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THE EFFECTS OF PROBLEM-SOLVING ABILITY AND TASK DIFFICULTY ON THE PUPIL RESPONSE DURING COGNITIVE TASKS EMPLOYING "CONTINUOUS" STIMULI.

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by

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ABSTRACT

Numerous investigators employing a variety of tasks have found that the pupil of the eye can serve as an index of cognitive effort or processing. Specifically, it has been demonstrated that during a cognitive task the pupil dilates in response to stimulus presentation and returns to baseline immediately following solution or task termination. Moreover the increase in pupil size during information processing periods has been found to be positively related to the difficulty level of the task employed. Thus more difficult tasks evoke larger pupillary dilation during processing periods.

The consistency of findings in this area has led reviewers to comment that the relationship between pupil size and mental effort is "well-established" and that the pupil is "the best single" physiological measure of processing load.

Previous research however has concentrated almost exclusively on the use of 'non-continuous' or short-duration stimuli. That is, tasks have employed digit strings, paired-associate learning, tone discrimination, single word imagery and the like. 'Continuous' stimuli, that is stimuli that provide an extended, contextual and grammatically-integrated information set, such as reading material, have been employed in but two studies, only one of which was concerned with the issue of cognitive effort. Interestingly this isolated study failed to support the relationship function typically obtained.

The essential purpose of the present study was to provide added information on how the pupil responds when 'continuous' stimuli are

employed. As well the influence of differing levels of 'processing ability' was also investigated.

The results obtained support the typical within-task findings of previous studies; that is, the pupil size was sensitive to the presence of processing periods. Mean pupil size did not discriminate between tasks of different difficulty levels but such discrimination was obtained when peak pupil size scores were employed. No convincing support was found for the influence of individual differences in processing ability on the pupillary response.

Recommendations were made regarding the need for further and more sophisticated research to support and elaborate the findings here obtained. It was also put forward that if the pupil could be brought under voluntary control through instrumental conditioning procedures then strategies of information presentation could be derived so that learning is facilitated by making such presentation contingent on the presence of 'pupillary states' deemed especially conducive to enhanced information integration and retrieval.

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INTRODUCTION

The pupil of the eye is the dark circular area bounded by the iris. It has been popularly referred to as the "window to the soul" in historical recognition of its responsiveness to emotional stimulation. In scientific circles it has also been referred to as "the only permanently implanted electrode" because of its direct connection to the optic nerve, and as "the only visible part of the brain" because among popular dependent variables it is clearly the psychophysiological response most available to unaided observation (Janisse, 1977).

The iris consists essentially of two muscles both of which are under autonomic nervous system control. These muscles, one activated by parasympathetic fibers the other by sympathetic fibers, in turn modulate pupil size by promoting, respectively, contraction and dilation in accordance with autonomic system activity (Janisse, 1977).

Various scientific writers as far back as the 18th century had reported observations suggesting that the pupil was a highly sensitive psychophysiological index. Most reports spoke of the pupil dilating in response to fear, anxiety, joy, and other emotions. Later, pupil dilation was reported in relation to cognitive activity,

> "With regard to mental activity, or thinking, as early as 1920 Lowenstein reported as 'widely accepted' the fact

> that increases in attention and virtually every kind of mental process resulted in dilation of the pupil" (Janisse, 1977, p. 2).

The validity of these assumptions, however, remained unclear. For one, there was the anecdotal nature of the reports. For another, the technology available then to monitor pupillary reactivity was crude. To accurately and reliably measure the often extremely rapid[1] and minute changes[2] associated with pupillary sensitivity more sophisticated technology was required.

Eckard Hess And The Recent Clarity Of How To Interpret The Pupil Response

Eckard Hess is generally credited with pioneering the modern day investigation of the relationship between pupil size variation and psychological processes. Hess (1965, 1975) and then others who have followed have studied changes in pupil size in relationship to personality, attitude, preference, affective state, and cognition. Of all these areas the greatest clarity and most positive

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[1]The pupil has been found to react to stimulation in as little as 0.18 seconds (Zinn, 1972).

[2]Significant changes in psychological research are usually in the order of 4 to 35% of criterion. Given that the pupil generally varies in size from only 2 to 5 mm. in diameter (with clinical extremes of 0.5 to a little more than 9.0 mm.) such changes are usually only a few tenths of a mm. (Goldwater, 1972; Zinn, 1972).

findings have been obtained in the area of cognition. It is this area that will be addressed and represents the focus of the study.

