS) was found not to be significantly related to FSQ nor with heart rate. In situations that require a specific kind of response to danger, a more specific measure would be required to measure the anticipated reaction.

Another study in which A-state intensities were unrelated to level of A-trait was reported by Lushene (1971). He had subjects view a stressful movie depicting physically painful accidents in a wood-working shop. The stressor did produce marked increases in A-state reaction, but the A-trait scores were unrelated.

Martens (1971) reviewed A-trait (MAS) and motor behavior studies which both included and excluded stressors. The results were for the most part inconsistent with the drive theory model. Because of the lack of consistent findings, the author suggested that an alternate approach was required to deal with the type of study and one approach might be the situational anxiety approach. This method would relate to specific objectives directly relevant to the study under consideration.

The Taylor Manifest Anxiety Scale (MAS, Taylor, 1953), Cattell IPAT Anxiety Scale (IPAT, Cattell & Scheier, 1963), State-Trait Anxiety Inventory (STAI, Spielberger, Gorsuch & Lushene, 1970) and the Affect Adjective Checklist (AACL, Zuckerman, 1960) are measures of general A-trait and for the most part they correlate very well with each other (Spielberger, 1972). Furthermore, general A-trait measures correlate only moderately with specific A-trait measures which is as expected when going from general indicators to specific indicators. Endler and Shedletsky (1973) criticized the STAI and MAS scales as focusing mainly on interpersonal anxiety and ignoring physical danger. They viewed trait anxiety as multidimensional, including interpersonal, physical danger and ambiguous threat aspects. In their study, they found that both ego threat (failure) and physical threat (shock) produced A-state arousal. Further, physical threat created greater A-state arousal than ego-threat for high A-trait subjects. This finding under the physical threat condition was contrary to Hodges' (1968) findings of no differences in A-state results for high and low A-trait subjects. Endler (1973) and Endler and Hunt (1966, 1968, 1969) emphasized the need to specify the situation when anxiety was being investigated. They found that the interaction of the person and the situation accounted for more anxiety variance than did the person per se, thus confirming the need to specify the kind of stress situations employed.

A-trait measures which attempt to assess an individual's disposition towards anxiety in a specific situation would be more likely to predict increased A-state reactions than a general measure. Lamb (1970) found that a specific A-trait measure which evaluated a person's anxiety experience in speaking situations was more predictive of A-state reactions in students required to give an impromptu speech than was a general A-trait measure. Further, Hodges and Spielberger (1966) found that the specific A-trait (FSQ) predicted increased A-state reactions to threat of shock, but the general A-trait (MAS) did not.

The situation-specific A-trait approach is especially designed to focus on definite situations and events, the better to evaluate a person's disposition toward these specific areas. The general A-trait measure is not constructed that way and thus would not be expected to achieve the same predictive power. Simpson and Molloy (1971) used this specific-situation approach with A-trait (audience anxiety) and a stressor (audience). They found a greater A-state reaction among subjects with high A-trait scores. Pupil size was their only dependent measure. It would appear that this kind of approach would be ideally suited to pupil research due to the sensitivity of the pupil response. 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).

The Test Anxiety Scale (TAS, Sarason, 1957) is one particular type of the situation-specific A-trait measure because it is more accurate in predicting performance decrements in test-like situations than are the general A-trait measures. The correlations between the TAS and other general A-trait measures are moderate. The TAS has been described as a measure of that anxiety felt when a person believes he is being evaluated (Atkinson, 1964; Lazarus, 1966). The assumptions are that the individual emits two types of responses: a task relevant response which facilitates completion of the task at hand and a task irrelevant response which facilitates completion of the task at hand and a task irrelevant response which interferes with the completion of the task. High-test-anxious persons are seen as emitting mainly task irrelevant responses while low-test-anxious individuals develop strong task relevant responses. As a result, low-test-anxious subjects tend to perform better in evaluation situations than do high-test-anxious people (Child, 1954). Janisse (1973b) found that when given a choice, low-test-anxious students tended to choose the traditional evaluation format more than did high-test-anxious individuals; "low anxious students do well in those evaluations, they are rewarded with higher marks and thus prefer to continue this kind of test-taking behavior over an alternative" (p. 353). Thus, how a person feels about his success in a given situation will influence his performance in that setting. People who are high scorers on the TAS generally perform poorly in evaluation or test-like situations which suggests that the TAS measures a proneness for the individual to experience high A-state reactions in situations where personal adequacy is evaluated (Sarason, 1972).

In summary, there are fairly predictable effects associated with the inclusion of A-state and A-trait measures in an experimental situation that involves personal or ego-threat. The use of specific-situation A-trait measures enhances the probability of an A-state reaction occurring in given situations. Thus it appears that using this type of A-trait measure in pupillometric research should increase the probability of noting the relationship between pupil size, anxiety and mental effort.

Anxiety and Intellectual Ability

The inclusion of intellectual factors in this study is related to the notion that the pupil is an indicator of mental effort. It has been reported that the more difficult the task the larger the pupil size, which reflects greater mental effort expended during the task. The level of intellectual functioning of a person should have some effect on how difficult it would be for that person to complete a cognitive task. A bright person would be able to resolve a cognitive task with little effort, whereas a less gifted individual would find the same task very difficult to solve. It would seem reasonable to control for intellectual ability in studies of cognition. Furthermore, anxiety can interfere in task performance and could be reflected in pupil size changes. The following discussion elaborates on the effect of both A-state and A-trait on intellectual functioning.

In a selected review of the literature, Matarazzo (1972) noted that the relationship between A-trait and intelligence measures, particularly the Wechsler Intelligence Scales, was inconsistent and for the most part, lacking. Matarazzo, Ulett, Guze and Saslow (1954) studied the relationship between the Wechsler Bellevue Scale (W-B), the American Council on Education Psychological Examination (ACE) and the Taylor Manifest Anxiety Scores (MAS). No relationship was found between MAS and W-B scores, but a significant negative correlation was found between the MAS and ACE scores. Calvin, Koons, Bingham and Fink (1955) did find a negative relationship between the MAS and W-B scores. Grice (1955) and Kerrick (1955), using United States Air Force trainees, found significant negative correlations between general A-trait measures and air force aptitude tests. Despite these few significant relationships cited, most research was not able to confirm these findings (e.g., Matarazzo, 1955; Jurjevich, 1963; Callen & Metzer, 1969), nor have the ACE and A-trait results been confirmed (e.g., Mayzner, Sersen & Tresselt, 1955; Klugh & Bendig, 1955; Sarason, 1956; Spielberger, 1958).

In an extensive undertaking, Spielberger (1958) obtained the ACE and MAS measures on 1142 college students over a period of six semesters. He found that the overall correlation between the ACE and MAS was miniscule. Some of the sub-samples were significant and he pointed out that low ability level sub-samples of the ACE scores were more likely to result in a significant negative correlation between anxiety and intelligence than any other factor.

The lack of relationship between A-trait and general intelligence measures in a neutral situation is consistent with the State-Trait theory of anxiety. Spielberger (1972) has pointed out that A-trait differences are not likely to occur in the absence of a stressful situation. In order to explain the significant findings of the intelligence measures, Matarazzo, Ulett, Guze and Saslow (1954) and Levitt (1967) have suggested that the negative correlations might be due to the timed aspect of the measures studied. Siegman (1956a) investigated the effects of anxiety on timed and untimed measures of the Wechsler Adult Intelligence Scale (WAIS, Wechsler, 1955) with 35 patients. It was found that high anxious subjects performed more effectively on the untimed subtests and less effectively on the timed subtests than the low anxious subjects. In another study, Siegman (1956b) confirmed his previous findings with a larger sample of 90 patients. As before, he failed to find a significant correlation between the MAS and the WAIS Full Scale. It appears that there is a need to specify the situation in order to better investigate and clarify the anxiety relationship with the intelligence factor.

Research into this area which attempts to include a stress factor and to become more specific in measuring intellectual factors has met with more success. Mandler and Sarason (1952) studied the effects of differential instructions on task performance. They administered the Kohs Block Design test and the WAIS-Digit Symbol task to undergraduates who were divided into high and low anxiety groups on the basis of the experimental affect self-report. It was found that subjects responded differently depending upon the instructional set. The anxious subjects demonstrated the best test behavior when no reference was made to their test performance. On the other hand, low anxious individuals improved their performance when informed that they were failing. In another study, Moldawsky and Moldawsky (1952) administered the W-S Full Scale to college students and later retested them on the WAIS Digit Span and Vocabulary subtests under different instructions. One group was retested in the standard manner; the other group was informed that their previous test behavior was odd and a retesting was needed. No differences were noted in the test-retest performance of the standard instruction group. In the stressed group there was a significant decrement in retest performance on the Digit Span, but only a slight nonsignificant increase in Vocabulary retest performance. It appears that Digit Span is sensitive to situation anxiety, but vocabulary appears to be more resistent to decreasing performance under stress.

Walker and Spence (1964) had 110 subjects take the MAS and the WAIS-Digit Span under control and experimental conditions. The control group who received neutral instructions showed no relationship between MAS and Digit Span. The experimental group was informed that their instructor requested that they be tested because of their poor personality questionnaire performance. After being administered the Digit Span, each subject was asked how it felt to be considered as "different". In the experimental group, 32 of 55 subjects said that they were disturbed by the statement, while the remaining 22 subjects were unconcerned about being considered different. The analysis showed that the disturbed subjects demonstrated a decrement in Digit Span performance relative to the control group. The unconcerned subjects were not different from the control group on Digit Span performance. It was noteworthy in this study that the authors based their analysis on the subjective feelings of the subjects in that instructions had to be perceived as stressful in order to have an influence on task performance. Walker, Sannito and Firetto (1970) repeated the above study and included all five verbal subtests of the WAIS. Those given the stress instructions achieved significantly poorer performance than the control group on Information, Similarities, Arithmetic and Digit Span. Walker, Neilsen and Nicolay (1965) set up a situation in which some subjects were given the Object Assembly task in such a manner as to make it impossible to complete. The control subjects received the standard object assembly task without first having to do the impossible object assembly task. The instructions also varied; the results for the control group showed no difference between the object assembly performance and anxiety measures. The experimental group which was given bland instructions correlated negatively with both the MAS and the measures of personal inadequacy. The researchers concluded that A-trait is correlated with intelligence performance under stress conditions that are directly associated with the testing instrument. Furthermore, anxiety and intelligence are unrelated under no-stress conditions.

Hodges and Spielberger (1969) obtained both an A-trait (MAS) and A-state (ZAAC) measure on subjects. They imposed stress on half of them during a Digit Span task by suggesting "that other testees typically do better than you are doing." The second half of the subject group did not receive such instructions. Digit Span and A-trait were unrelated, Digit Span and A-state were related. High A-state subjects showed decrement in Digit Span performance.

Some studies have failed to show the disruption in Digit Span or other subtest performance under stress. Guertin (1959) distracted subjects with noise during a Digit Span task but failed to find any differences. Craddick and Grossman (1962) used visual distractors and also failed to find any differences in a subject's performance. It may have been that in both these cases there was not any perception of threat by the person, therefore no A-state reaction developed.

Another approach to explain inconsistent findings is the proposition presented by Morris and Leibert (1969). They separated the TAS into two subscales: chronic worriers (cognitive aspect) and current emotionality (physiological arousal). Using five timed WAIS scales they timed one-half of the subjects ostentatiously, the remainder they timed covertly. High worriers did worse on timed tests when they knew they were being timed than when unaware. Low worriers performed better during the timed aspect when they were aware than when unaware. It may be this aspect of the subject's measure reflected in most studies and thus there would be little physiological response noted or measured. Also, with an external stressor that is reflected outside the subject and beyond his control, little performance change will occur. When the stress induced is within one's control but still intangible, however, there will be more concern. This would affect the subject's performance but does not create significant physiological reaction.

It appears that general measures of intelligence are not usually related to A-trait measures. It has, however, been found that the timed aspects of certain tests do reflect in poor performance on intelligence subscales. It has also been found that one's performance on subtests can be influenced by the type of instructions given, either to improve performance or decrease performance scores. When a subject feels threatened, he is likely to do more poorly on a task that is directly related to the original testing instrument. As was stated in an earlier section that situation-specific measures of A-trait are likely to be more predictive of A-state reaction, so too one is more likely to find differences in performance among A-state elevated subjects whose test-retest material is similar in nature.

Statement of Problem

The relationship between pupil response, mental effort, ego-threat and state-trait anxiety is still unresolved. A further investigation to assess the influences of these variables on pupil response would be a productive line of research. Certainly no one will argue against the possible interference of anxiety as a potential influence on pupil response, but little has been learned about its effects during tasks requiring mental effort.

Kahneman (1973) noted that there was evidence which suggests that momentary fluctuations of anxiety play a limited role in determining the pupillary responses in task situation (cf. Kahneman & Peavler, 1969; Kahneman, Peavler & Onuska, 1968; Kahneman & Wright, 1971). On tasks requiring mental effort, Kahneman contends that anxiety will not account for the greatest portion of the variance related to pupil response. Kahneman and Wright (1971) suggest that any study attempting to measure mental effort by a physiological measure must also take into account potential confounding variables such as anxiety. Few pupil studies have attempted to investigate the relationship between mental effort and anxiety by manipulating the various anxiety components using different experimental instructions. Peavler (1974) attempted to study anxiety effects on digit recall tasks of varying difficulty, but failed to confirm that anxiety influenced digit recall. Two serious problems are noted in this study, first, in his instructions to the subjects he indicated that some tasks would be impossible to recall, which might have reduced the probability of anxiety influencing the task; second, he did not include a related measure of anxiety in order to substantiate the presence or absence of state anxiety. The Simpson and Molloy (1971) study also failed to incorporate a corroborating A-state measure.

It was proposed in this research to study the effect of anxiety on the pupil response during a cognitive task by differentiating the anxiety concept into state and trait components, and by introducing a stressor. The stressor condition was created by presenting ego-involving instructions to some of the subjects during a digit span task of moderate difficulty. It was anticipated that the stressor will evoke an A-state reaction which then can be compared and the differences measured. In order to assess whether anxiety was produced by the ego-threat instructions, another A-state measure in addition to the pupil response was obtained.

Recent trends in the anxiety literature point to the need to differentiate between anxiety as a trait and anxiety as a state: a predisposition to become anxious in a given situation (A-trait) compared to anxiety actually present in a given situation (A-state). Even though a person may score high on an A-trait measure, the person may or may not be experiencing anxiety in a given situation (cf. Spielberger, 1966, 1972). For the most part, it appears that Kahneman's conception of anxiety refers to A-state reaction, and a relationship between this and A-trait would add clarity to the issue. Any attempts to study the relationship between mental effort, anxiety and pupil response should take this difference into account. This research proposes to make these differentiations in an attempt to clarify the role of anxiety in pupillary studies.

There have also been indications in the anxiety literature (e.g., Martens, 1971; Endler, 1973) that studies require a measure of anxiety that is specific to the type of situation and task being studied, rather than the more general measure of anxiety usually employed. Except for the study by Simpson and Molloy (1971), most pupil studies investigating anxiety have used a general A-trait measure which might have prevented the full potential differences in pupil response from emerging. This research attempted to rectify this situation by introducing an A-trait measure which was specifically related to the experimental situation, namely, a test anxiety measure.

Another consideration was that of intellectual efficiency and its relationship to anxiety and pupil response. If increased pupil response on a problem-solving task reflected mental effort and difficulty level, one would also have expected differences in effort required to accomplish a task to be related to level of intelligence as well. People with low intelligence would find greater difficulty in completing a task than those scoring high on intellectual measures. Simpson and Molloy (1971) failed to find a relationship between intelligence and pupil response. They suggested that a wider intellectual range may obtain a significant finding; however they used a general measure of intelligence which may not be an adequate measure to reflect the nature of the task. It may be that one must use a more specific measure that relates directly to the type of experimental task. In this study, the intelligence measure used was related to the task in order to provide better representation of the effects of level of intellectual ability on pupil response and performance.

Finally, one might expect differential effects of mental effort when a subject can or cannot respond correctly to a task item. Daly (Note 1) found no pupil size differences between correct and incorrect answers to problems. Kahneman (1973) has suggested that subjects would have larger pupil size for items totally recalled than for partial recall, but Bradshaw (1967) found the opposite effect between solved and unsolved problems.

Statement of Hypotheses

The following general hypotheses were tested within the framework of two experiments:

1. The High and Low Stress conditions are expected to produce differential effects:

a) Higher A-state scores are predicted from the High Stress group than from the Low Stress group. The High Stress instructions were intended to be ego-threatening and thus more anxiety-arousing.

b) During Input, it was predicted that those receiving High Stress instructions would have larger pupil size than those receiving Low Stress instructions.

2. A-trait differences were also predicted during Input:

a) The High A-trait group was expected to self-report more state anxiety in the High Stress condition than under Low Stress. The same group/condition relationship was also expected for pupil size difference during Input.

b) However, Low A-trait subjects were not expected to differ under either High or Low Stress.

c) Under ego-threat conditions, the High A-trait group will differ from other groups on both A-state measure and pupil response.

3. Effects due to intelligence during Input were also predicted:

a) High Intelligence group would recall more digits than Low Intelligence.

b) The Low Intelligence group was to show larger pupil size than the High Intelligence group.

c) It was expected that the largest pupil size was to be the Low Intelligence - High Stress group; the smallest pupil size from the High Intelligence - Low Stress group.

4. Pupil size differences during Input for Correct and Incorrect trials were expected, but direction was not predicted.

CHAPTER II

The hypotheses proposed in this investigation were examined by means of two experiments. The first experiment dealt with the relationship of the pupil response to mental effort, instructions and intellectual measures during a digit recall task. The second study included modifications in design as indicated from the results of the first experiment and also included an A-trait measure and heart rate measure in addition to the other variables manipulated in Experiment 1.

Experiment 1

Purpose of Experiment 1

The first study investigated the effects of ego-threatening instructions on a subject's pupil response during a short term memory task, namely, a digit span task. A secondary aspect was to assess the relationship of intelligence and correct-incorrect trials to the pupil response. Kahneman (1973) suggested that anxiety can influence the pupil response during task performance, but he has not manipulated the anxiety variable to study it specifically or obtain related anxiety measures. Peavler (1974) administered subjects digit span tasks of varying lengths with the prediction that the longer lists would generate anxiety and thus influence pupil response. He did not confirm this expectation but his instructional set may have confounded the results. In addition, he did not take a measure of state anxiety. In this study, a related A-state measure was included to confirm the presence or absence of anxiety during the experimental period.

It was predicted that subjects under the ego-threat or High Stress (HS) instructions would show greater pupil dilation than subjects under Low Stress (LS) instructions. Further, it was expected that subjects under the HS condition would score higher on the post A-state measure than under the LS condition.

The second aspect of the study looked at the relationship between intelligence and pupil response. It was predicted that high scorers on the WAIS-Digit Span would show less pupil dilation than low scorers because high scorers require less effort to accomplish the task. Further, high Digit Span scorers in the LS condition would have the least pupil size change and the low Digit Span scorers would have the largest pupil dilation under the HS condition.

Finally, subjects were compared on their task performance. It was expected that high scorers on Digit Span would obtain more correct responses than low scorers. It was also expected that the pupil dilation would be greater on incorrect trials than on correct trials.

Experimental Method

Subjects. Forty first year male introductory psychology students between the ages of 19 and 25 years at the University of Manitoba were selected for this experiment. Due to a mechanical error, the first eight subjects were discarded leaving a remainder of 32 subjects.

Apparatus. The apparatus for recording pupil responses was a Whittaker Space Sciences Eyeview Monitor and Television Pupillo[illegible]

System which provided 60 measures of pupil size per second. The pupil of the left eye was continuously monitored and the data output stored on magnetic tapes for later data analysis.

Stimulus materials. Eight sets of digit strings were prepared, each set consisted of eight strings and each string was eight digits. Each string included numbers from one to nine with no number repeated (see Appendix A). A string of eight digits was selected because it is at the upper end of the range that most college students can respond with any degree of consistency. Miller (1956) suggested that the average range for college students is seven digits plus or minus one.

The sets were randomly assigned to each of the 32 subjects, one set per subject.

Other measures. The Wechsler Adult Intelligence Scale Digit Span subscale (Wechsler, 1955) was administered to each subject individually. The standard test procedure was followed by administering this subtest. The Digit Forward score was used as the measure of intellectual efficiency. This subtest was selected for the pre-test measure because it most closely reflects the type of intellectual task used during the experimental period.

The other measure used was the Self-Evaluation Questionnaire (STAI Form X-1, Spielberger, Gorsuch & Luchene, 1970). This is an A-state measure which presents a number of statements which people have used to describe themselves as to how they feel at this time. The instructions were changed somewhat to indicate how the subject felt during the experimental session.

Design and procedure. Subjects were randomly assigned to one of the two groups, either the High Stress (HS) condition with ego-threatening instructions or the Low Stress (LS) condition with neutral instructions. Except for the instructions, each subject followed the same procedure and was tested individually. The subject was brought into the experimental room from the waiting area, seated at a table away from the pupil apparatus and administered the WAIS-Digit Span in the standard manner by the experimenter. While the subject was adapting to the lighting conditions, he was given a brief description of the pupillary apparatus. Then he was seated in the apparatus three meters from the focal target and his left eye was monitored by the camera. Once this was done he was given the instructions appropriate to his group assignment and a practice session followed.

The instructions for the High and Low Stress conditions are presented in Appendix B. Both the instructions and lists were pre-taped to provide a standardized presentation to all the subjects. Once the questions were answered, the subject's pupil was re-focued on the TV monitor. He had been relaxing out of the head-rest during the instruction period. Each subject received an auditory presentation of eight trials of eight digits per trial. The first two trials were practice trials and not used in the later analysis. The subject's eye was monitored during the digit presentation series, approximately three and one-half minutes of monitoring per subject.

Each trial consisted of a three second rest period, a two second ready period, and eight second listen phase, a nine second recall phase and a three second post-trial pause. Upon completion the subject filled out the STAI-X1 and was debriefed.

For the purpose of analysis, the subject's data were divided into high and low Digit Span scores in the High and Low Stress conditions. The pupil data were printed out at one second intervals. The ANOVA design then was a 2 (Stress) x 2 (Intelligence) x 6 (Trials) x 8 (Seconds) repeated measures on the last two variables. A separate analysis was conducted for both the Input and Output segments. The pre-stimulus period was analyzed in the same manner except it was based on a five second period.