Before proceeding to a review of the relevant literature mention need be made of Hess's popular and popularized "bi-directional hypothesis". Such attention is warranted in order to establish a crucial point regarding the properties of the pupil response.

Hess (1965) reported that extremely unpleasant or negatively arousing stimuli (e.g., pictures of dead bodies, a crippled child) were associated with pupillary constriction whereas pleasant or positively arousing stimuli (e.g., food to the hungry person, pictures of a nude female to a heterosexual male) were associated with pupillary dilation. From these and related findings Hess advanced the hypothesis that pupillary dilation indicates positive affect or liking, and pupillary constriction negative affect or aversion.

Attempts to replicate Hess's findings or otherwise demonstrate support for his "bi-directional index of positive and negative affect" stand out however by the consistency of lack of success. The methodological criticisms of Hess (1965) that explain the divergence of findings are summarized by Janisse (1977). Of importance here is that strong evidence now exists to the effect that an "intensity-dilation" rather than a "valence-dilation" hypothesis characterizes pupil size variation (Janisse, 1977). That is, the pupil dilates to virtually <u>ALL</u> stimulation, constricting only in response to increased illumination (the light reflex), decreases in the point of focus that elicit the near-vision reflex, fatigue, habituation (the "arousal-decrement effect"), various drugs, lid-closure (momentary constriction followed by redilation), and, possibly, advancement in age (over 40 years old) (Janisse, 1977; Zinn, 1972).

In other words, pupil size variation represents a purely physiological and therefore psychologically neutral response. Psychological interpretation, be it along a positive-negative valuation dimension or any other dimension, is something we impose on the physiological response by virtue of a logical analysis of situation and observations. Indeed the physiological response AS SUCH may be present under a variety of instances. For example, the pupil will dilate, and dilate to overall non-differentiating levels, under any condition of arousal be it surprise, nervousness triggered by alarm, pleasant feelings associated with viewing appealing pictures, or muscle strain, actual or fantasied (Nunnally et al., 1967). What the response indicates at a given time period is thus quite dependent on the circumstance and our ability to dismiss alternate explanations. Given this caution, the intent in the following section is to show that under certain circumstances (i.e., appropriate research designs) the pupil response can be considered, and considered with confidence, to be related to cognitive activity. Now the relevant literature.

Pupil Size Variation And Cognitive Activity: A Review Of The Literature

Hess conducted a series of experiments where he was able to determine exact changes in pupil size as well as the exact moment at which changes occurred in response to pre-selected and controlled stimulation. This was the start of the modern era of pupillary research. In the experiment relevant here, Hess and Polt (1964), five subjects were presented multiplication problems in increasing order of difficulty (7 x 8; 8 x 13; 16 x 23). The problems were presented verbally while the subjects fixated[3] on a control slide.[4] The authors found the following pupillary pattern during the task: a gradual increase in pupil size upon presentation of the problem rising to a peak immediately before the solution was given, followed by an immediate drop once the solution had been verbalized, and then a slow but steady return to baseline. Equally importantly, the data indicated that the mean percentage change in pupil diameter increased as a positive function of the difficulty of the problem.

Without providing additional statistical data Hess (1965) reported confirmation of the above findings in tasks involving spelling and deciphering of anagrams. In sum, Hess was stating that pupil

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[3] to minimize eye movement

[4] to ensure constant luminance as well as to provide a baseline

size was related to changes in what others (e.g., Kahneman & Beatty, 1966) later came to refer to as "cognitive demand", "processing load", "mental effort", or "information-processing", at both within and between-task levels.

The validity of Hess and Polt's findings is further attested to by the fact that numerous independent investigators have found markedly similar results. Figure 1 presents a graphical illustration of what has now become a typical pattern of findings in the area. The sources of support together with extensions of Hess and Polt's founding data follow below.