Results of Experiment 1

An ANOVA summary table of the A-state scores is presented in Table 1 in Appendix C. There were no significant differences between the Stress groups and the Intelligence groups on A-state scores.

The mean pupil size for the two Stress groups over the three segments of the experiment is presented in Figure 1. The ANOVA summary tables of pupil data for the Pre-stimulus, Input and Output segments are shown in Table 2. Tables 3 and 4 presented data from linear trend analyses on Trials and Seconds. (Note: All summary Tables referred to in text are found in Appendix C).

Pre-stimulus. The Pre-stimulus period is comprised of the Rest and Ready segments. The ANOVA indicated a significantly larger pupil size for subjects in the High Stress (HS) group than in the Low Stress (LS) group ($F(1,28) = 4.84$, $p < .05$). The significant decrease in pupil size over Trials ($F(5,140) = 8.24$, $p < .01$) was shown to be linear ($F(1,28) = 20.07$, $p < .01$). Finally, there was a significant Seconds effect

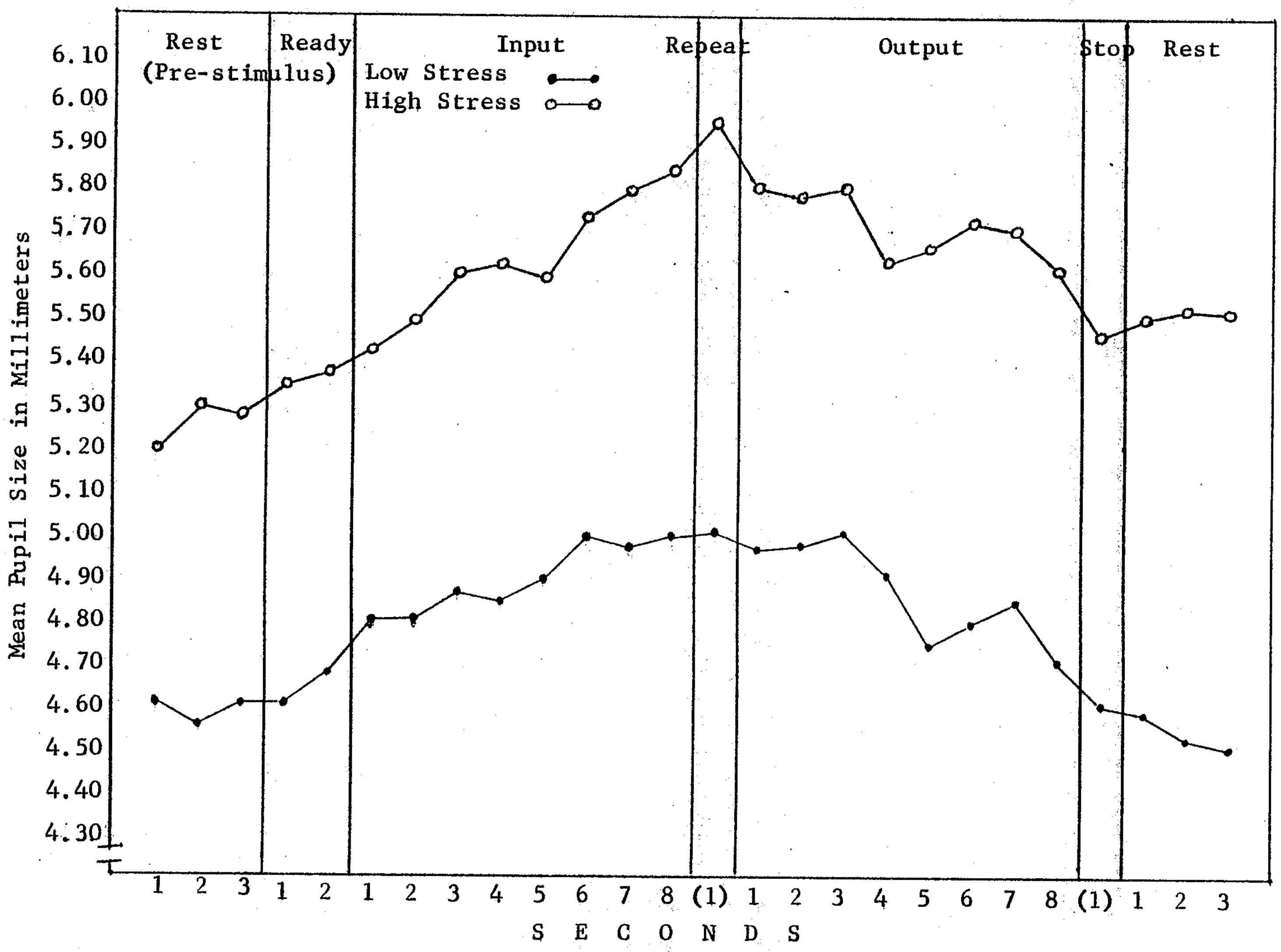

Figure 1. Mean pupil size over Seconds of High and Low Stress groups during the Digit Span period.

($\underline{F}(4,112) = 2.93$, $\underline{p} < .05$) with a non-significant linear trend ($\underline{F}(1,28) = 3.92$, $\underline{p} > .05$).

Input. Subjects in the HS group had significantly larger pupils than the LS group ($\underline{F}(1,28) = 4.29$, $\underline{p} < .05$). Both groups showed increases over Seconds ($\underline{F}(7,190) = 14.72$, $\underline{p} < .01$), but decreased over Trials($\underline{F}(5,140) = 8.39$, $\underline{p} < .01$). Both these linear trends were significant ($\underline{F}(1,28) = 29.21$, $\underline{p} < .01$; $\underline{F}(1,28) = 136.20$, $\underline{p} < .01$). A significant interaction between Instructions and Trials ($\underline{F}(5,140) = 2.70$, $\underline{p} < .05$), presented in Figure 2, indicated that the HS group habituated less than the LS group over the course of the experiment. This was further supported by a significant linear trend by Instructions interaction ($\underline{F}(1,28) = 6.77$, $\underline{p} < .05$). A significant Instructions x Intelligence linear trend over trials interaction ($\underline{F}(1,28) = 5.17$, $\underline{p} < .05$) is presented in Figure 3. A Scheffe's test (cf. Kirk, 1958) indicated that on trial one the Low Intelligence - Low Stress group differed significantly from the other three groups. No significant differences were found among the latter groups. On trial six the two High Stress groups did not differ from each other, nor did the Low Stress groups differ from each other, but the High Stress groups differed significantly from the Low Stress groups.

Output. The HS group had significantly larger pupils during recall than the LS group ($\underline{F}(1,28) = 7.04$, $\underline{p} < .05$). A significant Trials effect ($\underline{F}(5,140) = 10.96$, $\underline{p} < .01$) was shown to be a significant linear decrease over time ($\underline{F}(1,28) = 27.28$, $\underline{p} < .01$). The significant Seconds effect ($\underline{F}(7,196) = 4.23$, $\underline{p} < .01$) was a significant linear decrease ($\underline{F}(1,28) = 8.16$, $\underline{p} < .01$) in pupil size following instructions to recall.

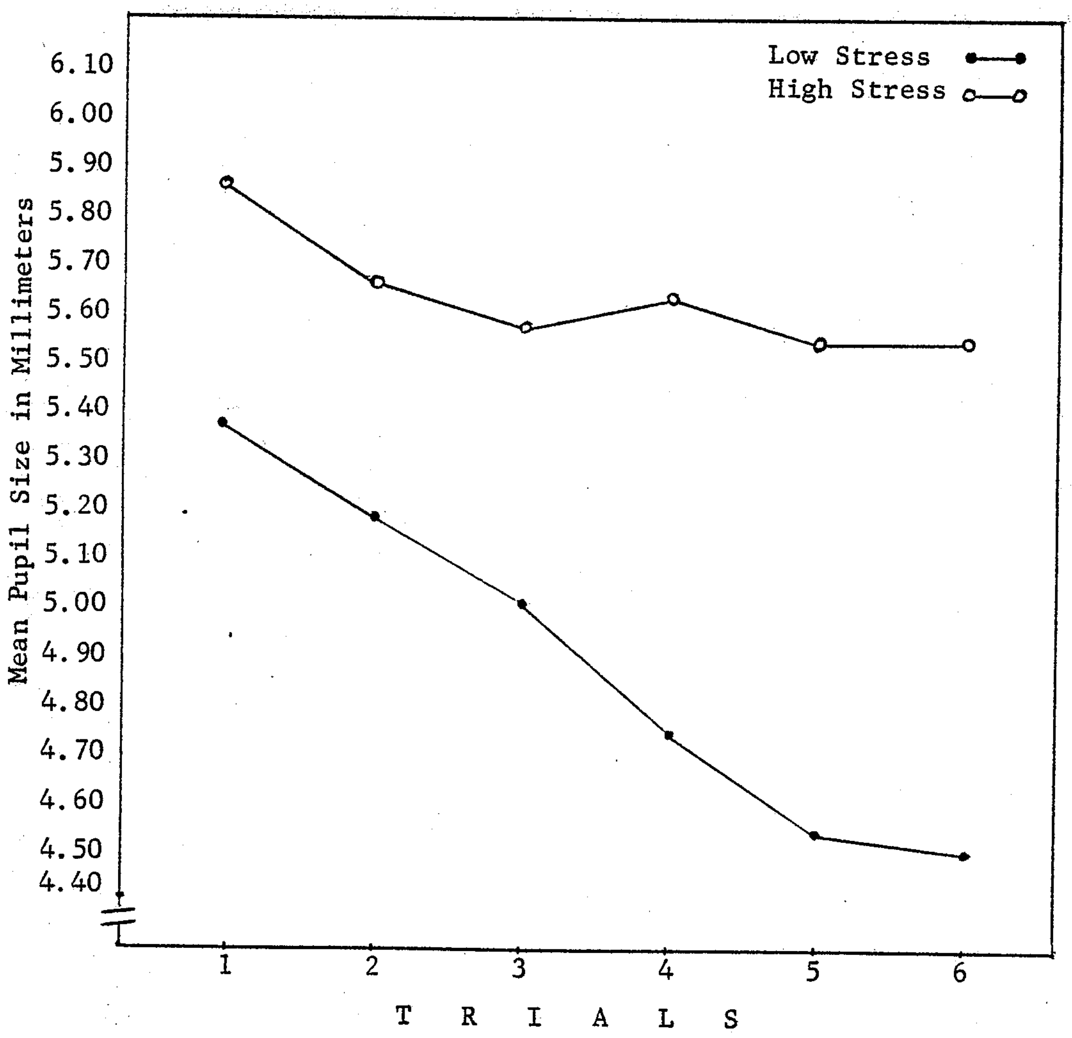

Figure 2. The mean pupil size for Trials of High and Low Stress groups during the Input segment.

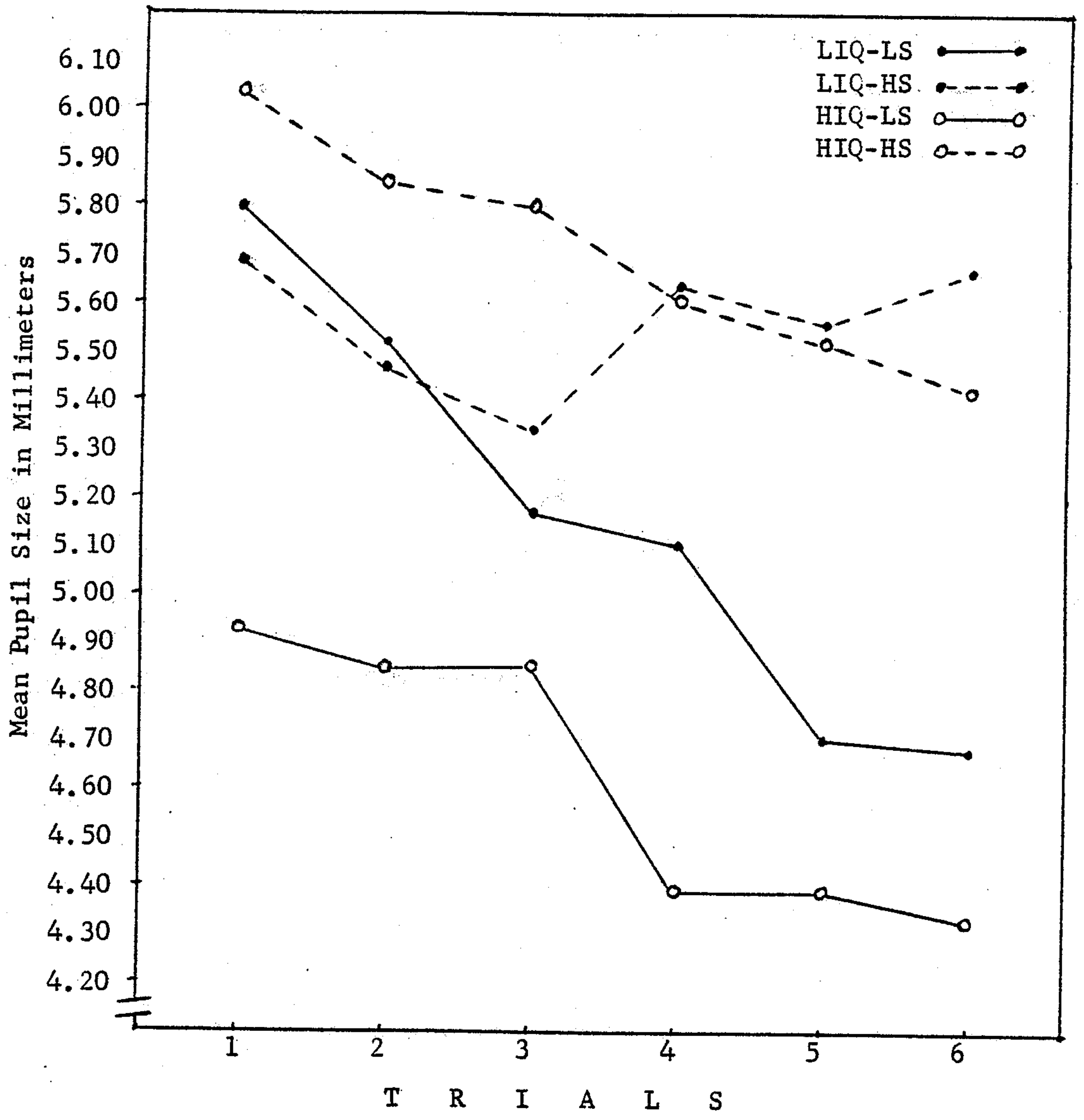

Figure 3. The mean pupil size of High and Low Intelligence groups under High and Low Stress instructions for Trials during Input segment of Digit Span period.

Finally, Table 5 presented the total number of correct responses obtained by all subjects, including practice trials, on the digit recall task. Because of this poor performance by subjects, no further analysis was made of the subject's pupil response comparing correct and incorrect trials. It was expected that subjects would respond at approximately the 50% correct level. Only 12 of 32 subjects were able to respond with any correct trials, and of these subjects, a total of 30 trials out of a possible 256 were correctly answered. An ANOVA of incorrect responses showed that High Intelligence subjects had significantly fewer incorrect responses (M = 6.50) than the Low Intelligence subjects (M = 7.63) (see Table 6).

Discussion of Experiment 1

The major finding in this study was that the High Stress (HS) instructions produced significantly greater pupil dilation during the cognitive task than did the Low Stress (LS) instructions over the entire experimental session (see Figure 1). The logical conclusion would be that the HS condition resulted in increased arousal or A-state reaction, thus greater dilation. No significant differences were found on A-state measures between groups, however, so the conclusion of increased anxiety as a result of the HS condition does not appear to support the findings.

An alternate viewpoint was considered which provided an explanation more in accord with the results. The State-Trait Anxiety theory "assumes that the arousal of anxiety states involves a process or sequence of temporally ordered events initiated by either external or internal stimuli that are perceived to be dangerous or threatening by an individual" (Spielberger, 1972, p. 42). The individual must appraise the situation as threatening before responding with an A-state reaction. It was likely that in this situation the students, rather than seeing the task as threatening, viewed it as a challenge to do their best and achieve as high an intellectual quotient as possible. It then seemed reasonable that these subjects would expend more mental effort during the task. As a result, their additional efforts (as compared with those receiving Low Stress instructions) would have the effect of increased pupil size during the digit task.

The interpretation that ego-involving instructions increases the subject's motivation to recalling digit strings, leading in turn to greater mental effort as is reflected in increased pupil dilation, was consistent with the suggestions made by Polt (1970). He found increased pupil dilation in subjects receiving threat of shock instructions (as compared to neutral instructions) during a problem-solving task. He reasoned that subjects faced with a threatening situation reappraised the situation by reasoning that obtaining the correct solution would avoid the shock and thus would be also rewarding. It thereby provided subjects with the incentive to obtain the correct response to problems presented. Subjects would thus expend greater mental effort to problem-solving and the result would be increased pupil dilation.

The findings of Kahneman and Peavler (1969) also add support to an incentive rather than an anxiety interpretation. Subjects were paid either five cents (high reward) or one cent (low reward) for correctly responding to some stimulus items in a list. They found that greater pupil dilation occurs on high-reward trials (vs low-reward trials) than on a paired-associate learning task. The authors concluded that "the pattern of pupillary responses . . . supports the conclusion that these responses are related to effort rather than to emotionality or arousal"(p. 315).

Further evidence for an increased mental effort interpretation is suggested in the habituation pattern over trials under the two sets of instructions (see Figure 2). There is usually a reduction in pupil size with continuous experience with the same stimulus or in the same stimulus situation. This phenomenon has been alluded to by Hess (1965), Kahneman and Beatty (1967) and Kahneman and Peavler (1969). The HS group in this study did not show the same rate of decreased pupil size as the LS group (see Figure 2). For the HS group there was only a small decrease in pupil size after the first trial followed by a leveling off over the next five trials; on the other hand, the LS group's pupil size followed a consistent decreasing pattern over the six trials. It seemed reasonable to conclude that those in the High Stress condition continued to expend greater effort during the Input segment over all trials (indicated by a consistently larger pupil size) than those in the LS condition. As suggested by Polt (1970), the High Stress manipulation may have motivated the subjects to expend more effort at the task rather than experience anxiety. Thus the subjects were more attentive to the task, particularly during Input which was quite difficult. This resulted in increased and sustained pupil dilation.

The relationship between pupil size and the intellectual measure failed to reach statistical significance. It may have been that both the instructions and the difficulty of the task confounded the results.

The instructions may have been too mild to generate the level of ego-threat required. Anxiety arousing instructions generally lead to decreased performance on a recall task, but in this study, those receiving High Stress instructions performed better than the Low Stress instructed students. Furthermore, those high on intellectual measures performed better than low scorers in each condition. However all groups performed poorly on the task and only 12 of 32 subjects were able to recall correctly any of the digit strings. The expected correct/incorrect ratio of 50/50 was never reached suggesting that the digit strings were far too difficult to achieve the desired effect. This difficulty factor may have confounded the intellectual efficiency differences among groups.

During the experiment, some methodological problems were noted which required comment. The eight digit strings were too difficult to provide an adequate measurement comparison, particularly for correct vs incorrect trials. This problem might be resolved in future studies by a shorter digit string. Another problem appeared to be that the High Stress instructions employed were too mild for the intended effect, since no differences among groups on the A-state measure were found. A more intense instructional set appeared necessary in order to achieve the required A-state reaction. Perhaps an additional physiological measure is needed during the instructional period to help assess the extent of instructional influence, particularly when attempting to generate an A-state response. Finally, the failure to obtain a pupil baseline measure prior to giving the instructions created an ambiguous situation when trying to relate the significant differences of the prestimulus period to the overall experimental results. A baseline measure is required to clarify these statements and help explain the findings based on the instructional set.

Experiment 2

Purpose of Experiment 2

This experiment was proposed to investigate pupillary response during a cognitive task and its relationship to anxiety, the individual difference variable of intelligence and correctness of response. In study one, no attempt was made to select subjects on the basis of Trait anxiety (A-trait) differences, and the findings indicated no A-state or momentary anxiety differences were observed between the groups tested. The inclusion of an A-trait measure was viewed as necessary and beneficial because such measures suggest a proneness towards A-state reaction in high scorers. Thus one might have expected a greater, more consistent A-state reaction from persons high on A-trait scores in an ego-threatening situation. The dearth of A-state differences among groups in Experiment 1 also suggested that the instructions were not perceived as threatening, but rather as an incentive to greater achievement. A more intense instructional set was formulated to accentuate the high stress condition.

In the digital task of Experiment 1, subjects did not perform as anticipated. It was thought that the task would be of moderate difficulty and subjects would likely respond at about the 50/50 incorrect-correct ratio. Because of the high degree of difficulty of the task, a correct trial response was made by only 12 of 32 subjects. There were only 30 correct responses made out of a total of 256 trials, giving a correct response portion of 12%.

The 'time-locked' procedure may have increased the degree of difficulty of the task. Not only did the subject have to recall the digits in the given serial order, but they also had to recall them at the prescribed one-per-second rate.

Experiment 2 incorporated the use of shorter digit strings so that a moderate difficulty level would be achieved. Spitz (1972) reviewed the literature for immediate memory for digits and found that the average channel capacity for adults of average intelligence was six digits, plus or minus one; somewhat lower than that suggested by Miller (1956). It was then concluded that a seven digit string, the upper limit of the average, would reduce the difficulty level to a moderate level. It was expected that this change would clarify the relationship of intelligence and pupil size previously confounded by task difficulty in Experiment 1.

The significant difference in pupil size between groups during the pre-stimulus segment of Experiment 1 raised the question whether there was an initial difference prior to the instructions or as a result of the instructions. In order to clarify this problem, a pre-instructional baseline was obtained to assess the pupil response prior to instructions. An additional physiological measure, one of heart rate, was proposed to complement the A-state measure. Spielberger (1972) suggested that the measurement of A-state required concurrent assessment of both physiological activity and subjective feelings via self-reports. This method and concurrent measure during the instructional set would provide a validity check of the stress variable and provide a more critical appraisal of pupil and heart rate responses to stress.