Daly (1966) selected 14 efficient and 14 inefficient problem solvers who were matched for intelligence and presented them with a problem requiring that the subject ask questions to provide him with differentially valuable solution-relevant information. The data showed significant dilation for all subjects during the problem solving period as compared to the control period. Pupillary dilation was observed during both the "problem presentation" and "question-answer" period, reaching a peak during the "final solution" period and then rapidly decreasing after the solution period. From this Daly concluded that pupillary dilation is related to increased cognitive activity at the time of dilation. The results however did not differentiate efficient and inefficient solvers nor correct and incorrect solutions. Yet there was indication that the variance of pupillary responses was much greater for control as compared to

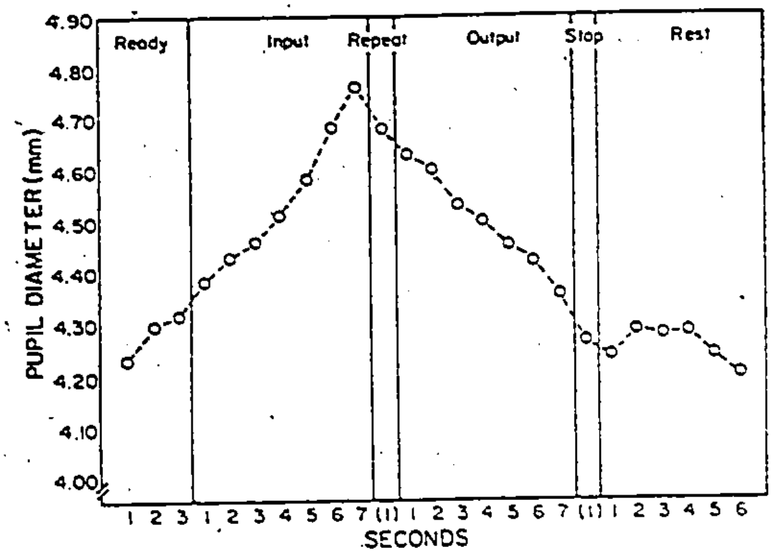


Figure 1. An example of a typical pupillary-response curve during a digit-span task. In this case, seven digits were presented, second-by-second, followed by a 1-second pause and then a 7-second repeat or recall period. Note the increasing pupil size during input or "loading" and the decreasing size during recall or "unloading." (From Janisse, 1977, p. 81.)

problem-solving periods. This observation led Daly to comment that

> "variance could be used as an estimate of the amount of fluctuation, inattention or concentration in future studies. Perhaps variance would be a better estimate of efficiency and inefficiency on a task than gross pupil size as was employed in the present study."

Investigators have yet to follow-up on this comment.

Kahneman and Beatty (1966) reported that on a digit span task (short-term memory) pupil size peaked following presentation, gradually returned to baseline during "unloading" or recall, and that dilation was larger for longer digit strings (See Figure 2). Similar within-task patterns were found for more difficult tasks involving transformation (e.g., digits presented were 3-0-9-1, subject had to add 1 to each and report 4-1-0-2) and word recall. Moreover dilation was greater for these latter two tasks as compared to the former which was the easiest of the three.

Beatty and Kahneman (1966) found the typical dilation pattern in a task requiring retrieval of information (a telephone number) from long term memory as did Kahneman and Beatty (1967) on a pitch discrimination task where the subject had to compare tones along a generalization gradient to a standard frequency. Kahneman and Beatty (1967) also reported finding a linear relationship between dilation and task difficulty as evidenced by the resemblance of the dilation curve to the data on error rates (See Figure 3).