With regards to physiological activity, Cattell and Scheier (1961) reported that heart rate (HR) ranked among the highest of the physiological variables loading their A-state factor. Martin (1961), in a review article, made a comparison of physiological measures associated with different emotional arousal states in four studies. Threat of shock was used for the fear or anxiety response, criticism for anger, and the cold pressor for pain. Despite the inconsistencies among studies, he noted that heart rate increased more for fear (anxiety) than for anger. The pain experience was clearly distinguished from fear, but the distinction between pain and anger was not as clear. Additional support for different heart rate responses between anxiety and anger was offered in a therapy setting. DiMascio, Boyd and Greenblatt (1957) measured physiological responses of one patient during the course of 11 psychotherapy sessions. A correlation (rho) of .69 was noted between heart rate and level of rated tension (anxiety), and -.37 between heart rate and rated antagonism in the interviews. These findings provided some evidence that heart rate response can indicate a differentiation between some of the arousal states.

The effect of anticipation of noxious stimuli has also been investigated. Studies by Deane (1961), Jenks and Deane (1963) and Deane (1964) have provided evidence that there are two opposing heart rate responses during experimentally induced anxiety. Subjects had been told to expect a noxious stimulus at a specific point in a sequence of visually presented numbers. Under these conditions the heart rate accelerated early in the sequence of numbers and decelerated just prior to and during the time the noxious stimulus was expected. It was also found that both responses appeared at about maximum amplitude on the first trial.

Deane (1966) found that instructions had an effect on heart rate deceleration. If the subject was told exactly when shock was to be received, the decelerative effect appeared immediately; if no warning was given, it took several trials before the decelerative response became apparent. Jenks and Deane (1963) used both shock and noise for noxious stimuli. They found that the shock-anticipation group showed greater acceleration than the tone-anticipation group. Deane (1964) did not find respiration to affect heart rate as was suggested by Westcott and Huttenlocker (1961). Similarly, Elliott (1975) did not find gross bodily movements to covary with heart rate. He did find that if shock was anticipated at all, heart rate and eyeblink activity were significantly higher than when it was not expected.

Bankart and Elliott (1974) found that intensity and number of shocks affected habituation rate. When the shocks were more severe, exposure to them interfered with habituation. One suggestion was that habituation may vary inversely with exposure to painful stimuli. Also noted was that the group who received the most shocks habituated more slowly than did the group receiving fewer shocks. One other interesting finding was that resting tonic levels of heart rate during the experiment were elevated about 8-10 bpm over normal resting levels taken prior to experiment exposure, a finding consistent with other reports in the literature (e.g., Elliott, 1970; Mansueto & Desiderato, 1971).

In other studies, Hodges (1968) examined the effects of ego-threat and threat of pain (shock) on state anxiety. He found that heart rate and AACL scorers increased from a rest period to the test period in which subjects performed a memory task. The size of the increase in AACL scores was significantly greater in the ego-threat condition than in the no-threat condition. The threat of shock produced greater increase in heart rate than in the no-threat condition. There was also a tendency, though not significant, for the mean score of the ego-threat group to be greater than that of the no-threat group. Increases in A-state measures from rest to test were evident in all conditions, but there were no differences between groups in the resting condition.

May and Johnson (1973) found that internally elicited thoughts produce physiological changes and the direction of the change was related to the affective nature of the cognitive event. The heart rate response appeared to be the most sensitive of the physiological responses. The heart rate means were highest for stressful words, lowest for relaxing words and midway for neutral words. Over trials, heart rate demonstrated a slight decrease in responding during the mid-trials of the experimental session, but at no time did the heart rate responding in the arousal (stressful words) condition return to the pre-stimulation level.

Baker, Sandman and Pepinsky (1975) had subjects discuss neutral and affect-arousing topics and measured heart rate during rehearsal, speech and post-speech periods. The multivariate analysis of heart rate data indicated the affect-arousing topic to have elicited significantly elevated heart rate responses as compared with the neutral topic. The directionality of this effect in heart rate was attributable to the difference in topic content and occurred only during the rehearsal period. It does appear then that internally elicited cues have an effect on heart rate response.

Autonomic responses to affective visual stimuli have also been noted. Hare (1973) selected subjects of varying degrees on self-reported fear of spiders. The cardiac responses to slides depicting spiders were acceleratory in fearful subjects and, in non-fearful subjects, their cardiac response consisted of a plateau followed by a deceleratory limb. Klorman, Wiesenfield and Austin (1975) presented neutral, incongruous and mutilation slides to those high or low in fear of mutilation. The results showed that the fearful subjects' cardiac responses to mutilation were acceleratory, their counterparts, deceleratory. Both groups showed decelerated heart rate on incongruous slides and accelerated heart rate on neutral slides.

While the literature has suggested that heart rate is influenced by various types of stressors, internally and externally cued, Lacey, Kagan, Lacey and Moss (1963) also suggested a relationship between heart response and cognitive activity. On tasks involving environmental "rejection" (wherein environmental 'input' is assumed to be disruptive, as in reversed spelling, in mental arithmetic, or during noxious stimulation), there is an increase in heart rate and in heart rate variability. On the other hand, during environmental "intake", as in simple visual attention or emphatic listening, most subjects produce cardiac deceleration and decreases in heart rate variability. An example of the latter would be in reaction time studies in which there is cardiac deceleration associated with the preparatory interval of a reaction time task. Incidently, increases in skin conductance were noted during the same period (Lacey & Lacey, 1970). This phenomenon is referred to as directional fractionation of physiological responses.

Kahneman, Tursky, Shapiro and Crider (1969) time-locked pupil response, skin conductance and heart rate to a digit-transformation task. All three measures showed a "sympathetic-like" increase in activity during the reception of the digits and during transformation, followed by a decrease in activity during report. The peak response for each measure was ordered as a function of task difficulty.

Tursky, Schwartz and Crider (1970) found heart rate decelerating during the intake phase of a digit-transformation task and heart rate acceleration during cognitive processing; skin resistance changes followed a pattern similar to that of the Kahneman et al. (1969). Heart rate did not follow this pattern, but differed during the Input phase. The authors explained this apparent contradiction by indicating that in the Kahneman et al. study the transformation instructions preceded the digit series, raising the possibility that the overall heart rate acceleration was due to the subject's on-line transformation of the information. In the Tursky et al. study, the instructions were not given until after the digit presentation. This would indicate that heart rate differences can occur within the same kind of problem solving task if instructions are differently ordered.

Some authors (e.g., Campos & Johnson, 1967) have attempted to explain the Lacey intake-rejection mental activity dichotomy in terms of task demand for verbalization. Adamowicz and Gibson (1970, 1972) have reported that heart rate change appears to be associated with the interaction of task attention demand level and verbalization requirements, something not considered in the Campos and Johnson (1967) experiment. What appeared to be important in studies using heart rate was that the demand characteristics of the task for the various groups need be considered in research also involving cognitive tasks. In this study the time-locked aspect was employed and level of task difficulty controlled.

While the primary concern of this experiment was to investigate the relationship of pupil size and anxiety during a cognitive task, its relationship to the individual difference variables of intelligence and correctness of response was also considered. The addition of the heart rate measure was an attempt to increase the sensitivity to detect the momentary or state anxiety variable during the instructional period. This would assist in clarifying the relationship between mental effort and anxiety in pupillary responding.

In the course of this experiment, the following predictions were considered. It was expected that the High Stress instructions would produce increased manifestations of A-state reaction. For the Instruction period, one expected increased heart rate under High Stress instructions as compared to Low Stress instructions. During input, there would be increased pupil size under HS conditions. The High A-trait group with HS instructions would demonstrate larger pupil size than High A-trait with LS instructions. The Low A-trait groups would not differ as a function of instructions. Differences in pupil size between High and Low scorers on the intelligence measure were also expected. These differences would be evidenced during the input period and the Low scorers would demonstrate larger pupil size than high scorers because they would find the task more difficult and would expend more effort at it. High scorers were expected to respond correctly to more items than the low intelligence group. Finally, correct-incorrect trial comparisons of pupil response during input were made and differences expected, but there was no prediction regarding direction of the projected differences.

Experimental Method

Subjects. One hundred and twenty male subjects were selected from a larger pool of introductory male psychology students who had completed the Test Anxiety Scale (TAS) as part of a larger battery. Sixty subjects were chosen from the upper half and the remaining 60 were selected from the lower half of the TAS score distribution. All were volunteers participating as part of course requirements and all had been screened for visual defects.

Apparatus. As in Experiment 1, the apparatus for recording pupil responses was the Whittaker Space Sciences Eyeview Monitor and Television Pupillometer System. The pupil of the left eye was continuously monitored and the data output was stored on magnetic tape for later data analysis.

The additional apparatus employed was a Whittaker Space Sciences Pulse Watch device for the measurement of heart rate (HR). HR was based on the time interval between beats on a second by second basis. A connector was attached to the index finger of the right hand for continuous monitoring and the data output stored simultaneously on magnetic tape with pupil response output.

Stimulus materials. Eight sets of digit strings were prepared, each set consisted of eight strings with seven digits per string. Each string included numbers from one to nine with no number repeated (see Appendix A).

The sets were randomly assigned to each of the 120 subjects, one set per subject.

Other measures. As in Experiment 1, the Wechsler Adult Intelligence Scale Digit Span (Forward) subscale and the Self-Evaluation Questionnaire were used.

An additional measure of A-trait used in this study was the Test Anxiety Scale (TAS, Sarason, 1957, 1972). It had been administered to all subjects in a previous experimental setting. This is an A-trait measure which specifically identifies people who experience anxiety in test-like or examination situations.

Design and procedure. The same procedure as that used in Experiment 1 was followed, except that subjects were assigned to one of four groups on the basis of their A-trait scores. Each subject was tested individually. Once the WAIS-Digit Span had been given and before giving them the stress instructions, each subject's eye was focused in the pupillometer and the finger pulser attached to the index finger of the right hand. Baseline measures of his pupil response and heart rate were obtained.

The instructions, as well as the digit strings, were pre-taped for audio presentation. The instructions for the Low Stress condition were the same as in Experiment 1, except the practice digit string was increased and was the same as the one used in the High Stress instructions. The High Stress condition instructions were made stronger to increase the ego-threat factor (see Appendix B). The pupil and heart response were monitored during the instruction period. The remaining procedure on the apparatus was the same as in Experiment 1. In addition, the HR was obtained. All subjects were de-briefed upon completion of experiment.

In summary, each trial of the Digit Span Period followed the same time-locked sequence and was divided as follows: there was a three second Ready segment followed by the Input segment of seven seconds; a one second Repeat pause was next, followed by the Output segment of seven seconds; finally, a one second instruction to Stop was given followed by a six second Rest.

For the purpose of analysis, each of the four pre-selected groups was again divided in half, a median split on the basis of Digit Span Forward scores. The data was then subjected to the appropriate statistical procedures. The analysis involved was a repeated measures design ANOVA on the last two factors, a 2 x 2 x 2 x 6 x 7 (A-trait x Stress x Intelligence x Trials x Seconds), for the Input and Output segments for pupil and heart rate scores. Appropriate modifications were made for the pre- and post-stimulus segments. During Instructions, a correlation was obtained between heart rate and pupil size. Finally, a separate ANOVA for correct-incorrect responses was made for pupil size and heart rate.

Results of Experiment 2

State and trait anxiety data. An initial ANOVA on the A-state self-report measure prior to the experimental manipulations showed a significant main effect on A-trait ($\underline{F}(1,112) = 9.30$, $\underline{p} < .01$)(see Table 7, App.C). The High Test Anxious (High A-trait) subject had a mean A-state score of 40.07, while their counterparts had a mean score of 36.15.

Upon completion of the experimental session, a second A-state measure was obtained to ascertain the subject's feeling state during the experiment. An analysis of covariance (A-trait x Stress x Intelligence) using the pre-A-state scores as covariate, showed a significant main effect on the Stress instructions ($\underline{F}(1,111) = 4.41$, $\underline{p} < .05$)(see Table 8). The mean A-state scores for the Test Anxiety/Stress groups are presented in Figure 4. All groups showed an increase in A-state anxiety during the experimental session over the pre-experimental period.

Pupil size and heart rate data. The following will include the major pupil response and heart rate data analyses under the appropriate heading to their progression during the experiment. The task for each subject was divided into three periods: Baseline, Instructions, and Digit Span. The Digit Span period was further divided into six segments: Ready, Input, Repeat, Output, Stop, and Rest.

Baseline period: an ANOVA of pupil size and heart rate on the last 10 seconds of the 30 second baseline period yielded no significant main effects or interactions (see Table 9).

Instructional period: the data scores used for the analyses during this period are based on the mean score for each successive

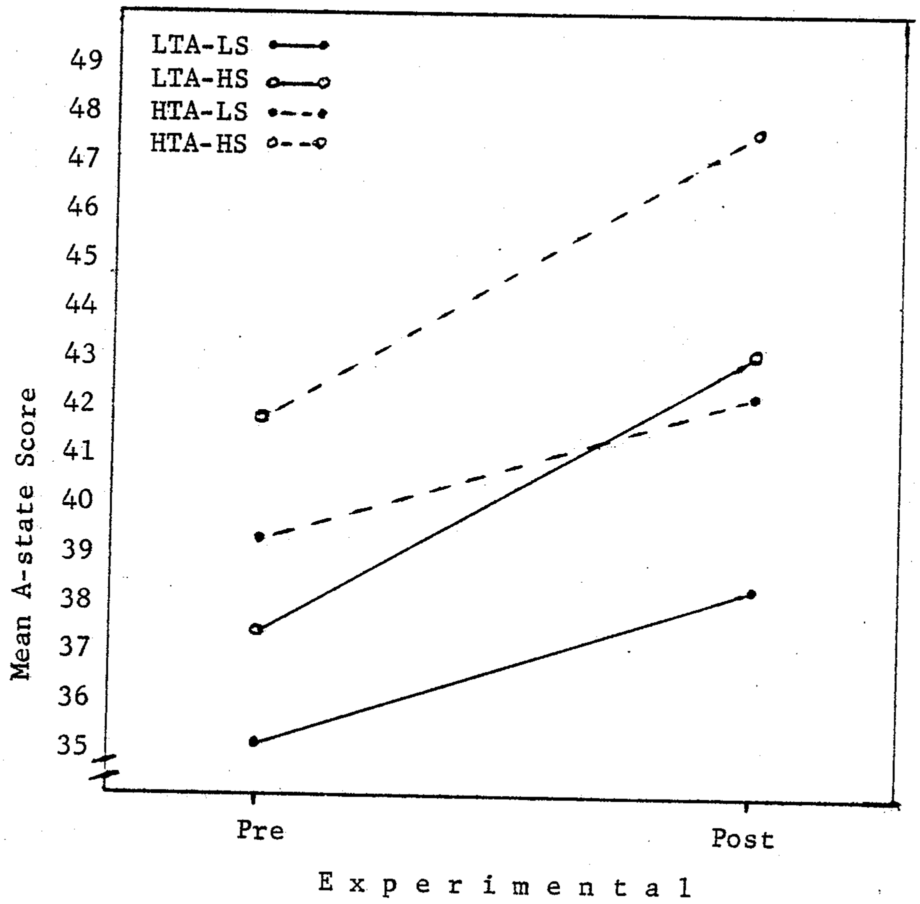

Figure 4. Mean A-state score of Test Anxiety-Stress groups for the pre- and post-experimental period of Experiment 2.

5-second Epoch from the beginning until the end. Because the High Stress instructions were 20 seconds longer in duration than the Low Stress instructions, the ANOVAs are based on the last 21 Epochs for each data set.

A four factor ANOVA, repeated on the last factor, was conducted on the pupil data (Source,Table 10). Only the repeated factor (Epochs) was significant ($\underline{F}(20,2240) = 12.04$, $\underline{p} < .01$). The general trend for this effect can be seen in Figure 5 in which both the High and Low Stress groups showed pupil size decreases over time until the 'Practice Sequence'. During the 'Practice Sequence" there was a sharp increase in pupil size, followed by a reversion to the progressive decrease in size.

A similar ANOVA was conducted on the heart rate data (see Table 10). A significant Epoch main effect ($\underline{F}(20,2240) = 16.62$, $\underline{p} < .01$) and a Stress x Epoch interaction ($\underline{F}(22,2240) = 4.24$, $\underline{p} < .05$) were observed. The Stress x Epoch interaction is shown in Figure 6. A test of simple effects showed significant differences between Stress groups on the last six Epochs (see Table 11). Heart rate gradually increased over the instructional period reaching a peak shortly after the 'Practice Sequence' and decreased thereafter. The heart rate increase for the HS group tended to be greater than for the LS group during the procedure and maintained this relationship for the remainder of the Instruction period. A test of simple effects indicated a significant difference between the HS and LS groups after the 'Practice Sequence' (see Table 11).

A correlation between the mean heart rate and mean pupil size at each of the Epochs was not significant ($\underline{r}(20) = .13$, $\underline{p} > .05$) for the Low Stress group, and significant ($\underline{r}(24) = -.55$, $\underline{p} < .01$) for the High Stress group.

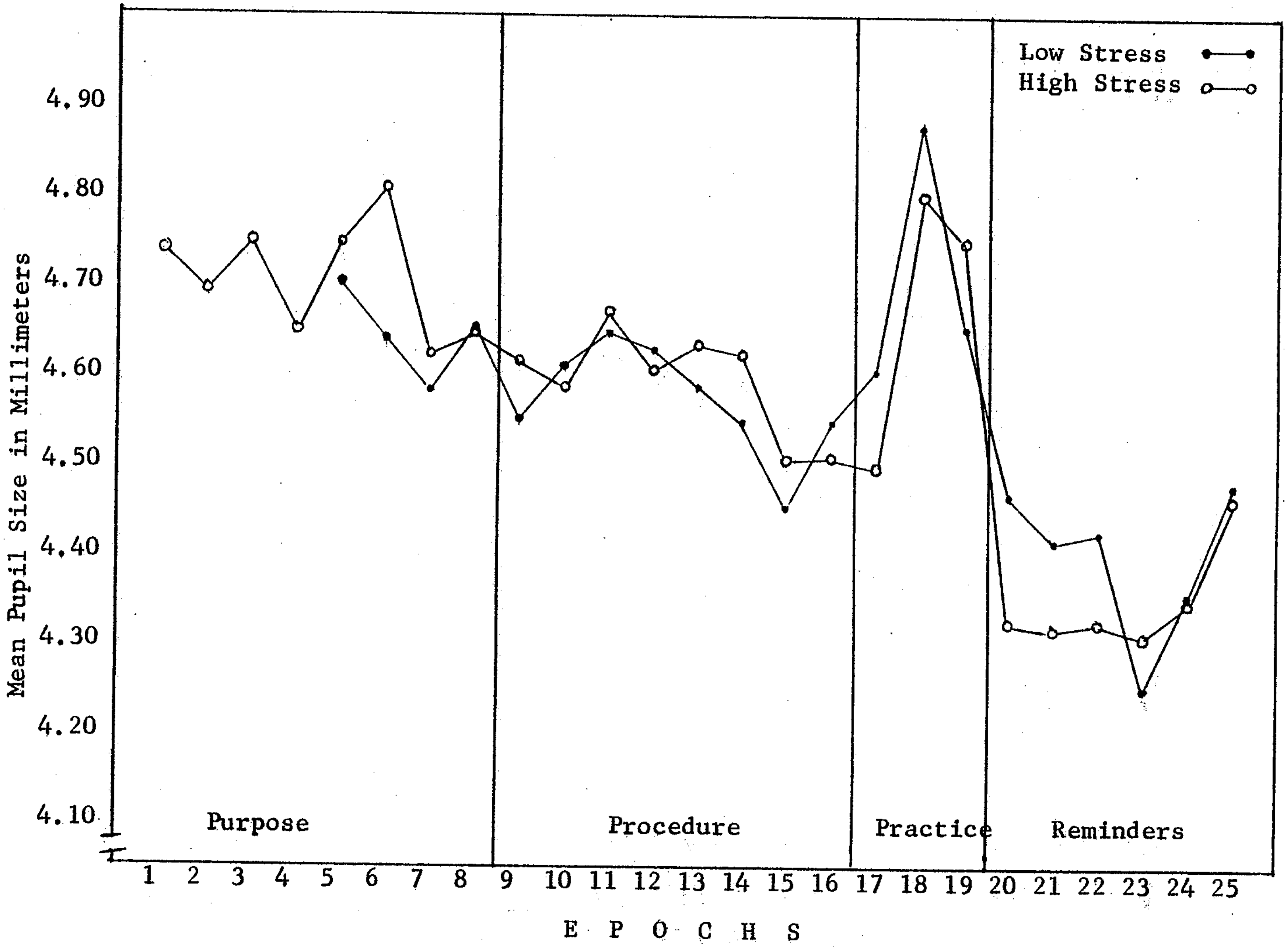

Figure 5. The mean pupil size of High and Low Stress groups over Epochs (1 Epoch - 5 sec) during Instruction period.

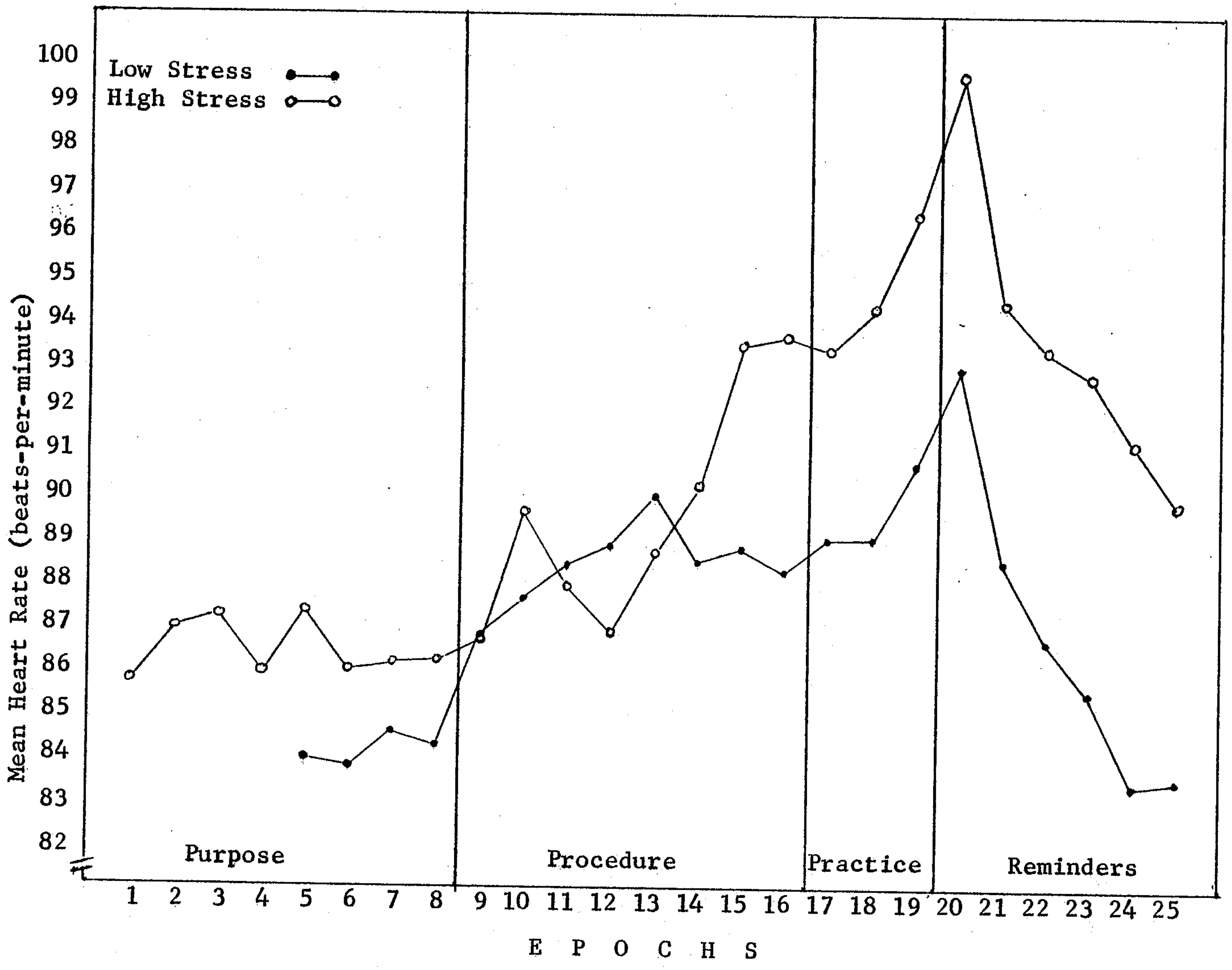

Figure 6. The mean heart rate of High and Low Stress groups over Epochs (1 Epoch - 5 sec) during Instruction period.

Digit span period: the pupil size and heart rate data for the Digit Span period of the High and Low Stress groups are presented in Figures 7 and 8. These graphs will be referred to later as they relate to the respective segments of the Digit Span period.

1. The Ready segment was the three second period during the Digit Span period preceding the presentation of a digit string. A five factor ANOVA, repeated on the last two factors, was conducted on the pupil size data (see Table 12). Significant main effects for Trials ($F(5,560) = 13.40$, $p < .01$) and Seconds ($F(2,224) = 9.65$, $p < .01$) were found and a significant Test Anxiety x Intelligence interaction ($F(1,112) = 4.415$, $p < .05$) was also noted. Pupil size gradually increased during each Trial, but showed an habituation effect over Trials. The Test Anxiety x Intelligence interaction (see Figure 9) indicated that the High Intelligence group had larger pupil size than the Low Intelligence group only when both were high in A-trait.

Table 12 presents the ANOVA for the heart rate data during the ready segment. A significant Stress main effect ($F(1,112) = 5,15$, $p< .05$) was found, indicating that the High Stress group had a greater heart rate than the Low Stress group. The heart rate for both groups tended to increase over Seconds as indicated by a Seconds main effect ($F(2,224) = 17.03$, $p < .01$)(see the Ready segment in Figure 8). The Intelligence x Seconds interaction also reached significance ($F(2,224) = 5.41$, $p < .01$) (see Figure 10). The heart rate of the High Intelligence group was initially lower than that of the Low Intelligence subjects and both groups had almost identical rates by the end of the Ready segment. A

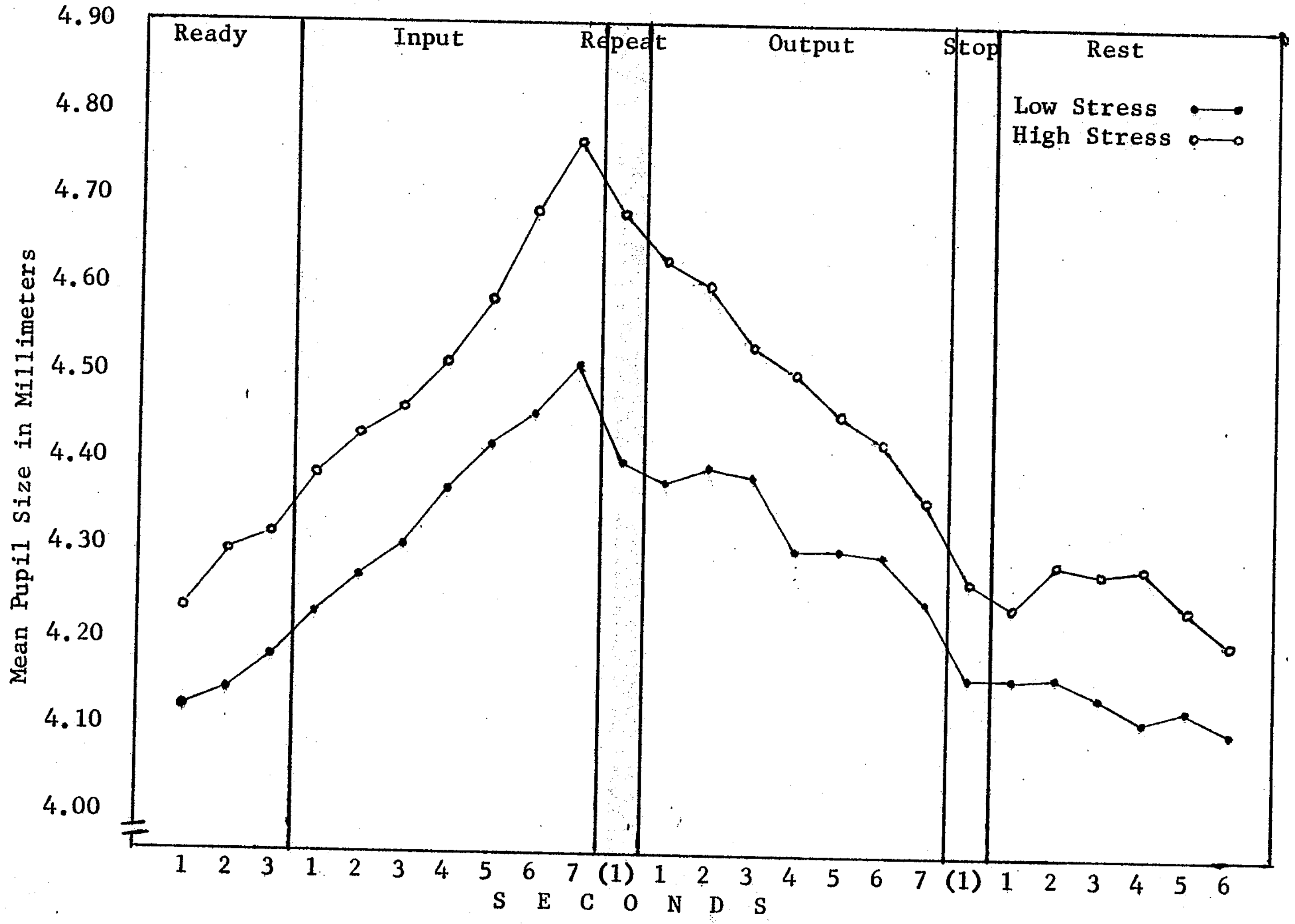

Figure 7. The pupil size of High and Low Stress groups during the Digit Span period.

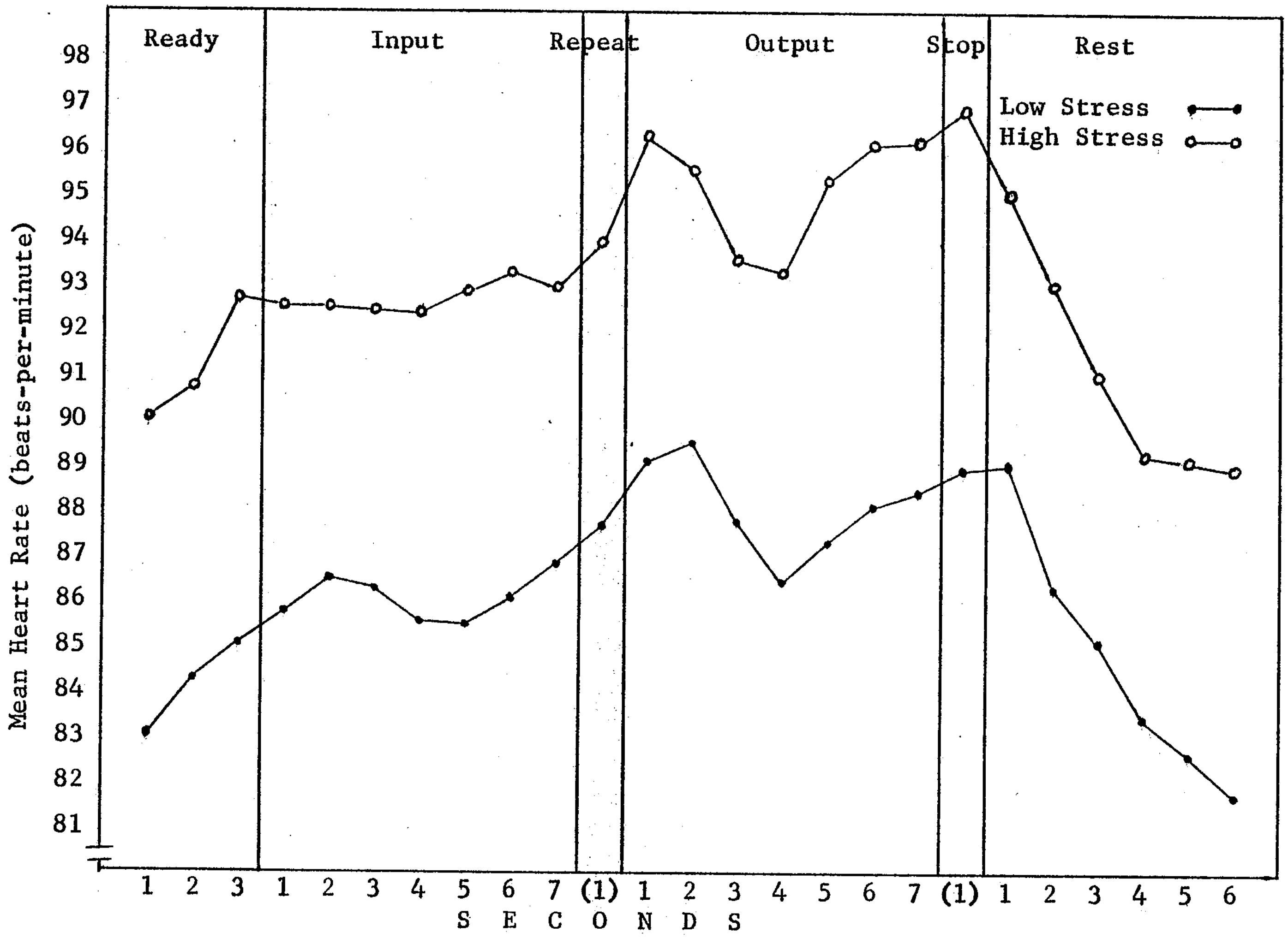

Figure 8. The mean heart rate of High and Low Stress groups during the Digit Span period.

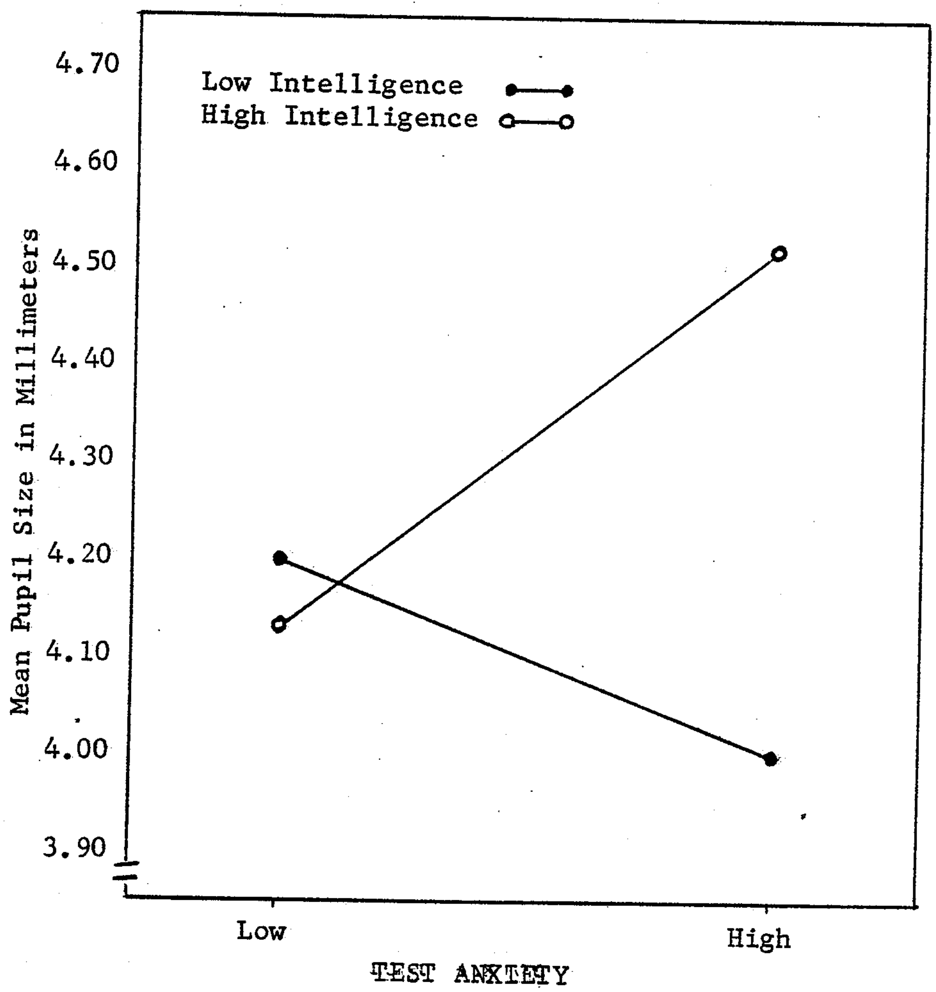

Figure 9. The mean pupil size of the High and Low Intelligence groups under High and Low Test Anxiety during the Ready segment of the Digit Span period.

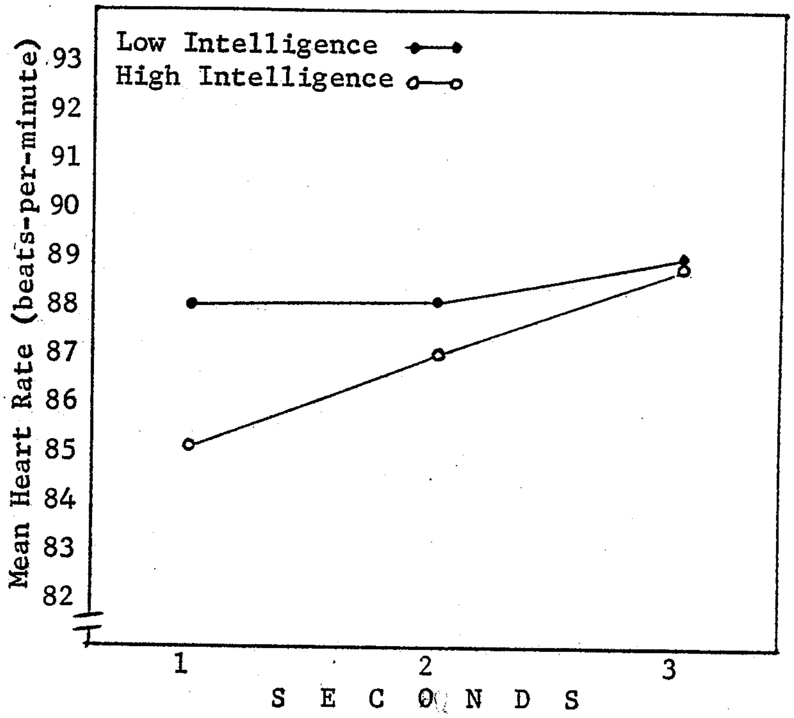

Figure 10. The mean heart rate of High and Low Intelligence groups for the three second Ready segment of the Digit Span period.

test of simple effects failed to produce significant differences at any of the one second intervals (see Table 13).

2. The Input segment was a seven second period immediately following the Ready segment. During this time a string of seven digits at the rate of one-per-second rate was presented.

The summary table of the ANOVA on pupil size is presented in Table 14. The Seconds main effect was significant ($F(6,672) = 91.96$, $p < .01$) and a trend analysis (Table 15) showed a linear ($F(1,112) = 175.86$, $p < .001$) and quadratic ($F(1,112) = 5.62$, $p < .05$) trend with an increasing pupil size over seconds. A trials main effect was also significant ($F(5,560) = 24.12$, $p < .01$) as was the linear trend analysis (Table 16) for Trials ($F(1,112) = 35.72$, $p < .001$) which showed a decreasing slope. A significant Test Anxiety x Intelligence interaction ($F(1,112) = 4.72$, $p < .05$) was also shown. A simple effects analysis of this interaction confirmed that, as with pupil size during the Ready period, the pupil size of the High Intelligence group was larger than that for the Low Intelligence group ($F(1,112) = 4.43$, $p < .05$), only for the High Test Anxiety groups (see Table 17). A significant Stress x Seconds interaction ($F(6,672) = 3.02$, $p < .01$) was also noted in which the slope of the High Stress group was steeper (see Table 15) than that of the Low Stress group, both groups showing an increase in pupil size during the Input segment.

The ANOVA for heart data is presented in Table 14. Only the Stress main effect ($F(1,112) = 4.32$, $p < .05$) was significant, the High Stress group having higher heart rate than the Low Stress group.

3. The Repeat segment was next. After the presentation of the digit string, a one second pause was given with the word 'Repeat'

alerting the subjects to begin recalling the digits. The ANOVA for the pupil size data is presented in Table 18. Stress main effect was significant (F(1,112) = 3.94, $p < .05$) and is represented graphically in Figure 7. Test Anxiety x Intelligence interaction was also significant (F(1,112) = 5.38, $p < .05$) and followed the same pattern as previously seen during the Ready and Input segments (also see Table 19 for simple effects). Trials (F(5,560 = 17.51, $p < .01$) was also significant, indicating a pupil size decrease over trials. An Intelligence x Trials interaction (F(5,560) = 2.27, $p < .05$) was significant and is presented in Figure 11. High Intelligence subjects tended to habituate at a slower rate over trials than did the Low Intelligence subjects, but only on Trial 5 were the two groups significantly different (see Table 20).

The ANOVA for the heart rate data during the Repeat segment is presented in Table 18. Only the Test Anxiety x Trials interaction was significant (F(5,560) = 2.746, $p < .05$) with the Low Test Anxiety group showing a slightly higher heart rate than the High Test Anxiety group. The relationship between groups was not significant in a post hoc test of simple effects (see Table 21).

4. The Output segment was the seven second period during which the subjects verbalized the digit string at the same rate as it was presented to them. The ANOVA summary for the pupil size data is presented in Table 22. The main effect for Seconds (F(16,672) = 21.13, $p < .01$) was significant, demonstrating a decreasing linear trend (F(16,672) = 40.51, $p < .001$)(see Table 23). A Stress x Seconds interaction was also significant (F(6,672) = 2.182, $p < .05$) with a linear

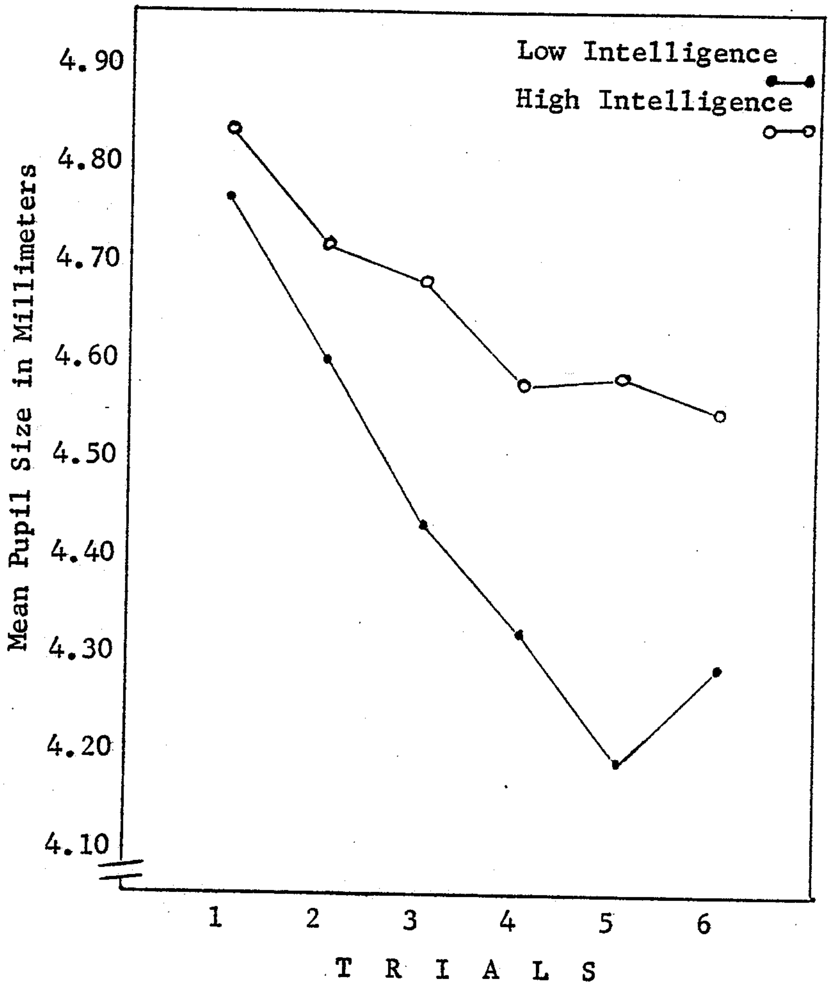

Figure 11. The mean pupil size of High and Low Intelligence groups for six trials of the Repeat segment of the Digit Span period.

interaction (F(1,112) = 3.816, $p < .053$). The pupil size of the HS group was larger than that of the LS group at the Repeat segment and decreased at a correspondingly faster rate during the Output segment. A test of simple effects indicated that the HS and LS groups were not significantly different, but the slopes were different (see Table 24). Trials (F(5,560) = 16.126, $p < .01$) was significant as well, indicating a decreasing linear (F(1,112) = 16.992, $p < .001$) and quadratic (F(1,112) = 23.699, $p < .001$) trend (see Table 25).