Kahneman, Beatty, and Pollock (1967) found support for the

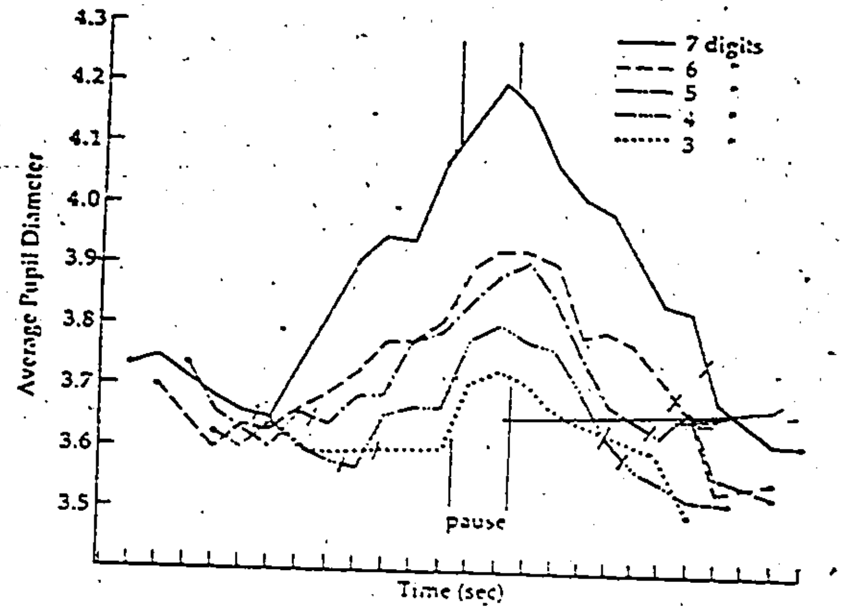


Figure 2. Subjects were asked to remember series of three to seven digits read to them at the rate of one per second. Subjects were instructed to repeat the series after a 2-second pause for retention. Pupil diameter increased as each new digit was heard (increasing "load" or difficulty) and decreased as each digit was spoken (decreasing "load"). Peak pupil diameter at the pause was greater as the number of digits to be retained or remembered increased. (From Kahneman & Beatty, 1966.)

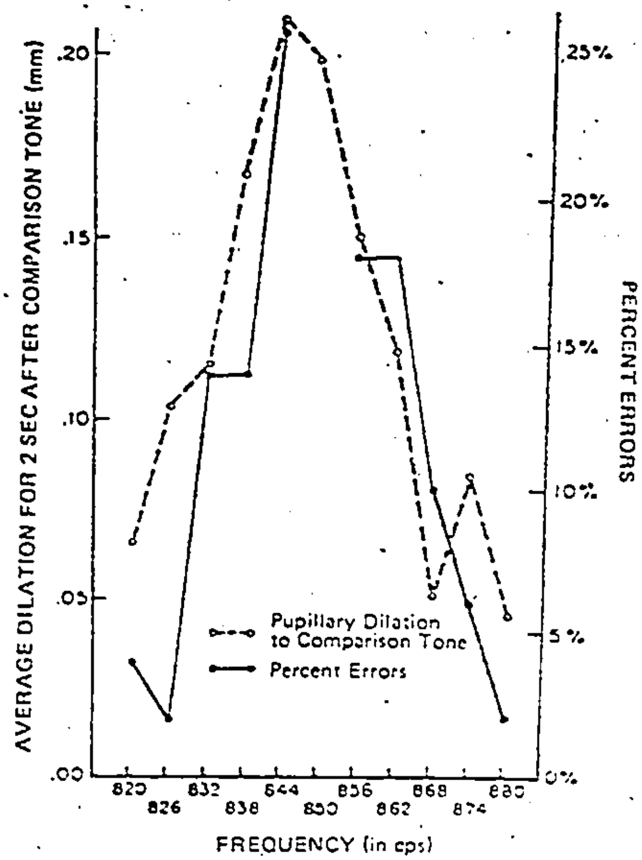


Figure 3. Tone discrimination task with 850-cps tone serving as the standard stimulus against which others compared. Note that there was dilation at each comparison tone with the degree of dilation being related to the difficulty of the discrimination as indicated by (a) the lowered dilations for tones further along the gradient from the standard tone, and (b) the mirroring of the dilation curve to the data on error rates. (Recall that pupillary dilation was shown by Hess and Polt (1964) to be positively related to task difficulty.) (From Kahneman & Beatty, 1967.)

notion that dilation reflects cognitive effort or load by demonstrating that problem-solving efficiency varies with cognitive load and therefore the associated pupillary response. Subjects were instructed to perform a transformation of four digits while attempting at the same time to detect a "K" in a visual display that flashed five letters per second. So that subjects would give priority to the more difficult transformation task and thus ensure a high cognitive load a payoff structure was employed whereby the subject was paid for the visual task only if he had performed the transformation task adequately. Results confirmed previous findings and demonstrated that the detection task suffered in direct relationship to the cognitive effort demanded of the subject, i.e., the number of digits being processed (See Figure 4).

Kahneman, Onuska, and Wolman (1968) found that the dilation curve for a string of 9 digits presented ungrouped (presented at rate of 1/sec. with 1-sec. intervals) was larger when compared to 9 digits presented in grouped order (3 digits presented at 1/sec. and separated by 3-sec. intervals). The authors reasoned that since the grouped format was easier to process or rehearse the data again confirmed pupil size as an index of task difficulty or the effort involved in mental activity.

Paivio and Simpson (1966; 1968) and Simpson and Paivio (1966; 1968) have shown that the pupil dilates significantly beyond baseline during an imagery task. They also found that the dilations,

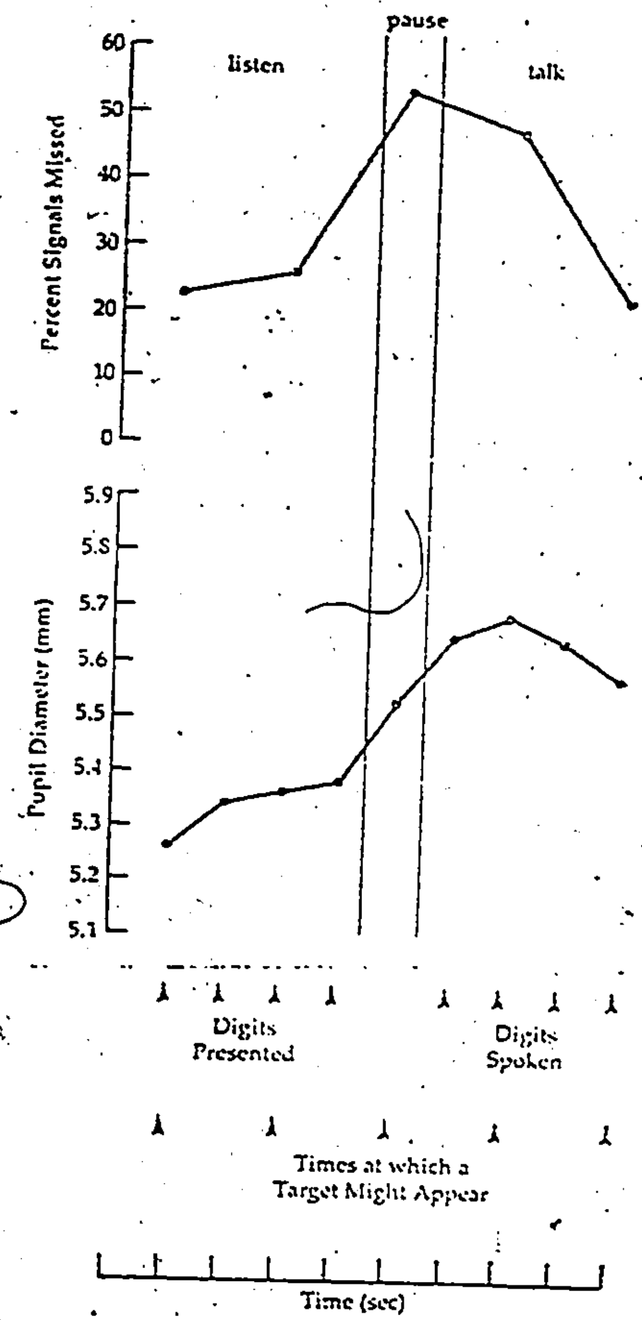


Figure 4. Subjects were required to perform two tasks simultaneously. They were required to listen to four digits, add one to each of the digits, and then report the transformed string. As well they were required to detect a specified letter ("target") that appeared at different points among a visual display of letters. Note that the pupil diameter reflects the level of mental activity necessary at each stage of the simultaneous task. In other words, although the data here are not as clear as one would have liked, it appears that as difficulty increases (the number of digits to be processed) dilation increases (indicating increased mental effort) and the error rate on the detection task simultaneously increases (indicating an "overloading" given the other task). As difficulty decreases (the number of digits to be processed), dilation while high nonetheless starts to decrease (indicating lowered mental effort) and the error rate on the detection tasks simultaneously decreases (indicating increased ability to process his second task). (From Kahneman, Beatty, & Pollock, 1967.)

although statistically significant only when an overt response (verbalization or key press) is required but showing a tendency to significance when no overt response is required, were greater for abstract as opposed to concrete word images. In that imaging to abstract words was considered to be more difficult than imaging to concrete words the authors concluded that they found added support for the pupil as an index of mental effort. Interestingly, the authors found that with or without an overt response requirement the latency to peak size was consistently greater for imaging to the abstract as compared to the concrete words. It would appear, for reasons yet to be determined, that for certain conditions a latency measure may be more telling than a measure of change in absolute size or percentage change from baseline.