Table 22 presents the results of the ANOVA for the heart rate during the Output segment. The Stress main effect was significant (F(1,112) = 4.612, $p < .05$), the High Stress group having greater heart rate than the Low Stress group (refer to Figure 8). The Seconds (F(6,672) = 9.037, $p < .01$) main effect showed a significant quadratic trend (F(1,112) = 13.403, $p < .001$) as presented in Table 26. The HR showed an initial decrease from the start to the mid-point of the Output segment, after which it began to increase through the second half of the segment. The Stress x Seconds cubic interaction (F(1,112) = 5.687, $p < .05$) showed slight differences in the High and Low Stress groups' response rates. The HR of the LS group continued to rise for one second into the Output segment before demonstrating a decrease. This contrasted to the HR pattern of the HS group which showed no delay in decrease response (see Figure 8).

5. The Stop segment was a one second period following the recalling of digits to inform subjects by the word "Stop" to cease recalling numbers and relax in preparation for the next trial. Table 27

presents the ANOVA summary table for pupil size response during this one second period. Trials was significant (F(1,112) = 4.11, $\underline{p} < .05$) with pupil response decreasing in size over the course of the digit-string presentation. The Test Anxiety-Intelligence interaction was also significant and the simple effects test (see Table 28) showed that High Intelligence - High Test Anxiety group differed from the remainder of the groups.

The summary table of the ANOVA for heart rate is presented in Table 27. The main effect for Stress ($\underline{F}(1,112) = 5.95$, $\underline{p} < .05$) was significant, with the High Stress group having larger pupil size than Low Stress group (see Figure 8). A Stress x Trials interaction ($\underline{F}(5,560) = 2.88$, $\underline{p} < .05$) indicated that HS and LS groups did not differ significantly on the first trial but did so for the remainder of the trials (see also Table 29). A Test Anxiety x Intelligence interaction ($\underline{F}(1,112) = 4.71$, $\underline{p} < .05$) was also present and a test of simple effects showed that the HR of the Low Test Anxiety - Low Intelligence group was higher than that of the other groups (see Table 30).

6. The Rest segment was a six second period after Stop to allow subjects a brief period of relaxation before the next digit presentation. An ANOVA summary of the analysis for pupil size data is provided in Table 31. There was a Test Anxiety x Intelligence interaction ($\underline{F}(1,112) = 4.33$, $\underline{p} < .05$). The relationship between Test Anxiety and Intelligence follows a pattern similar to the previous segments. A main effect for Trials ($\underline{F}(5,560) = 11.04$, $\underline{p} < .01$) was present and follows a general decreasing function over time, with a linear ($\underline{F}(1,112)$

= 4.89, $p < .05$) and quadratic ($F(1,112) = 17.50$, $p < .001$) trend over trials (see Table 32). The Seconds ($F(5,560) = 2.43$, $p < .05$) effect was also significant and a quadratic trend ($F(1,112) = 5.74$, $p < .05$) was noted in which there was a slight increase during the first two seconds followed by a decrease to end of the Rest segment (see Table 33). The Test Anxiety x Seconds interaction ($F(5,560) = 2.972$, $p < .05$) is presented in Figure 12 and this relationship was not only linear ($F(1,112) = 5.021$, $p < .05$), but also cubic ($F(1,112) = 4.539$, $p < .05$) in direction.

Table 31 presents the ANOVA summary table of the heart rate during the Rest segment. The Stress main effect ($F(1,112) = 4.91$, $p < .05$) indicated a faster HR for the HS group than for the LS group. The Seconds main effect ($F(5,560) = 35.55$, $p < .01$) was also significant and there were decreasing linear ($F(1,112) = 73.16$, $p < .001$) and quadratic ($F(1,112) = 9.22$, $p < .01$) trends (see Table 34). After the command "Stop" was given, the HR decreased rapidly over a four second period before leveling off. An Intelligence x Seconds interaction ($F(5,560) = 2.94$, $p < .05$) indicated a linear ($F(1,112) = 6.19$, $p < .05$) relationship with the High Intelligence groups' pupil size decreasing at a greater rate across the six second period than did the Low Intelligence group (see Figure 13). Trials ($F(5,560) = 2.84$, $p < .05$) was significant, not as a decreasing function but as a variability from trial to trial. The trend analysis (see Table 26) indicated a cubic ($F(1,112) = 4.48$, $p < .05$) relationship. A Test Anxiety x Stress x Trials interaction ($F(5,560) = 2.43$, $p < .05$) was found to have quadratic ($F(1,112) = 4.51$, $p < .05$) relationship (see Figure 14). Although some relationship between the

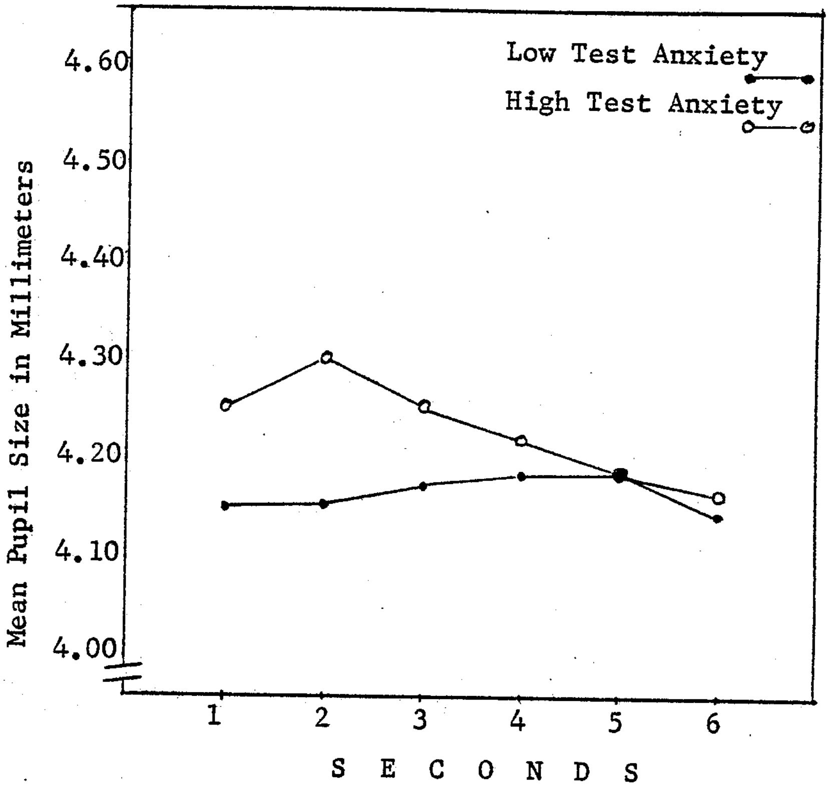

Figure 12. The mean pupil size of High and Low Test Anxiety groups for the six second Rest segment of the Digit Span period.

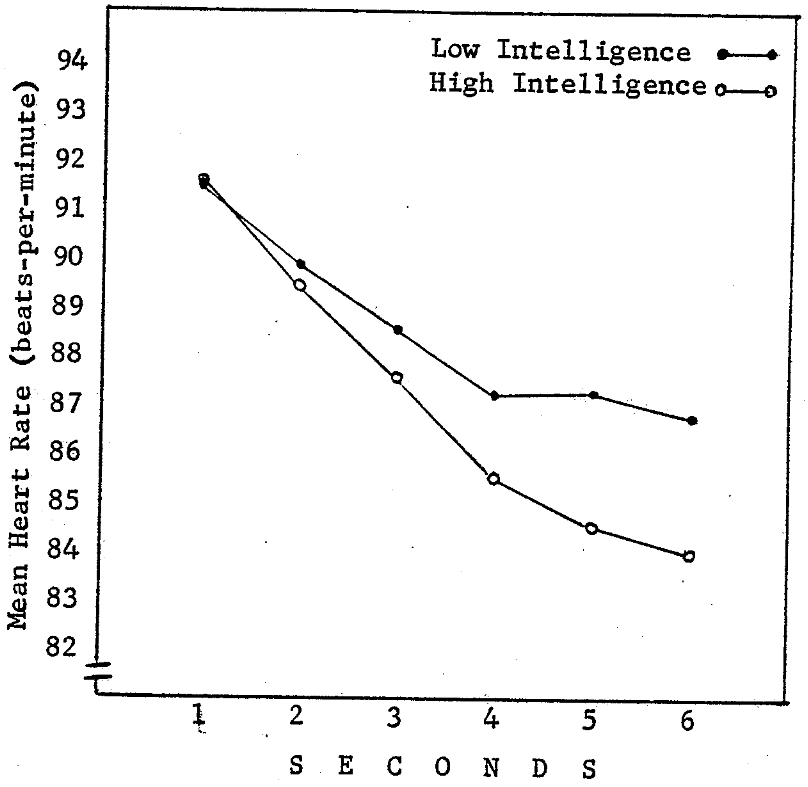

Figure 13. The mean heart rate of High and Low Intelligence groups for six second Rest segment of the Digit Span period.

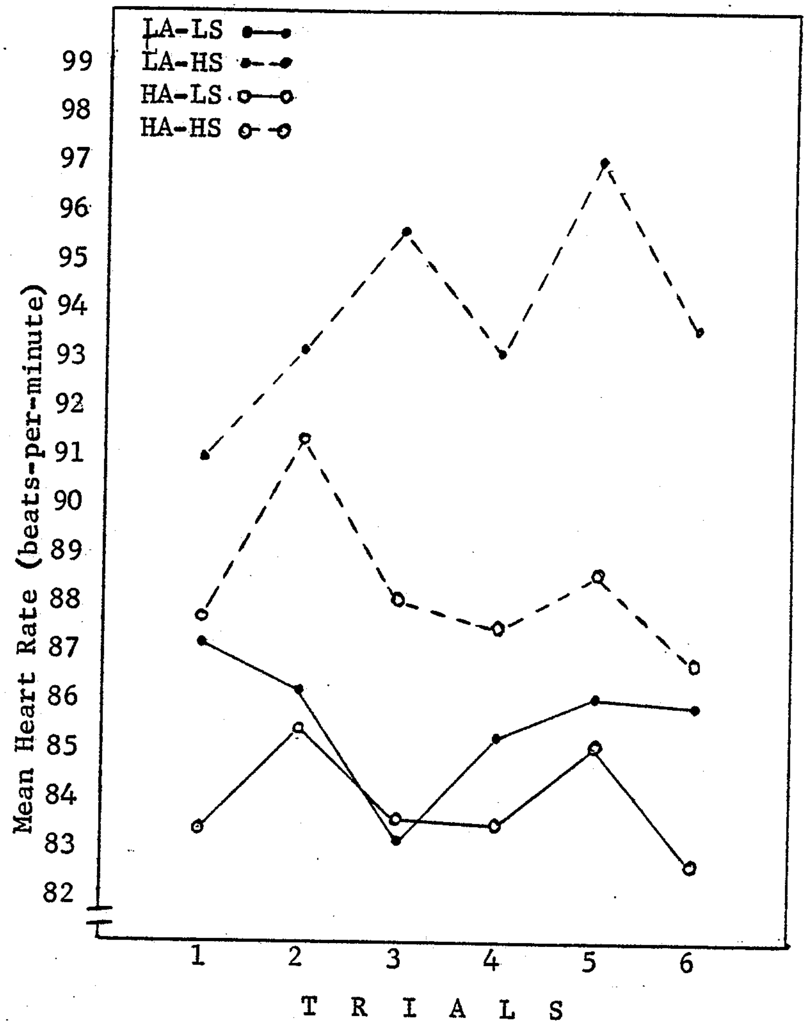

Figure 14. The mean heart rate of High and Low Test Anxiety groups under High and Low Stress instructions for six trials of the Rest segment of the Digit Span period.

groups was apparent, there was sufficient variability in the graph pattern for each group over trials to establish a quadratic interaction. The order of the groups, based on heart rate, appeared to be determined by the Stress condition. The Low Test Anxiety - High Stress group had the highest rate, followed by the High Test Anxiety - High Stress group, with the other two groups having the slowest rate.

Performance data. This section deals with the digit performance scores and the pupil size and heart rate data comparing differences on correct and incorrect trials.

An ANOVA was carried out on the number of digits correctly recalled during the six experimental trials and these results are presented on Table 36. Only the Intelligence factor reached significance ($F(1,112) = 28.09$, $p < .001$). The total number of digit strings correctly and incorrectly recalled are presented on Table 37. The High Intelligence group recalled 48% of the digit strings correctly, while only 23% of the digits were credited to the Low Intelligence group. Because Intelligence was the only significant variable in the digit recall, this factor was included in the analyses comparing pupil size and heart rate responses to correct and incorrect trials.

A three factor ANOVA, repeated on the last factor, was conducted for each of the segments - Ready, Input, Output and Rest - for both pupil size and heart rate data. The ANOVAs for the preceding periods are shown on Tables 38, 39, 40 and 41. The Correct-Incorrect Trials (CIT) comparison was significant during all segments beyond the .01 level (see Figure 15). Intelligence was also significant in each period,

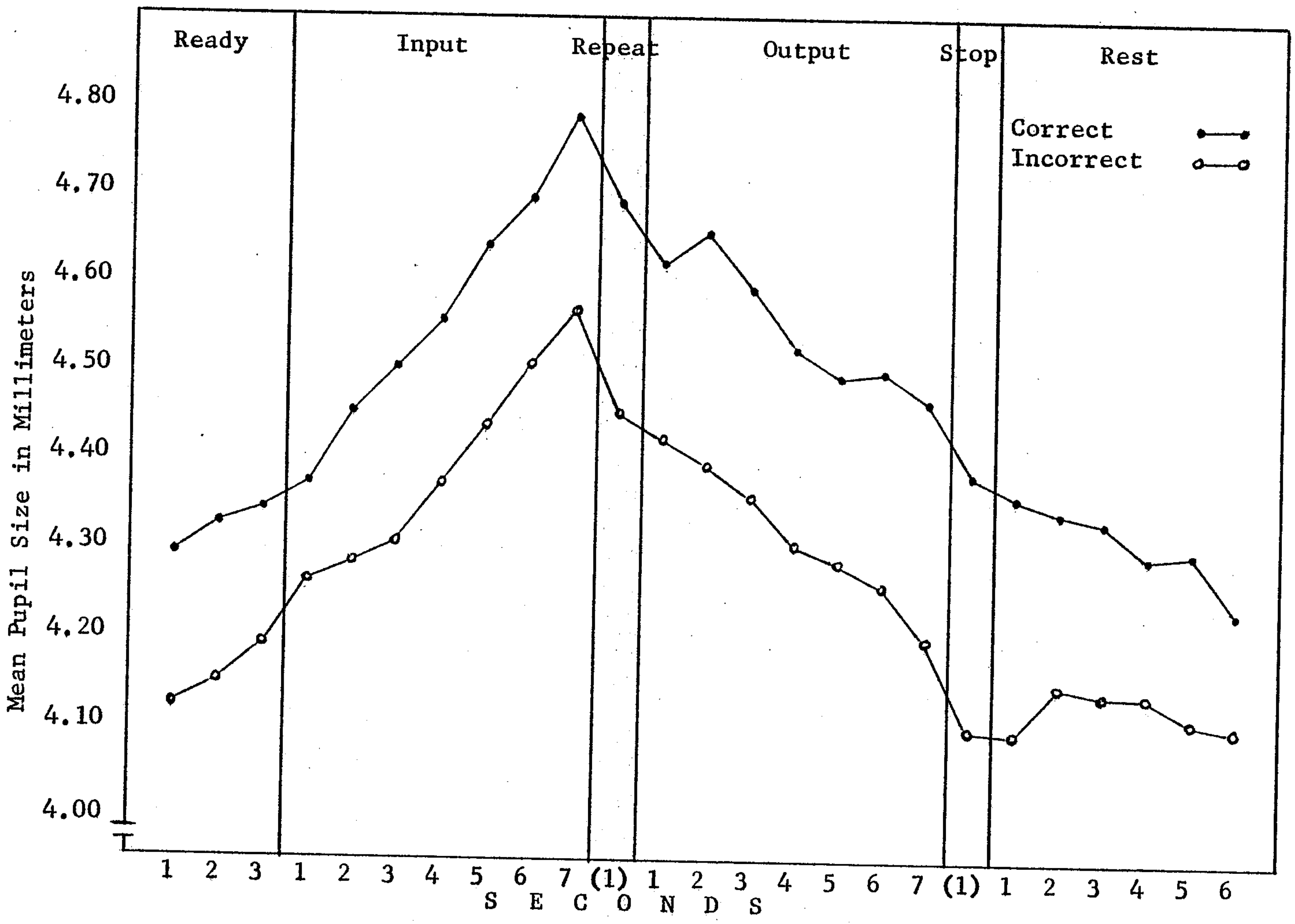

Figure 15. The pupil size of Correct and Incorrect trials during the Digit Span period.

except Output, beyond the .01 level. Pupil size was larger for the High Intelligence group than for the Low Intelligence group. An Intelligence x CIT x Seconds interaction was found during the Ready segment ($\underline{F}(2,1432) = 4.59$, $\underline{p} < .01$) and Input segment ($\underline{F}(6,4296) = 4.25$, $\underline{p} < .01$) (see Figures 16 & 17). It is seen that during the Ready and Input segments the High Intelligence - Correct group had the largest pupil size the Low Intelligence - Incorrect group had the smallest pupil size, and the two remaining groups were in between these. The CIT x Seconds interaction ($\underline{F}(6,4296) = 2.46$, $\underline{p} < .05$) was significant during the Input segment and can be viewed on Figure 15. Pupil size was larger when the subject completed a correct trial than when the subject completed an incorrect trial while following the characteristic pupil size increase during Input segment (see Table 42 for Simple Effects). Finally, the Seconds effect was significant in all analyses, showing a similar pattern to the Seconds data discussed in the previous section.

The summary table for the ANOVA of heart rate data on Correct and Incorrect differences during the Ready, Input, Output, and Rest segments can be found on Tables 38, 39, 40 and 41 respectively. During the Ready segment, Seconds was significant as well as the Intelligence x Seconds interaction; however this data has already been discussed under the appropriate headings in the previous section. Finally, there was a CIT x Seconds interaction ($\underline{F}(5,3580) = 4.75$, $\underline{p} < .01$) in which heart rate on Correct trials was higher than on Incorrect trials in the initial phases of the Rest segment, but decreased at a faster rate than on Incorrect trials, becoming lower at three seconds into the Rest segment (see Figure 18).

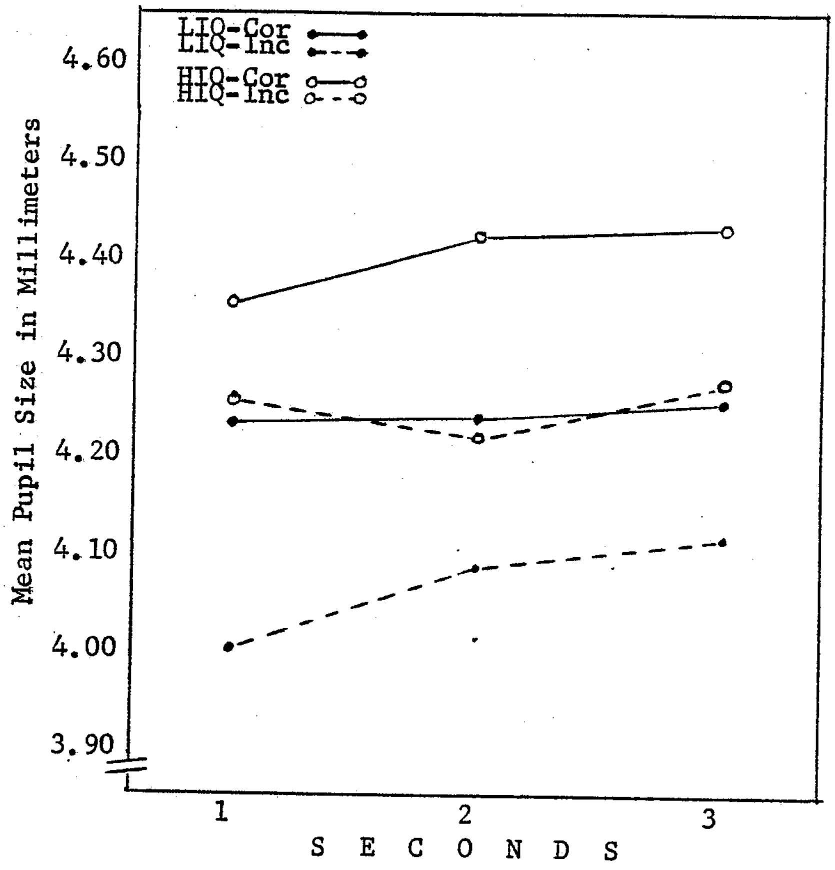

Figure 16. The mean pupil size of High and Low Intelligence groups on correct and incorrect trials during the three second Ready segment of the Digit Span period.