These studies from Paivio's laboratory bring two additional points to attention, (a) the issue of contaminating factors such as muscle tension, and (b) the issue of what is the 'best', that is, what is the most sensitive and appropriate measure of pupillary activity as related to psychological processes. (Recall Daly's comment, for example, on the potential usefulness of the variance measure.)

The first of the two issues will be addressed much later. Janisse (1977) has commented on the second. He concludes that it remains to be determined whether average size, peak size, latency to peak size, minimum size, or variance is the 'best' measure of pupillary activity.

Continuing with the review, Bradshaw (1967; 1968a; 1968b) has provided added support for a cognitive activity - pupil size tie. Employing single and multiple-solution anagrams, mental arithmetic tasks of varying kind and difficulty, varying the rate of stimulus presentation to further discriminate levels of difficulty, and in one experiment having subjects perform a "continuous-processing" task or one that required considerable and relatively extended (10 minutes) concentration, Bradshaw's data were consistently corroborative of previous findings in the area. Bradshaw (1968c) also showed in a reaction time experiment that dilation was significantly greater when there was no warning foreperiod as compared to when either a long or short warning foreperiod was available. The author argued that uncertainty required increased cognitive load or attention (concentration) and that therefore the association with larger pupil size reflects the required increase in mental effort.

Janisse (1977) has reviewed the more recent studies that lend yet further support to the findings already cited. These studies have employed tasks involving paired-associate learning and sentence recall and paraphrase to name a few. Among the new data the studies have shown that given identical tasks, rehearsal interference, which assumedly disrupts the cognitive process flow, is associated with decreased pupil size as compared to the noninterference condition. This finding would be predicted from the "cognitive hypothesis" of pupillary activity given so much support by the earlier findings.

Of course not all studies in the area are mutually supportive. However the non-supportive studies number but three and they tend to be methodologically unsophisticated (Janisse, 1977). In sum, the weight of the evidence in this area is strong enough that reviewers have remarked that among autonomic indicators of mental effort the pupil is the "best single index" (Kahneman, 1973, p. 18) and that

> "The use of pupillary activity as an index of mental effort during the input, processing, or retrieval of information by now seems established and widely accepted" (Janisse, 1977, pp. 98-99).

<u>The "Cognitive" vs. "Arousal" Hypothesis: The Effect Of Contaminating Factors</u>