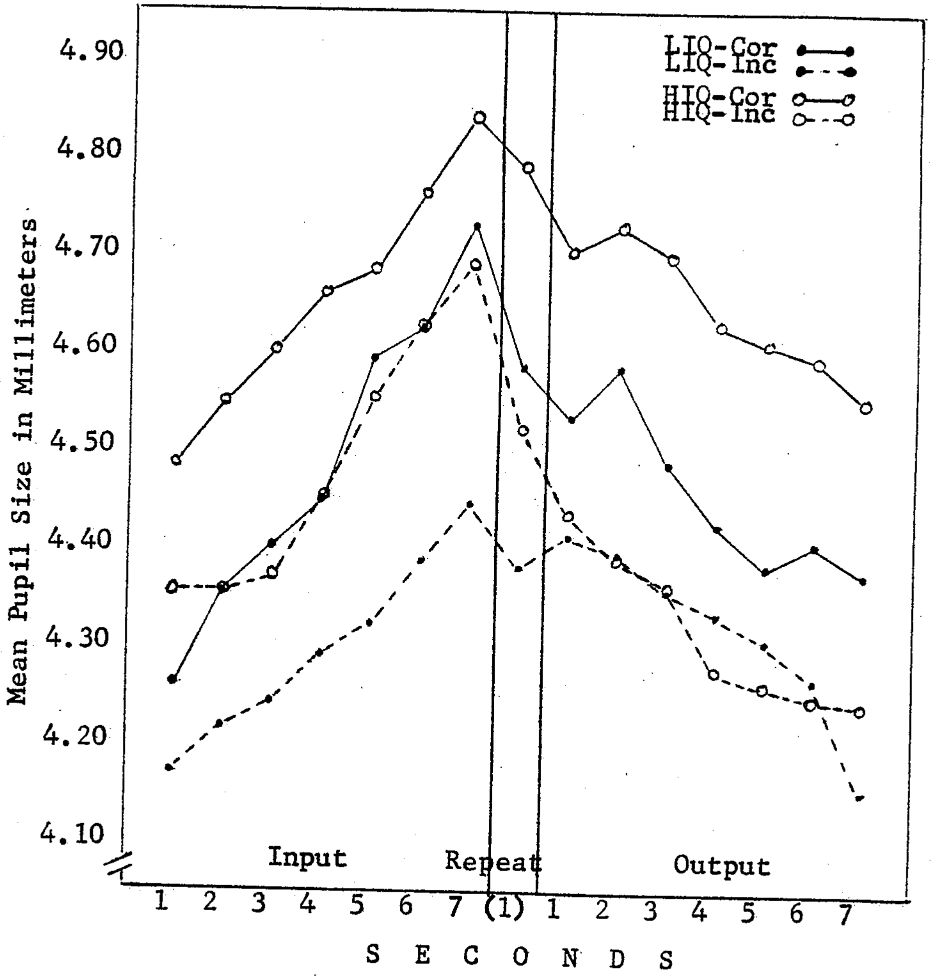

Figure 17. The mean pupil size of High and Low Intelligence groups on correct and incorrect trials during the Input and Output segments of the Digit Span period.

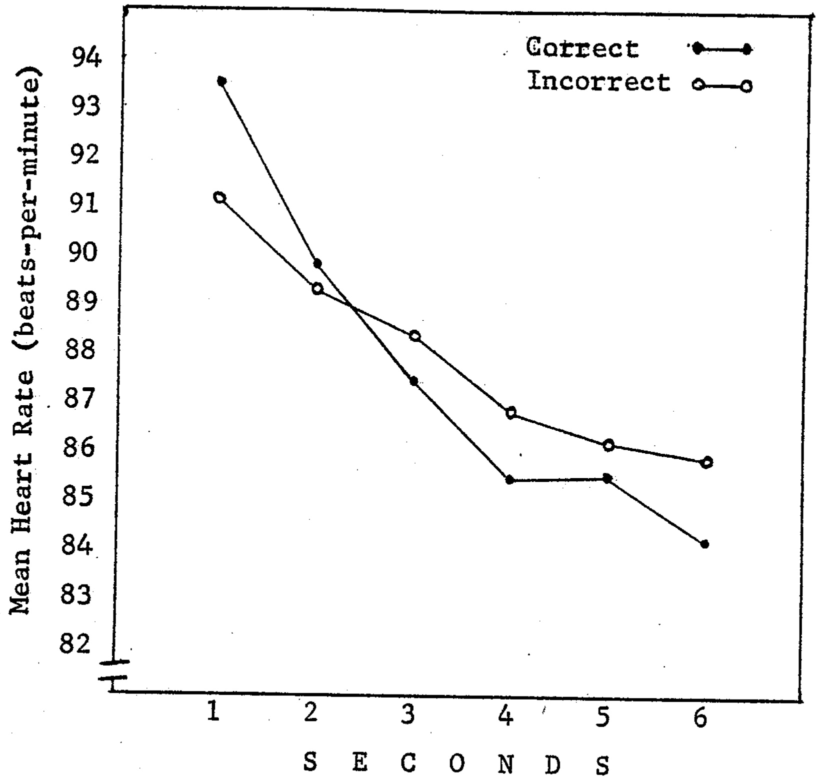

Figure 18. The mean heart rate of Correct and Incorrect trials for the six second Rest segment of the Digit Span period.

Discussion of Experiment 2

Overview. The main purpose of this experiment was to study pupil size and its relationship to anxiety, the individual difference variable of intelligence and correctness of response during a cognitive task. Concurrent measures of state or momentary anxiety were obtained by self-report and by psychophysiological means (heart rate). The secondary purpose was to see whether pupil size most adequately reflected the cognitive variable and whether heart rate most adequately reflected the emotional aspect.

Validation of State anxiety and intelligence. The differential effect of High and Low Stress instructions was verified by the validity measures used to gauge the presence of anxiety. It appeared that anxiety was consistently higher under High Stress instructions than Low Stress instructions. The self-report paper and pencil A-state measure (STAI, Spielberger et al., 1970) significantly differentiated the High and Low Stress instruction groups. The physiological measure of heart rate also was higher for the High Stress group than for the Low Stress group; however this was not the case with pupil size differences.

Also validated was the intelligence measure (WAIS Digit Span Forward) used, thus supporting the prediction made in the hypotheses. Subjects scoring high on the intelligence measure recalled more digit strings correctly (48%) than did the low intelligence group (22.5%). No other performance differences on digit recall were found.

Instruction period. The heart rate data evidenced differences in A-state reaction during the instruction period, but not so with the pupil size data. There was an interaction between Stress and Epochs for the heart rate (see Figure 6). The High and Low Stress groups initially showed no differences in their heart rate, but as the instructions progressed, the High Stress group showed an increase in heart rate. A test of simple effects on the interaction further indicated that a significance between groups was noted in the last six Epochs. This suggested that as the subjects became aware of the implications of the instructions and the task expectations, a differential and significant response was elicited. This finding, along with the A-state differences previously cited, tend to confirm the hypothesis dealing with heart rate during the Instruction Period. On the other hand, the pupil size data did not differentiate between the two Stress groups during the same period (see Figure 5).

Comparison of the group mean pupil size and heart rate for the Low Stress group showed a non-significant positive correlation. For the High Stress group there was a significant negative correlation. The indication was that under High Stress instructions the pupillary and heart rate changes are negatively related. Even though the subjects perceived the situation as stressful, their pupil size and heart rate reacted to the situation differentially. This kind of response difference has been referred to by Lacey (1967) as 'directional fractionation', and has been previously demonstrated with these two measures (cf. Libby, Lacey, & Lacey, 1973). A comparison of Figures 5 and 6 further exemplified this relationship between the pupil size and the heart rate data. Pupil size was quite large at the onset of the instructions, but became progressively smaller as the instructional time elapsed. The opposite effect was seen with the heart rate response; the initial heart rate was somewhat low and subsequently displayed progressive increases until the end of the 'Practice Sequence' of the Instruction Period. Both groups showed the increasing-decreasing curve during the 'Practice Sequence' of a digit string presentation and recall. The pupil response curve during this practice task was typical and similar to that reported in the literature. The heart rate accelerated during the entire practice sequence, decelerating somewhat more slowly than in the study reported by Kahneman, Tursky, Shapiro and Crider (1969).

From these data it appeared that within a stressful instructional set the pupil response did not reflect this change. The increasing heart rate, particularly the accelerated response for the High Stress group, was suggestive of an A-state reaction when the implications of the instructions are fully comprehended. Those differential physiological responses of heart rate and pupil size suggested that the heart rate reflected the emotional aspect more readily than did pupil size. This difference does not appear unusual considering that the cardiovascular system is required to adapt readily to a variety of real and perceived needs of the organism. Lacey (1970) has suggested that increased heart rate is associated with decreased cortical activity, thus the pupil response with cortically initiated origins would be in tune with the task at hand but would not necessarily reflect other physiological excitation. This phenomenon will be further elucidated by the results of the responses taken during the Digit Span Period.

Digit Span Period

During the Digit Span Period the different levels of stress instructions were related to subsequent levels of pupil size and heart rate. Prior to discussing these results, it should be noted that the pupil size and heart rate data, particularly the pupil data, followed the characteristic inverted U-shaped function associated with the digit span task, similar to the curves reported by Kahneman et al. (1969).

The most important part of Digit Span was the Input segment where the organism must actively engage in the task to process and store the information presented. The Stress main effect for pupil size data during Input was not significant; however the Stress x Seconds interaction was significant. The interaction was further analyzed by a test of simple effects and none of the one second intervals reached significance. The linear and quadratic trend interactions were significant, suggesting that the slopes were different. From observing the Input segment of Figure 7, it was seen that the slope of the High Stress graph in the last four seconds became steeper than in the preceding seconds. The slope of the Low Stress group remained virtually the same across time. Overall, these data suggested that pupillary arousal to stress in this situation was minor, accounting for an increased rate of dilation only near the end of the Input period. The major portion of the pupil response is related to the "mental effort" component of arousal which is required in the loading phase as suggested by Kahneman (1973). This finding supports the contention, presented in the discussion of Experiment 1, that the effect of instructional set on pupil size was likely to be due to increased motivation (greater effort) to do well on the task; this greater effort thus increased pupillary dilation. Polt (1970) has suggested that stress instructions, rather than reflecting anxiety through increased pupil size, might rather be reflecting increased motivation. This increase in effort appeared mainly in the last part of the Input segment as the task requirements increased. High Stress subjects worked harder at the task, not because of anxiety but because of greater effort exerted to complete the task successfully.

This was a significant main effect on the Stress factor for heart rate during Input. The High Stress group had a higher rate than the Low Stress group. There appeared to be a rapid acceleration of heart rate during the Ready segment followed by a relatively flat slope during the digit presentation. The lack of acceleration and deceleration may be the intermediate stage referred to by Libby, Lacey and Lacey (1973) on tasks which combine requirements for attention and for mental work (requiring storage, manipulation, and retrieval of symbolic information). The differences between High and Low Stress groups in heart rate would be accounted for by significant A-state reaction. The larger A-state scale scores for the High Stress group supported this interpretation. The increased heart rate to the High Stress instructions may also be reflecting a tonic heart response referred to by Obrist (1976). The organism has adapted to the stress demands by a general elevation in heart rate as was seen toward the end of the Instruction Period and extended into the Digit Span Period.

While still on Input, another interesting finding, again showing support for the contention that pupil size mainly reflects cognition and heart rate mainly reflects emotion, can be further developed by looking at the intelligence variable. In the main analysis, neither of the A-state measures (self-report or heart rate) distinguish between intelligence levels, however the pupil size differences between groups on intelligence was marginally significant ($p < .06$). This suggested that pupil size changes were more associated with the subject's cognitive ability than were heart rate or self-report measures. Both of these latter measures were more reflective of anxiety associated with the situation.

Turning to the Output segment of the Digit Span period, both High and Low Stress groups reached their peak pupil size on the seventh second of the Input segment, then demonstrated a decreasing linear function during Output. The differences between groups were not significant at any of the one second intervals during Output, but an interaction occurred reflecting a difference in slopes. The decreasing slope of the High Stress group was steeper than that of the Low Stress group. There was probably a greater reduction in effort by the High Stress group than by the Low Stress group during the unloading phase.

The heart rate data maintained a significant Stress main effect difference between groups during the Output period. The High Stress group reached its peak heart rate during the first second of Output, Low Stress, the second second. There was a deceleration to the fourth second, followed by acceleration until the Stop and Rest segment. This second acceleration during Output may be somewhat related to respiration rate as suggested by Kahneman et al. (1969) or it may be a characteristic of heart rate variability during these kinds of tasks.

The stress aspect of the data for pupil size and heart rate suggested that during a cognitive task, specifically a digit span task, the effect of stress was negligible for the pupil response when the subject was engaged in a task requiring 'mental effort'. The effect of stress was more a motivational variable which enhanced pupil dilation. The effect of a stressor on heart response was to increase the rate and to maintain the increase for a longer time. While the rate was increased, the pattern of responding to the task appeared to remain the same. The graph representing heart rate during the Digit Span Period (Figure 8) had some similarity to the Kahneman et al. (1969) results of a four digit recall task. Thus, while the slope of the response to the task remained the same, there was an increased level of heart rate associated with the ego-threatening situation.

It was interesting to note that pupil size over the six trials showed habituation, that is, the pupil size decreased progressively over the six trials. Also it was noted on pupil size that less habituation over trials occurred for the High Intelligence group as compared to the Low Intelligence group. Heart rate failed to show the same progressive decrease from trial to trial but decreased a slight, non-significant degree. It was natural to anticipate some degree of habituation for all subjects. This was expected as a result both of increasing familiarity with the task and of the presence of a fatigue factor. In keeping with the interpretation of pupil size largely reflecting momentary cognitive variables and heart rate reflecting emotional variables, it may have been that, as the task was performed repeatedly, less effort was expended by the subject (thus pupil size became smaller) whereas the emotional component remained relatively the same (thus heart rate showed slight decrease). It was noted that there were fewer correctly recalled digit strings in the latter trials than in the initial trials. The continuing high level of response by heart rate might be partially explained in the light of Obrist's (1976) discussion of tonic effects. He has suggested that the organism has been given the opportunity to respond but has not achieved total success due to the demand characteristics. As a result certain physiological changes are likely to occur which would not interfere with task requirements, expectations or performance.

Finally, little need be said about the Ready and Rest segments except that both responses, heart rate and pupil size, showed a general increasing function before the task and a decreasing level during the Rest phase between tasks.

Correctness of response and intelligence. The present study controlled for task difficulty and selected items of moderate difficulty so that subjects would have a 50/50 relationship on correct-incorrect responses. Also, the intelligence measure used was directly related to the experimental task rather than one of a general nature as used in previous and inconclusive experiments (e.g., Simpson & Molloy, 1970). The High Intelligence subjects recalled significantly more digit strings than did the Low Intelligence subjects. As a matter of fact, the High Intelligence people correctly recalled 48% of the trials, very close to the

50/50 correct-incorrect relationship expected from all subjects. However, only 22.5% were correctly answered by Low Intelligence subjects. This considerable difference between groups validates the intelligence measure.

Initially, upon considering Correct-Incorrect trials, differences were predicted, but not direction of difference because reasons could be given for each direction. For example, one might have expected that pupil size would be smaller for correct responses because the subject would find these trials easier and would thus expend less effort in recalling them. (Incidentally, none of the digit strings were recalled correctly more often than any other.) On the other hand, one might have predicted that the subject would work harder at, and expend more effort to obtain, a correct response and thus the pupil size would be larger for the correct trial than the incorrect. Upon considering the marginally significant intelligence differences from Table 14, in which High Intelligence students produced a larger pupil size than their counterparts, the latter appeared to be the case.

During the Input and Output segments it was found that there was a larger pupil size associated with Correct than Incorrect trials, but there were no differences found between the two on heart rate. A Correct-Incorrect x Seconds interaction was found during Input on pupil data. It appeared that subjects exerted greater mental effort and tried harder and thus achieved success. Conversely, the smaller pupil size for Incorrect trials reflected a failure to perform to criterion as subjects did not expend as much mental effort.

Perhaps what was more interesting was the significant main effect of pupil size for Intelligence during Input, but not during Output. During Input, the brighter subjects exerted more effort to achieve their objective, but this difference was not reflected in Output. The Input period was when the subject was working to process information being presented. Also noted during Input was a significant Intelligence x Correct-Incorrect x Seconds interaction. As can be seen in Figure 17, the largest pupil size overall was associated with the High Intelligence - Correct (H-C) group. The smallest size was associated with the Low Intelligence - Incorrect (H-I) group, and the medium pupil size was associated with the Low Intelligence - Correct (L-C) and the High Intelligence - Incorrect (H-I) groups. During Output, the H-C and L-C groups had the larger pupil size than the H-I and L-I groups, thus negating the intelligence differences but not the Correct-Incorrect difference. The difference between the Correct and Incorrect trials during Output might be associated with a greater amount of verbalization (at least seven digits must be spoken) required by the two correct groups. Previous research has shown that the overt response requirements of verbalization enhance pupil size (e.g., Simpson & Paivio, 1968).

While the pupil size was associated with both intelligence and correctness of response, the heart rate results were unrelated to these factors and failed to reach significance. One thing in the pupil data which required clarification was that intelligence on the previous analysis was only approaching significance ($\underline{p} < .06$) but did show significance in the subsequent analysis of Correct and Incorrect responses. The reason may have been due to the way the data was treated. In the previous analysis all trials were treated as a repeated measure of each subject, in this analysis each trial was treated independently thus increasing the sample size.

The literature related to pupil size, intelligence and correctness of response has failed to demonstrate consistent findings. Some studies have failed to find a relationship (e.g., Simpson & Molloy, 1971, Daly, Note 1); some have demonstrated findings in a direction opposite to the present results (e.g., Crough, 1971); and some have been supportive of this study (e.g., Boersma, Wilton, Barkam & Muir, 1970; Peavler & Nellis, Note 7).

Daly (Note 1) found no differences in pupil size between efficient and inefficient problem solvers, nor between correct and incorrect trials on a cognitive task. He had equated subjects for general intelligence on the basis of the Raven Progressive Matrices (Raven, 1938) and divided subjects on the basis of their scores on Thought Problems (see Tate, Stanier & Harootunian, Note 8). It may have been that pupil size was not sensitive to efficiency of problem solving or that the test used did not differentiate validly on the efficiency dimension. Also, equating on the intelligence measure may have cancelled out any potential pupil size differences.

Crough (1971) confirmed his general hypothesis that low 'reasoning' ability subjects would show greater pupil dilation than high ability subjects. He used four measures -- Raven's test, DAT (Abstract Reasoning), and SAT (Verbal and Mathematical Scales). The pupil measure was taken as subjects responded to the odd numbered items of the Raven's test. While he explained the results in light of Activation Theory (Duffy, 1962), he might as readily have used Kahneman's explanation of larger pupil size associated with greater mental effort and greater task difficulty. That is, low ability subjects worked harder and exerted more effort to achieve than did their better reasoning counterparts. Crough did not make any comparison between correct and incorrect problems solved and the pupil response.

Simpson and Molloy (1971) did not find pupil size differences between high and low intelligence groups divided on the basis of the Otis Intelligence Test, but Peavler and Nellis (Note 7) found a larger resting pupil size among subjects scoring high on this test than among those scoring low. Pupil size was measured several times during a normal working day.

Boersma, Wilton, Barham and Muir (1970) presented problems of varying difficulty to ten normal and ten educable mentally retarded (EMR) children (average age of 10 to 11 years). Both groups showed increased pupil size as function of problem difficulty. More particularly, greater pupil size was related to correct response trials rather than to incorrect trials. Initially during the experiment no group pupil size differences occurred, but later the normal group's pupil size became increasingly larger than the EMR group. One reversal occurred in the last third of the experiment in which the largest pupil size was associated with the easiest problems for the EMR group; a result interpreted by the authors as a combination of increased attention and arousal.

In the Boersma et al. study, the poorer reasoning ability subjects (EMR group) had the smaller pupil size (incidently the average IQ difference was 40 points between groups), but Crough found a larger pupil size for the low reasoning group, the opposite result. Peavler and Nellis' findings would be more supportive of Boersma's findings but there was no task analysis or work evaluation associated with the differences in the resting pupil size. In Boersma's study, the larger pupil size was associated with correct responses rather than incorrect responses. The larger pupil size may have implied that subjects worked harder and exerted greater effort to achieve a correct solution. The normal group's performance was better overall than the EMR group. If the analysis was performed on only correct data, the results might be related to those of Crough, but such an analysis was not done. In conclusion, the Boersma et al. study, as did this study, showed a relationship between pupil size and both intelligence and correctness of response; thus, neither variable should be considered alone in a pupillary response experiment.

Test anxiety. It appeared that the High Test Anxiety subjects perceived the experimental situation as more stressful than did the Low Test Anxiety subjects, as verified by the pre-experimental A-state paper and pencil measure. This finding was understandable considering that the situation would be of a test-like nature. When this Test Anxiety difference was covaried in the post-experimental measure, there was a significant difference due to Stress instructions. The High Stress subjects had a higher A-state score than the Low Stress subjects, with the High Stress - High Test Anxiety group having the greatest mean score (M=47.57); the Low Stress - Low Test Anxiety group, the lowest score (M=38.23); and the other two groups ranged midway between them. These findings supported the notion that High Test Anxiety subjects responded to test-like situations with increased A-state arousal as opposed to Low Test Anxiety subjects; but these findings were only supported by the paper and pencil measures, not by the physiological measure.

There was consistent Test Anxiety x Intelligence interaction for pupil response. The test of simple effects indicated that High Test Anxiety - High Intelligence group differed from the other groups. It may be that this group was more motivated to do well and exerted greater effort; however their performance differences did not verify this contention. For the most part the Test Anxiety factor did not appear related to the physiological measures.

General Discussion

Results from both experiments suggested a consistent pupillary response pattern during the presentation of the memory tasks. There were, however, differences in the two experiments which require further explanation. In Experiment 1, none of the predictions posited for the Intelligence variable reached statistical significance, but the results were in the predicted direction. The High Intelligence subjects had a slightly larger mean pupil size for the Input segment than did the Low Intelligence subjects. Only the High Intelligence - High Stress group had a larger mean pupil size than did the High Intelligence - Low Stress group. The question raised was whether the lack of significance was related to an inadequacy of the Intelligence measure or to the difficulty level of the digit recall task. The latter explanation appeared to be the case because of the overall poor performance of all groups, with the High Intelligence group's performance being better on number of digit strings recalled than the Low Intelligence groups. In fact, there were so few correctly recalled digit strings that the analysis of the pupillary responses to correct and incorrect trials was not feasible. This problem was resolved in Experiment 2 by decreasing the length of the digit strings.

The results of Experiment 2 were much more encouraging. During the Input segment, pupil size was significantly larger for High Intelligence subjects than for the Low Intelligence scores when the analysis was made on the Intelligence variable and the Correct-Incorrect response factor. Also found in the analysis was a significantly larger pupil size for Correct trials than for Incorrect trials. The High Intelligence group's performance was also significantly better than that of the Low Intelligence group. These findings for the Intelligence variable in Experiment 2 were consistent with the trend in Experiment 1 for pupil size. The findings in Experiment 2, however, are stronger than those in Experiment 1 and thus more supportive of the contention that the High Intelligence subjects expended greater effort on the task as reflected by the larger pupil size. The Correct-Incorrect trial differences in pupil size were in keeping with the explanation of greater effort expended. It was possible that when task difficulty was perceived as within reasonable grasp, the subject worked harder to achieve the objective. Possibly the non-significant differences found in Experiment 1 can be related to Hess' (1972) suggestion that when a task was too difficult or the subject perceived the task to be too difficult, he did not try as hard to complete the task successfully. This lack of effort would then be reflected in the pupil response. The task in Experiment 2 was more within the range of accomplishment of the subjects and the increased effort was demonstrated by the pupil response differences.

A-state differences between groups was inconclusive in Experiment 1. There were no differences for A-state on the paper and pencil measure between the High and Low Stress instructions; however during Input, a significantly larger pupil size was associated with the High Stress instructions condition than with the Low Stress condition. One particular difficulty associated with the latter finding was that no baseline measure was taken to account for potential differences among groups on the pre-experimental resting pupil size. The assumption at the time was that no differences would be apparent. The discussion regarding the pupil size differences between the High and Low Stress groups was related to Polt's (1970) increased motivation interpretation.

A number of changes were incorporated in the second experiment to offset the above problem. The High Stress instructions were made more stressful, a baseline measure was taken prior to the experimental task and a heart rate measure was taken along with the pupil response measure particularly for comparison during the Instruction period. The heart rate measure was highly correlated with anxiety and it was hoped that the added physiological measure would be more sensitive to the presence of A-state anxiety. The results of Experiment 2 indicated that there was a differential effect created by the High and Low Stress instructions for the heart rate response. The A-state paper and pencil measure also differentiated between stress groups, but these differences were not evident for the pupillary response. During the Instruction period, a differential fractionation was noted between heart rate and pupil size, in which the former under High Stress Instructions increased significantly in comparison to the Low Stress Instructions as the subjects became cognizant of the task demands. There was no difference in pupil size between Instruction groups during the Instruction period.

During Input there was no significant main effect for Stress on pupil size, but there was a Stress x Seconds interaction. The slope of the graph of the High Stress group showed a marked increase in pupil size in the latter part of the Input segment. This, incidentally, was very similar to the slope of the High Stress group during Input in Experiment 1; however this interactional difference between the High and Low Stress Instruction groups did not reach statistical significance in Experiment 1. These findings again supported the contention of Polt (1970) that an increased motivation enhances pupil size. The subject who is highly motivated would work harder at the task, especially towards the latter part of the input of digits, so as to keep the digit string intact for later recall. It was noted that the High Stress Instructions were not disruptive of performance on digits recalled correctly, but the High Stress group recalled slightly more numbers ($\underline{M} = 4.289$) than did the Low Stress group ($\underline{M} = 4.069$). The heart rate for the High Stress group during Input remained at a higher level than for the Low Stress group, suggesting a tonic level of heart rate response. Furthermore, the paper and pencil measure of A-state also showed a higher score for the High Stress group than the Low Stress group, which was in keeping with the prediction in the hypothesis.

In the two studies, the pupil response was an effective gauge of mental effort as suggested by Kahneman (1973). When the organism engaged in a specific cognitive task, the pupil was able to indicate the association of arousal to task. It is important to note that when there was a stressor involved, the pupil size was enhanced to a greater extent as the task progressed. The pupil then reflected the cognitive activity associated with the task. The heart rate was more reflective of the anxiety associated with the instructions by an increased heart rate during the task. This response to stress was not disruptive; the differential response can be explained in that the pupil response was more reflective of cortical changes occurring within the organism, while the heart response must account for several other influences imposed on the organism by situational demands. It can be concluded that pupil size was more reflective of cognition, heart rate more reflective of emotion in a task-oriented situation in which both stress provoking stimuli and mental activity demands were presented simultaneously.

The individual difference variable of intelligence and correctness of response further support the pupil's relationship to the mental effort component of arousal. It is reasonable to accept the rationale that bright people expend more effort to achieve a response and also that a correct response generally requires more effort than an incorrect response. Both of these effects are then reflected in pupil size.

Support for this conclusion can be found in the literature (e.g., Boersma et al., 1970).

Finally, the results of the Test Anxiety variable supported the notion that whereas High Test Anxiety subjects showed increased A-state reaction to stress, Low Test Anxiety subjects did so to a lesser degree; however this was supported only by the paper and pencil measure, not by the physiological measure.

In conclusion, the most significant finding in this study points out the fact that pupil response during cognitive tasks is related to cognition while heart rate reflects the anxiety component. Further research in this area must look at the relationship of pupil size and heart rate in a variety of problem solving situations. It also appears necessary that such tasks must consider both intelligence and correctness factors.

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Appendix A

Digit Recall Task in Experiment 1

One of the following eight sets of eight-digit strings was presented to each of the subjects. The first two digit strings in each set were presented as practice trials.

	Set A	Set B	Set C
(1)	5-4-7-1-6-3-8-2	2-6-4-8-7-5-3-1	4-7-1-3-5-2-6-8
(2)	4-7-3-6-2-8-1-5	3-4-5-1-7-2-6-8	2-4-8-6-3-1-5-7
(3)	8-5-6-3-4-1-7-2	8-6-1-4-3-5-2-7	6-3-4-2-8-7-1-5
(4)	2-1-6-5-4-7-8-3	5-8-4-2-6-7-1-3	4-2-6-1-8-7-3-5
(5)	3-4-7-6-8-1-2-5	5-4-1-3-8-7-6-2	8-2-4-3-7-1-5-6
(6)	4-8-7-3-1-6-5-2	7-6-5-4-1-3-8-2	1-6-7-4-8-5-2-3
(7)	3-1-2-4-8-5-6-7	5-4-1-2-8-6-3-7	2-6-1-3-5-4-8-7
(8)	8-7-2-3-1-4-5-6	8-1-4-7-5-6-2-3	1-3-8-4-6-2-7-5

	Set D	Set E	Set F
(1)	8-3-1-7-6-2-5-4	8-2-5-1-7-4-3-6	1-6-3-4-5-2-8-7
(2)	6-1-3-5-2-8-4-7	2-3-8-6-5-7-4-1	4-1-5-7-6-3-8-2
(3)	5-1-3-4-8-6-2-7	2-5-4-6-3-1-7-8	4-8-1-2-3-7-6-5
(4)	5-1-7-4-2-3-6-8	6-4-3-2-8-5-7-1	1-6-3-8-4-7-2-5
(5)	6-4-8-7-5-1-3-2	7-4-6-8-5-3-1-2	8-2-3-6-5-1-7-4
(6)	2-1-4-7-3-6-8-5	1-2-6-5-7-8-3-4	1-6-4-2-5-3-8-7
(7)	5-2-7-6-8-4-3-1	7-3-6-4-5-1-8-2	3-2-5-6-4-1-7-8
(8)	5-2-6-7-3-8-1-4	6-1-3-4-5-8-7-2	7-1-8-2-3-5-6-4

	Set G	Set H
(1)	3-6-4-1-8-5-2-7	6-3-4-7-8-2-1-5
(2)	7-2-4-1-6-8-3-5	1-7-6-3-2-5-8-4
(3)	3-8-7-5-2-6-1-4	6-7-3-2-4-8-5-1
(4)	7-2-8-5-1-4-3-6	5-4-7-8-2-6-1-3
(5)	2-3-7-4-6-5-8-1	7-3-1-5-4-8-6-2
(6)	7-3-5-2-8-1-6-4	3-2-5-7-4-6-8-1
(7)	2-5-6-1-8-4-3-7	4-8-7-3-5-1-6-2
(8)	2-1-5-4-3-6-8-7	6-1-4-5-8-7-2-3

Digit Recall Task in Experiment 2

Eight strings of digits were randomly selected. Each string consisted of seven digits with no number repeated. The strings were as follows:

(1) 7-9-4-5-2-3-1

(2) 2-8-1-4-7-3-9

(3) 4-6-9-5-7-2-3

(4) 9-5-7-4-8-1-6

(5) 3-1-4-6-7-5-8

(6) 2-1-7-9-8-4-3

(7) 6-5-1-4-3-9-2

(8) 3-6-2-4-9-5-1

Each subject received the same eight digit strings, except the order was varied from subject to subject. Five sets were developed for presentation. The order of the lists were as follows:

(1) The same order as the above set.

(2) 8-4-1-2-6-5-3-7

(3) 1-2-8-4-3-7-6-5

(4) 4-6-1-3-2-8-5-7

(5) 4-1-6-5-7-3-8-2

Appendix B

Instructions for Experiment 1

The instructions for Experiment 1 of the High Stress condition were as follows:

> This is an experiment to assess a person's intellectual ability, particularly regarding recall capacity. Thus far you have completed phase one of the experiment and should be reasonably familiar with the numerical task. The next phase is similar to the first part except in this phase your pupillary reaction will be monitored in order to obtain a measure of intellectual efficiency. Very recent research findings have shown that the pupillometric response is a reliable indicator of intellectual efficiency. We expect to replicate these findings in this study.
>
> This task will be to recall a series of numbers in the same order and at the same rate of speed as you heard them presented to you. When you hear the word "Ready" spoken, listen carefully to the numbers which will follow. Do not begin to say these numbers aloud until you have heard the word "repeat" spoken, then start. Recall the numbers in the same order and at the same rate of speed as you heard them given. Remember the procedure: listen after ready, speak after repeat, and rest after stop. Okay, let us try a practice sequence.
>
> "Ready"..3-7-1-4.."Repeat"......"Stop"

> Here are some things you should remember while positioned in the apparatus. Look at the middle of the chart, if you do look from side to side, try not to let the focus of your vision wander off the chart. Finally, remember to keep your forehead on the bar. Keep your eyes wide open and try not to blink. This procedure will help us get an accurate measure of your intellectual efficiency. Are there any questions about what you have to do?

The instructions for those students in the Low Stress condition for Experiment 1 were as follows:

> This experiment is a straight forward memory task. You have just completed the first phase which will have familiarized you with the numerical presentation. During the next phase, your eye will be photographed while you repeat the numbers. This task will be to recall a series of numbers in the same order and at the same rate of speed as you heard them presented to you. When you hear the word "Ready" spoken, listen carefully to the numbers which will follow. Do not begin to say these numbers aloud until you have heard the word "Repeat" spoken, then start. Recall the numbers in the same order and at the same rate of speed as you hear them given. When you hear the word "Stop", cease saying the numbers and relax before

> the next sequence of numbers. Remember the procedure: listen after ready, speak after repeat, and rest after stop. Okay, let us try a practice sequence.
>
> "Ready"..3-7-1-4.."Repeat"......"Stop"
>
> Here are some things you should remember while positioned in the apparatus. Look at the middle of the chart, if you do look from side to side, try not to let the focus of your vision wander off the chart. Finally, remember to keep your forehead on the bar. Keep your eyes wide open and try not to blink. Are there any questions about what you have to do?

Instructions for Experiment 2

The instructions for the High Stress condition for Experiment 2 were as follows:

> 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 in part 1 of the A-Bey 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 the task you will be required to recall a series of numbers and you will have to repeat this series in the same order and at the same rate of speed as you hear them presented. When you hear the word "Ready" spoken, listen carefully to the series of numbers to follow. When you hear me say "Repeat", repeat the series of numbers at the rate of speed and in the same order. When you hear "Stop", quit saying the numbers and relax until the next set begins. Remember the procedure: listen after ready, speak after repeat, and rest after stop. Okay let us try a practice sequence.

"Ready"..5-3-7-1-4.."Repeat"......."Stop"

(Remainder of instructions after practice sequence were the same as Experiment 1)

APPENDIX C

Table 1

Summary of Variance of the Effects of Instructions and Intelligence on A-state Measures

Source of variation	df	MS	F
A (Stress)	1	84.50	.60
B (Intelligence)	1	4.50	.03
AB	1	78.12	.55
Within cell	28	139.77	
Total	31		

---

* $p < .05$

Table 2

Analysis of Variance of Pupil Data for
Pre-stimulus, Input and Output segments

Source of Variation	df	Pre-stimulus MS	Pre-stimulus F	Input MS	Input F	Output MS	Output F
A (Stress)	1	52455.44	4.84*	98028.75	4.28*	129182.18	7.04*
B (Intelligence)	1	4614.00	.42	6816.96	.29	1388.12	.07
AB	1	13204.37	1.21	20763.26	.90	19437.66	.56
Error 1	28	10834.77		22860.85		18348.52	
C (Trials)	5	3800.11	8.24**	6216.96	8.38**	8955.92	10.96**
AC	5	552.60	1.19	1999.70	2.69*	893.00	1.09
BC	5	496.63	1.07	703.82	.94	800.72	.98
ABC	5	947.44	2.05	1382.81	1.86	959.51	1.17
Error 2	140	461.09		741.32		816.85	
D (Seconds)	4 (7)+	212.85	2.92*	1118.62	14.71**	743.79	4.23**
AD	4 (7)	84.87	1.16	112.39	1.47	110.28	.62
BD	4 (7)	111.89	1.53	74.52	.98	120.90	.68
ABD	4 (7)	19.14	2.05	61.58	.81	182.12	1.03
Error 3	112 (196)	72.76		76.00		175.73	
CD	20 (35)	41.61	.55	44.39	.64	107.37	1.06
ACD	20 (35)	33.16	.44	96.91	1.39	105.63	1.04
BCD	20 (35)	61.27	.82	73.45	1.05	92.88	.91
ABCD	20 (35)	58.77	.78	41.32	.59	41.83	.41
Error 4	560 (980)	74.76		69.41		101.23	
Total	959 (1535)						

+ () refers to df for Input and Recall Segments
* $p < .05$
** $p < .01$

Table 3

Analysis of Linear Trend of Trials on Pupil Data for Pre-stimulus, Input and Output segments

Source of Variation	df	Pre-stimulus		Input		Output	
		MS	F	MS	F	MS	F
Within S (linear)	32						
C (linear)	1	3380.90	20.06**	3813.60	136.20**	5053.02	27.27**
AC (linear)	1	371.50	2.20	1183.62	6.77*	89.24	.48
BC (linear)	1	77.25	.45	19.60	.11	189.87	1.02
ABC (linear)	1	567.59	3.36	903.94	5.17*	444.14	2.39
Error	28	168.47		174.77		185.25	

A = Stress, B = Intelligence, C = Trials.

* $p < .05$

** $p < .01$

Table 4

Analysis of Linear Trend of Seconds on Pupil Data for Pre-stimulus, Input and Output segments

Source of Variation	df	Pre-stimulus		Input		Output	
		MS	F	MS	F	MS	F
Within S (linear)	32						
C (linear)	1	100.34	3.92	1302.68	29.20**	832.49	8.81**
AC (linear)	1	12.26	.47	111.29	2.49	10.72	.11
BC (linear)	1	9.74	.38	53.33	1.19	62.77	.66
ABC (linear)	1	.99	.03	37.79	.04	32.83	.34
Error	28	25.59		44.59		94.42	

A = Instructions, B = Stress, C = Seconds

* $p < .05$

** $p < .01$

Table 5

Total Number of Correct Responses

Obtained for All Trials

Including Practice

Groups	Intelligence	
	Low	High
High Stress	5	15
Low Stress	1	9

Table 6

Analysis of Variance of Incorrect Responses
in Experiment 1

Source of Variation	df	MS	F
A (Stress)	1	3.12	1.45
B (Intelligence)	1	10.12	4.69*
AB	1	.12	.06
Error	28	2.16	
Total	31		

---

* $p < .05$

Table 7

Analysis of Variance of Pre-experimental

A-state Measure during Experiment 2

Source of Variation	df	MS	F
A (Test Anxiety)	1	559.01	9.30**
B (Stress)	1	165.67	2.76
C (Intelligence)	1	.21	.00
AB	1	.41	.01
AC	1	3.67	.06
BC	1	161.01	2.68
ABC	1	.41	.01
Error	112	60.08	
Total	119		

* $p < .05$

** $p < .01$

Table 8

Analysis of Covariance of Post-experimental A-state Measure during Experiment 2

Source of Variation	df	MS	F
A (Test Anxiety)	1	27.58	.37
B (Stress)	1	326.35	4.41*
C (Intelligence)	1	8.39	.11
AB	1	1.35	.01
AC	1	59.13	.79
BC	1	88.34	1.19
ABC	1	87.97	1.18
1 st Covar	1	3780.47	51.07**
Error	111	74.01	
Total	115		

* $p < .05$

** $p < .01$

Table 9

Analysis of Variance of Pupil and Heart Rate Data for Baseline Period

Source of Variation	df	Pupil MS	Pupil F	Heart MS	Heart F
A (Test Anxiety	1	3541.46	.83	6680.85	2.64
B (Instructions)	1	816.21	.19	1764.25	.69
AB	1	5479.10	1.29	1748.90	.69
C (Intelligence)	1	15237.13	3.60	450.52	.17
AC	1	3530.86	.83	3439.22	1.36
BC	1	845.39	.20	657.12	.26
ABC	1	1335.05	.31	2001.56	.79
Error 1	112	4225.58		2525.75	
D (seconds)	9	30.84	.50	63.66	1.42
AD	9	14.47	.23	28.24	.63
BD	9	77.55	1.25	23.99	.53
ABD	9	78.12	1.26	27.40	.61
CD	9	60.61	.98	64.86	1.45
ACD	9	90.00	1.46	67.74	1.51
BCD	9	40.18	.65	30.61	.68
ABCD	9	17.46	.28	83.15	1.86
Error 2	1008	61.60		44.61	
Total	1199				

* *p* .05

Table 10

Analysis of Variance of Pupil and Heart Rate Data for Instruction Period

Source of Variation	df	Pupil		Heart	
		MS	F	MS	F
A (Test Anxiety)	1	1434.25	.20	11942.22	2.27
B (Instructions)	1	.99	.00	7993.64	1.52
AB	1	5932.03	.83	1210.99	.23
C (Intelligence)	1	13766.54	1.92	159.78	.03
AC	1	6930.99	.96	14267.92	2.72
BC	1	926.13	.13	.29	.00
ABC	1	3604.45	.50	512.75	.09
Error 1	112	7150.33		5245.66	
D (Epochs)	20	1396.82	12.04**	1031.39	16.62**
AD	20	67.08	.57	37.43	.60
BD	20	105.79	.91	263.20	4.24**
ABD	20	92.68	.79	35.32	.57
CD	20	144.74	1.24	44.25	.71
ACD	20	117.55	1.01	69.72	1.12
BCD	20	107.75	.92	69.07	1.11
ABCD	20	88.29	.76	32.14	.51
Error 2	2240	115.96		62.02	
Total	2519				

* $p < .05$

** $p < .01$

Table 11

Test of Simple Effects of the Stress (B) x Epochs (D) interaction for Heart Rate during Instruction period.

Source of variation	df	MS	F
B at d1	1	332.06	1.07
B at d2	1	143.88	.46
B at d3	1	71.98	.23
B at d4	1	113.84	.36
B at d5	1	.02	.00
B at d6	1	113.60	.36
B at d7	1	7.62	.02
B at d8	1	117.84	.38
B at d9	1	50.07	.16
B at d10	1	87.00	.28
B at d11	1	650.90	2.10
B at d12	1	855.14	2.76
B at d13	1	577.89	1.87
B at d14	1	839.84	2.71
B at d15	1	981.55	3.17
B at d16	1	1364.85	4.41*
B at d17	1	1042.17	3.37
B at d18	1	1324.68	4.28*
B at d19	1	1562.55	5.05*
B at d20	1	1813.05	5.87*
B at d21	1	1207.00	3.91*
Error	112	308.86	

(see Table 10 for main ANOVA summary table)

B = Stress
D = Epochs

* $p < .05$

Table 12

Analysis of Variance of Pupil and Heart Rate Data for Ready Segment of Digit Span Period

		Pupil		Heart	
Source of Variation	df	MS	F	MS	F
A (Test Anxiety)	1	2936.36	.51	11322.39	2.19
B (Instructions)	1	5611.43	.98	26530.39	5.15*
AB	1	625.68	.10	226.39	.04
C (Intelligence)	1	14735.69	2.57	1036.50	.20
AC	1	25287.55	4.41*	16119.92	3.12
BC	1	562.04	.09	368.53	.07
ABC	1	15569.69	2.71	14.09	.00
Error 1	112	5727.64		5151.80	
D (Trials)	5	4152.11	13.40**	153.11	.90
AD	5	247.93	.80	90.63	.53
BD	5	486.63	1.57	98.41	.58
ABD	5	214.97	.69	179.40	1.06
CD	5	250.02	.80	55.39	.32
ACD	5	378.08	1.22	328.60	1.94
BCD	5	435.29	1.40	122.36	.72
ABCD	5	490.92	1.58	136.34	.80
Error 2	560	309.70		169.00	
E (Seconds)	2	530.78	9.65**	978.49	17.03**
AE	2	38.00	.50	48.03	.83
BE	2	44.74	.81	62.79	1.09
ABE	2	34.20	.62	18.85	.32
CE	2	82.66	1.50	311.06	5.41**
ACE	2	7.63	.13	18.86	.32
BCE	2	22.39	.40	116.66	2.03
ABCE	2	44.47	.80	9.30	.16
Error 3	224	54.97		57.44	
DE	10	37.52	.85	114.93	1.98
ADE	10	29.07	.66	25.35	.43
BDE	10	18.05	.41	106.59	1.84
ABDE	10	23.69	.53	60.93	1.05
CDE	10	48.59	1.10	101.01	1.74
ACDE	10	39.51	.89	47.84	.82
BCDE	10	51.73	1.17	72.31	1.24
ABCDE	10	18.73	.42	39.88	.68
Error 4	1120	44.00		57.90	
Total	2159				

* $p < .05$ ** $p < .01$

Table 13

Test of Simple Effects for Intelligence (C) x Seconds (E) interaction of Heart Rate during Ready segment of Digit Span period

Source of variation	df	MS	F
C at e1	1	1438.54	.81
C at e2	1	208.01	.11
C at e3	1	11.52	.00
Error	112	1755.56	
E at c1	2	237.74	2.06
E at c2	2	2340.75	20.37**
Error	224	57.44	

(see Table 12 for main ANOVA summary table)

C = Intelligence
E = Seconds

** $p < .01$

Table 14

Analysis of Variance of Pupil and Heart Rate Data for Input segment of Digit Span period

Source of Variation	df	Pupil		Heart	
		MS	F	MS	F
A (Test Anxiety)	1	10095.52	.64	25546.87	.99
B (Stress)	1	23365.42	1.49	55384.86	4.32*
AB	1	5185.48	.32	509.99	.04
C (Intelligence)	1	37349.53	2.38	162.98	.01
AC	1	73908.75	4.72*	37240.44	2.91
BC	1	4717.79	.30	686.78	.05
ABC	1	28784.17	1.84	1041.60	.08
Error 1	112	15630.75		12795.81	
D (Trials)	5	13361.58	24.12**	127.06	.58
AD	5	536.36	.96	243.68	1.11
BD	5	1152.57	2.08	332.52	1.52
ABD	5	912.54	1.64	450.08	2.06
CD	5	807.45	1.45	342.42	1.57
ACD	5	593.35	1.07	455.40	2.08
BCD	5	466.51	.84	222.88	1.02
ABCD	5	489.83	.88	160.97	.73
Error 2	560	553.91		218.05	
E (Seconds)	6	5943.30	91.96**	76.84	1.17
AE	6	22.82	.35	25.81	.39
BE	6	195.16	3.02**	50.32	.76
ABE	6	21.97	.34	11.20	.17
CE	6	43.12	.66	10.84	.16
ACE	6	40.61	.62	21.59	.32
BCE	6	47.60	.73	50.57	.77
ABCE	6	164.28	2.54*	33.59	.51
Error 3	672	64.62		65.65	
DE	30	46.65	1.10	34.96	.64
ADE	30	34.94	.83	39.24	.72
BDE	30	37.56	.89	51.59	.95
ABDE	30	38.05	.90	56.20	1.03
CDE	30	30.68	.72	51.97	.95
ACDE	30	43.05	1.02	42.66	.78
BCDE	30	49.71	1.18	44.31	.81
ABCDE	30	62.79	1.49	47.72	.87
Error 4	3360	42.11		54.32	
Total	5039				

* $p < .05$ ** $p < .01$

Table 15

Trend Analysis of Seconds effect of
Pupil Data for Input segment of
Digit Span period

Source of variation	df	F(linear)	F(quadratic)	F(cubic)
Within Subject	120			
D	1	175.86**	5.62	.05
AD	1	.00	1.03	.37
BD	1	3.63*	4.20*	.15
CD	1	.80	.41	1.29
ABD	1	.06	.10	.07
ACD	1	1.04	.01	.11
BCD	1	.10	.21	4.94*
ABCD	1	4.17	.00	.88
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Seconds

* $p < .05$

** $p < .01$

Table 16

Trend Analysis of Trials effect of Pupil
Data for Input segment of Digit Span period.

Source of variation	df	F(linear)	F(quadratic)	F(cubic)
Within Subject	120			
D	1	35.72	46.08	4.00*
AD	1	.38	.69	1.43
BD	1	1.02	2.05	.01
CD	1	.55	3.06	.25
ABD	1	1.32	2.79	.00
ACD	1	.41	.03	1.03
BCD	1	.29	.10	3.71
ABCD	1	2.96	.58	3.55
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Seconds

* $p < .05$

** $p < .01$

Table 17

Test of Simple Effects for Test Anxiety (A)
x Intelligence (C) of Pupil Data
for Input segment of Digit Span period

Source of variation	df	MS	F
A at c1	1	14691.12	.93
A at c2	1	69312.04	4.43*
Error term	112	15630.75	
C at a1	1	3090.92	.19
C at a2	1	108163.72	6.91**
Error term	112	15630.75	

(see Table 14 for main ANOVA summary table)

A = Test Anxiety
C = Intelligence

* $p < .05$

** $p < .01$

Table 18

Analysis of Variance of Pupil and Heart Rate Data for Repeat segment of Digit Span period

		Pupil		Heart	
Source of Variation	df	MS	F	MS	F
A (Test Anxiety)	1	2318.12	1.13	3043.08	1.45
B (Stress	1	8088.10	3.94*	7031.54	3.35
AB	1	181.27	.08	.87	.00
C (Intelligence)	1	5141.21	2.50	58.36	.02
AC	1	11051.36	5.38*	7055.31	3.37
BC	1	973.91	.47	927.99	.44
ABC	1	3014.16	1.46	67.55	.03
Error 1	112	2051.58		2093.26	
D (Trials)	5	1767.46	17.51**	117.27	1.66
AD	5	106.45	1.05	193.79	2.74*
BD	5	138.23	1.37	96.91	1.37
ABD	5	99.16	.98	61.17	.86
CD	5	229.53	2.27	78.66	1.11
ACD	5	89.95	.89	48.92	.69
BCD	5	110.82	1.09	4.60	.06
ABCD	5	58.02	.57	35.94	.50
Error 2	560	100.92		70.57	

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* $p < .05$

** $p < .01$

Table 19

Test of Simple Effects for Test Anxiety (A) x Intelligence (C) interaction of Pupil Data for Repeat segment of Digit Span period

Source of Variation	df	MS	F
A at c1	1	1623.33	.79
A at c2	1	11745.69	5.72*
Error term	112	2051.58	
C at a1	1	558.45	.27
C at a2	1	15634.11	7.62**
Error term	112	2051.58	

(see Table 18 for main ANOVA summary table

A = Test Anxiety
B = Intelligence

* $p < .05$

** $p < .01$

Table 20

Test of Simple Effects for Intelligence (C) x Trials (D) interaction of Pupil data during Repeat segment of Digit Span perod

Source of variation	df	MS	F
C at d1	1	79.31	.18
C at d2	1	235.20	.55
C at d3	1	1065.29	2.50
C at d4	1	1120.32	2.62
C at d5	1	2638.96	6.19*
C at d6	1	1149.48	2.69
Error	112	426.03	
D at c1	5	1586.66	15.72**
D at c2	5	410.33	4.06**
Error	560	100.92	

(see Table 18 for main ANOVA summary table)

C = Intelligence
D = Trials

* $p < .05$
** $p < .01$

Table 21

Test of Simple Effects for Test Anxiety (A) x Trials (D) interaction of Heart Rate during Repeat segment of Digit Span period

Source of variation	df	MS	F
A at d1	1	3.30	.00
A at d2	1	1366.47	3.35
A at d3	1	747.00	1.83
A at d4	1	1388.83	3.40
A at d5	1	292.59	.71
A at d6	1	214.66	.52
Error	112	407.69	
D at a1	5	207.23	2.93*
D at a2	5	20.60	.29
Error	560	70.57	

(see Table 18 for main ANOVA summary table)

A = Test Anxiety
D = Trials

* $p < .05$

Table 22

Analysis of Variance of Pupil and Heart Rate
for Output segment of Digit Span period

Source of Variation	df	Pupil		Heart	
		MS	F	MS	F
A (Test Anxiety	1	5316.56	.32	23096.77	1.70
B (Stress)	1	21043.35	1.27	62450.68	4.61*
AB	1	2201.48	.13	694.16	.05
C (Intelligence)	1	11560.89	.70	101.18	.00
AC	1	39358.12	2.39	39301.81	2.90
BC	1	12293.32	.74	1648.60	.12
ABC	1	21420.29	1.30	579.01	.04
Error 1	112	16455.09		13541.21	
D (Trials)	5	11527.16	16.12**	50.27	.27
AD	5	56.02	.07	157.94	.85
BD	5	308.84	.43	113.75	.61
ABD	5	271.55	.38	345.58	1.87
CD	5	657.79	.92	102.20	.55
ACD	5	268.12	.37	102.61	.55
BCD	5	998.61	1.39	259.76	1.40
ABCD	5	540.80	.75	136.70	.74
Error 2	560	714.79		184.53	
E (Seconds)	6	2357.48	21.13**	803.22	9.03**
AE	6	128.83	1.15	51.39	.57
BE	6	243.42	2.18	144.04	1.62
ABE	6	82.07	.73	15.56	.17
CE	6	99.48	.89	54.34	.61
ACE	6	84.67	.75	73.48	.82
BCE	6	151.19	1.35	76.86	.86
ABCE	6	85.45	.76	27.16	.30
Error 3	672	111.54		88.87	
DE	30	45.65	.67	52.85	.97
ADE	30	100.21	1.47	50.72	.93
BDE	30	53.95	.79	42.05	.77
ABDE	30	47.85	.70	49.32	.91
CDE	30	55.51	.81	43.31	.80
ACDE	30	65.02	.95	72.58	1.34
BCDE	30	71.65	1.05	103.74	1.92
ABCDE	30	74.19	1.09	101.08	1.87
Error 4	3360	67.95		54.00	
Total	5039				

* $p < .05$ ** $p < .01$

Table 23

Trend Analysis of Seconds Effect of Pupil data for Output segment of Digit Span period

Source of Variation	df	F(linear)	F(quadratic)	F(cubic)
Within subject	120			
D	1	40.51**	.13	.48
AD	1	.18	1.08	.03
BD	1	3.81*	.04	1.84
CD	1	.13	1.41	2.39
ABD	1	.43	.37	3.29
ACD	1	.03	.94	6.06*
BCD	1	1.99	1.74	.06
ABCD	1	.05	.64	3.88*
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Seconds

* $p < .05$

** $p < .01$

Table 24

Test of Simple Effects for Stress (B) x Seconds (E) interaction for Pupil data during Output segment of Digit Span period

Source of variation	df	MS	F
B at e1	1	6421.81	2.62
B at e2	1	4362.46	1.78
B at e3	1	2157.37	.88
B at e4	1	4093.80	1.67
B at e5	1	2412.52	.98
B at e6	1	1695.27	.69
B at e7	1	1363.23	.55
Error	112	2446.34	
E at b1	6	587.63	5.26**
E at b2	6	1641.21	14.63**
Error	672	111.54	

(see Table 22 for main ANOVA summary table)

B = Stress

E = Seconds

** $p < .01$

Table 25

Trend Analysis of Trials Effect of Pupil data for Output segment of Digit Span period.

Source of Variation	df	F(linear)	F(quadratic)	F(cubic)
Within subject	120			
D	1	16.99**	23.69**	1.69
AD	1	.03	.04	.01
BD	1	.12	.00	.10
CD	1	.03	.58	.68
ABD	1	.14	.04	.51
ACD	1	.11	.90	1.00
BCD	1	4.74*	1.56	1.58
ABCD	1	.31	1.01	.08
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Trials

* $p < .05$

** $p < .01$

Table 26

Trend Analysis of Seconds Effect of Heart Rate for Output segment of Digit Span period.

Source of variation	df	F(linear)	F(quadratic)	F(cubic)
Within subject	120			
D	1	.26	13.40**	.73
AD	1	.28	.38	.06
BD	1	1.75	.29	5.68*
CD	1	.00	.51	.00
ABD	1	.03	.25	.02
ACD	1	.94	.54	1.25
BCD	1	.20	.04	1.00
ABCD	1	.01	.00	.19
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Seconds

* $p < .05$

**$p < .01$

Table 27

Analysis of Variance of Pupil and Heart Rate for Stop segment of Digit Span period

		Pupil		Heart	
Source of Variation	df	MS	F	MS	F
A (Test Anxiety)	1	628.35	.30	2513.05	1.31
B (Stress)	1	1161.97	.57	11361.96	5.95*
AB	1	106.40	.05	1158.64	.60
C (Intelligence)	1	5355.64	2.62	283.12	.14
AC	1	8392.67	4.11*	9011.41	4.71*
BC	1	168.16	.08	967.71	.50
ABC	1	3590.74	1.76	220.73	.11
Error 1	112	2039.74		1909.48	
D (Trials)	5	1438.46	8.62**	29.43	.30
AD	5	125.41	.75	133.11	1.38
BD	5	73.59	.44	276.98	2.88*
ABD	5	187.45	1.12	135.00	1.40
CD	5	186.14	1.11	52.40	.54
ACD	5	138.46	.83	29.67	.30
BCD	5	291.99	1.75	70.70	.73
ABCD	5	89.47	.53	44.30	.46
Error 2	560	166.77		96.09	
Total	719				

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* $p < .05$

** $p < .01$

Table 28

Test of Simple Effects for Test Anxiety (A) x Intelligence (C) interaction of Pupil data for Stop segment of Digit Span period.

Source of variation	df	MS	F
A at c1	1	2215.03	1.08
A at c2	1	6804.27	3.33
Error term	112		
C at a1	1	169.90	.08
C at a2	1	13576.27	6.65*
Error term	112		

(see Table 20 for main ANOVA summary table)

A = Test Anxiety
C = Intelligence

* $p < .05$

Table 29

Test of Simple Effects for Stress (B) x Trials (D) interaction for Heart Rate during Stop segment of Digit Span period

Source of variation	df	MS	F
B at d1	1	236.71	.59
B at d2	1	1612.30	4.04*
B at d3	1	2992.80	7.51**
B at d4	1	2315.81	5.81*
B at d5	1	4078.66	10.23**
B at d6	1	1509.74	3.79
Error	112	398.32	
D at b1	5	131.58	1.36
D at b2	5	174.82	1.81
Error	560	96.09	

(see Table 27 for main ANOVA summary table)

B = Stress
D = Trials

* $p < .05$

** $p < .01$

Table 30

Test of Simple Effects for Test Anxiety (A) x Intelligence (C) interaction for Heart Rate during Stop segment of Digit Span period

Source of variation	df	MS	F
A at c1	1	2694.84	1.41
A at c2	1	10520.94	5.50*
Error	112	1909.48	
C at a1	1	6245.00	3.27
C at a2	1	3049.56	1.59
Error	112	1909.48	

(see Table 27 for main ANOVA summary table)

A = Test Anxiety
C = Intelligence

* $p < .05$

Table 31

Analysis of Variance of Pupil and Heart Rate for Rest segment of Digit Span period

Source of Variation	df	Pupil		Heart	
		MS	F	MS	F
A(Test Anxiety)	1	2562.82	.23	14205.05	1.61
B (Stress)	1	9112.60	.84	43372.25	4.91*
AB	1	2.33	.00	4104.88	.46
C (Intelligence)	1	39532.42	3.66	1691.37	.19
AC	1	46758.96	4.33*	25678.42	2.91
BC	1	1050.55	.09	657.29	.07
ABC	1	12248.82	1.13	40.47	.00
Error 1	112	10775.62		8818.70	
D (Trials)	5	6421.84	11.04**	599.16	2.84*
AD	5	271.76	.46	307.16	1.45
BD	5	308.84	.53	395.18	1.87
CD	5	516.24	.88	113.25	.53
ACD	5	492.83	.84	172.36	.81
BCD	5	163.24	.28	104.24	.49
ABCD	5	524.21	.90	307.45	1.45
Error 2	560	581.26		210.88	
E (Seconds)	5	273.98	2.43*	4695.32	35.55**
AE	5	334.93	2.97*	122.78	.93
BE	5	103.75	.92	56.22	.42
ABE	5	49.24	.43	91.03	.68
CE	5	10.09	.09	388.68	2.94*
ACE	5	65.63	.58	65.87	.49
BCE	5	96.76	.85	183.47	1.38
ABCE	5	98.67	.87	83.01	.62
Error 3	560	112.69		132.04	
DE	25	85.06	.98	57.19	.85
ADE	25	60.83	.70	84.48	1.25
BDE	25	59.97	.69	73.18	1.08
ABDE	25	91.67	1.05	69.23	1.02
CDE	25	67.30	.77	68.90	1.02
ACDE	25	93.94	1.08	44.94	.66
BCDE	25	111.71	1.28	90.32	1.34
ABCDE	25	122.22	1.41	63.31	.94
Error 4	2800	86.67		67.30	
Total	4319				

* $p < .05$ ** $p < .01$

Table 32

Trend Analysis of Trials Effect of Pupil data for Rest segment of Digit Span period.

Source of variation	df	F(linear)	F(quadratic)	F(cubic)
Within subject	120			
D	1	4.89*	17.50**	.61
AD	1	.34	.09	.09
BD	1	.00	.49	.03
CD	1	.51	2.50	.45
ABD	1	.60	1.65	.62
ACD	1	.47	.52	2.55
BCD	1	.55	.07	.52
ABCD	1	.08	1.08	1.96
D x S within group	112			

A = Test anxiety
B = Stress
C = Intelligence
D = Trials

* $p < .05$

** $p < .01$

Table 33

Trend Analysis of Seconds Effect of Pupil data for Rest segment of Digit Span period

Source of variation	df	F(linear)	F(quadratic	F(cubic)
Within subject	120			
D	1	3.47	5.74*	.30
AD	1	5.02*	.00	4.53*
BD	1	.04	5.57*	.00
CD	1	.02	.01	.00
ABD	1	.22	.81	.01
ACD	1	.00	.07	3.63
BCD	1	.31	.69	3.89*
ABCD	1	.02	3.51	1.77
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Seconds

* $p < .05$

Table 34

Trend Analysis of Seconds Effect of Heart Rate for Rest segment of Digit Span period.

Source of variation	df	F(linear)	F(quadratic)	F(cubic)
Within subject	120			
D	1	73.16**	9.22**	.00
AD	1	1.80	.24	.01
BD	1	.27	.42	.73
CD	1	6.19*	.36	.00
ABD	1	.72	.97	.12
ACD	1	.11	1.12	.73
BCD	1	2.15	.00	.04
ABCD	1	.19	.37	.69
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Seconds

* $p < .05$
** $p < .01$

Table 35

Trend Analysis of Trials Effect of Heart Rate data for Rest segment of Digit Span period.

Source of variation	df	F(linear)	F(quadratic)	F(cubic)
Within subject	120			
D	1	2.02	1.16	4.48*
AD	1	6.83**	5.51	.08
BD	1	1.23	.14	1.61
CD	1	.46	.05	1.15
ABD	1	.09	4.51*	2.47
ACD	1	2.85	3.36	.36
BCD	1	1.37	1.15	.00
ABCD	1	2.74	3.66	.00
D x S within group	112			

A = Test Anxiety
B = Stress
C = Intelligence
D = Trials

* $p < .05$

** $p < .01$

Table 36

Analysis of Variance of the Digit Strings Correctly
Recalled for the Six Trials of the
[illegible]

Source of Variation	df	MS	F
A (Test Anxiety)	1	2.13	.84
B (Stress)	1	.13	.05
C (Intelligence)	1	70.53	28.09**
AB	1	.83	.33
AC	1	.03	.01
BC	1	.30	.11
ABC	1	1.20	.47
Error	112	2.51	

** $p < .01$

Table 37

The Correct-Incorrect Trials Recalled
for All Groups

		Low Test Anxiety		High Test Anxiety	
		Correct	Incorrect	Correct	Incorrect
Low Stress	Low Intelligence	24	66	19	71
	High Intelligence	42	48	44	46
High Stress	Low Intelligence	21	69	17	73
	High Intelligence	48	42	39	51

Table 38

Analysis of Variance of Pupil and Heart Rate
for Ready segment of Digit Span period
(Correct-Incorrect Response)

		Pupil		Heart	
Source of Variation	df	MS	F	MS	F
A (Intelligence)	1	9311.46	7.47**	526.88	.51
B (Correct-Incorrect	1	7565.06	6.07*	296.09	.29
AB	1	25.36	.02	203.50	.19
Error 1	716	1245.66		1021.84	
C (Seconds)	2	360.31	8.04**	1191.32	20.35**
AC	2	20.40	.45	226.99	3.87*
BC	2	19.49	.43	26.56	.45
ABC	2	205.69	4.59**	45.15	.77
Error 2	1432	44.80		58.54	
Total	2159				

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* $p < .05$

** $p < .01$

Table 39

Analysis of Variance of Pupil and Heart Rate
for Input segment of Digit Span period
(Correct-Incorrect Response)

		Pupil		Heart	
Source of Variation	df	MS	F	MS	F
A (Intelligence)	1	22964.67	7.21**	15.13	.00
B (Correct-Incorrect)	1	21146.44	6.64**	307.50	.13
AB	1	75.79	.02	1356.03	.57
Error 1	716	3183.33		2354.55	
C (Seconds)	6	6895.32	150.74**	63.17	1.13
AC	6	25.28	0.55	10.44	.18
BC	6	112.60	2.46*	19.09	.34
ABC	6	194.72	4.25**	62.26	1.12
Error 2	4296	45.74		55.46	
Total	5039				

* *p* < .05

** *p* < .01

Table 40

Analysis of Variance of Pupil and Heart Rate for Output segment of Digit Span period (Correct-Incorrect Responses)

Source of Variation	df	Pupil		Heart	
		MS	F	MS	F
A (Intelligence	1	6477.49	1.95	489.71	.20
B (Correct-Incorrect)	1	35648.96	10.74**	69.91	.02
AB	1	5212.50	1.57	920.23	.37
Error 1	716	3316.83		2448.52	
C (Seconds)	6	2298.81	30.62**	757.79	12.62**
AC	6	46.83	.62	101.94	1.69
BC	6	63.97	.85	89.69	1.49
ABC	6	96.85	1.29	95.44	1.59
Error 2	4296	75.05		60.03	
Total	5039				

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* $p < .05$

** $p < .01$

Table 41

Analysis of Variance of Pupil and Heart Rate for Rest segment of Digit Span period (Correct-Incorrect Response)

Source of Variation	df	Pupil		Heart	
		MS	F	MS	F
A (Intelligence	1	26959.55	11.83**	1331.58	.79
B (Correct-Incorrect)	1	19686.66	8.63**	86.72	.05
AB	1	78.92	.03	43.30	.02
Error 1	716	2278.71		1684.77	
C (Seconds)	5	320.46	3.52*	5463.42	70.53**
AC	5	3.86	.04	247.80	3.19**
BC	5	188.40	2.07	368.54	4.75**
ABC	5	48.77	.53	31.76	.41
Error 2	3580	90.94		77.46	
Total	4319				

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* $p < .05$

** $p < .01$

Table 42

Test of Simple Effects for Correct-Incorrect
(B) x Seconds (C) interaction of Pupil data
during Input segment

Source of Variation	df	MS	F
B at c1	1	1132.78	2.29
B at c2	1	2548.10	5.15*
B at c3	1	3545.45	7.17**
B at c4	1	3146.61	6.37*
B at c5	1	3808.19	7.70**
B at c6	1	3239.34	6.55*
B at c7	1	4402.58	8.91**
Error	112	493.96	
C at b1	6	2984.27	65.24***
C at b2	6	3609.95	78.92***
Error	4296	45.74	

(see Table 39 for main ANOVA summary table)

B = Correct-Incorrect

C = Seconds

* $p < .05$

** $p < .01$

*** $p < .001$