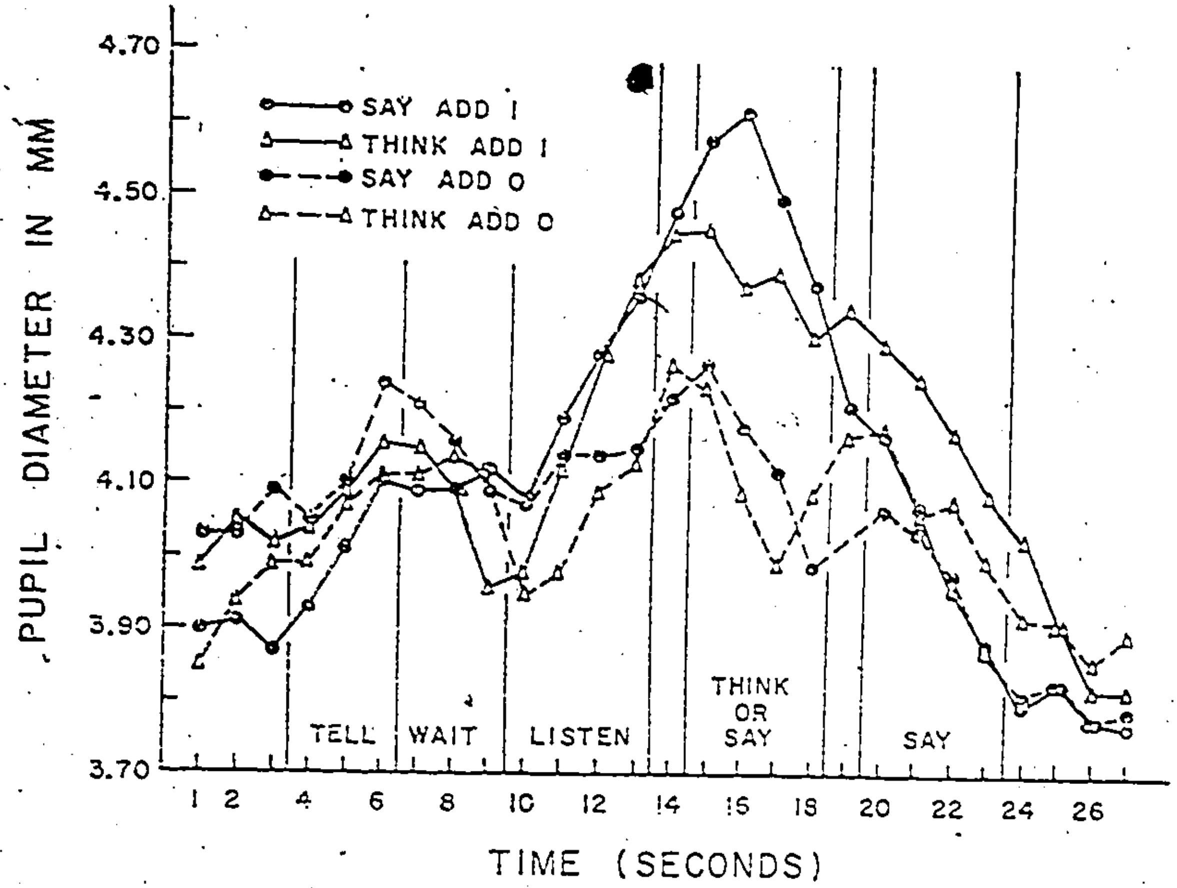
As already indicated the pupil, like other autonomic subsystems, is sensitive to arousal - and arousal considered in a much broader sense than feelings excited by affect-laden stimulation. In that there are innumerable determinants of arousal all of which affect pupillary reactivity in similar ways (Nunnally et al., 1967) it is entirely possible that pupil size variations may reflect the effects of such general or 'non-aligned' arousal and not be related to cognitive activity. For example, muscular tension arises whenever a motor response is involved. As well, anxiety due to evaluation apprehension may be present whenever the subject must make an overt response, such anxiety moreover being expected to increase with increased task difficulty. Thus,

> "In order to ascribe a particular autonomic change to mental effort, the investigator must...assume the burden of proving that this change is not due to such miscellaneous determinants of arousal as muscular strain or anxiety" (Kahneman, 1973, p. 22).

Investigators have met the challenge. The effects attributable to such contaminating factors have been isolated with the result that the data more convincingly than ever support the tie between pupil size changes and cognitive activity. Following are some of these studies.

Kahneman, Peavler, and Onuska (1968) presented subjects with a string of four digits. The subjects were instructed to either repeat the string (Add 0) or perform a transformation (Add 1). In the "Say" condition subjects repeated the response twice while in the "Think" condition they first thought or retained their answer and then verbalized it. Instructions (e.g., Say - Add 1) were given on seconds 4-6 of the trial, the digits were then presented, and the answer was either verbalized or retained, with verbalization occurring for all subjects between seconds 20-23. Figure 5 presents the findings. The data show that while verbalization, including both muscle tension and making public one's decision, did increase dilation the basic pattern or time course of pupillary changes was still observed in the "Think" condition.

In a second experiment of the same study, subjects were instructed to do the typical digit span task ("Say") or perform a



Average pupil size for 7 Ss in 4 experimental conditions. Task instructions were given on "Tell."

Figure 5. Subjects were required to repeat a digit string twice (Say - Add 0), first retain the string and then verbalize (Think - Add 0), add 1 to each digit of the string and verbalize twice (Say - Add 1), or add 1, first retain the response and then verbalize (Think - Add 1). Note that for both "Think" conditions dilation is present and that the dilation is greater for the more difficult task (Add 1). Thus a verbal response (Say conditions) may only enlarge the already present dilations. (From Kahneman, Peavler, & Onuska, 1968.)

transformation ("Add & Say"). As well half of the correct trials in both conditions were rewarded with 2¢ apiece and the other half with 10¢ apiece, with subjects being penalized equal amounts for incorrect responses. As expected the transformation task, being the more difficult of the two, resulted in larger dilation than the digit span task. However the incentive effect produced significantly larger pupil size only for the easier task (See Figure 6). The authors concluded from the two experiments that verbalization and incentive effects may enhance but cannot account for the relationship between pupil size changes and performance during cognitive tasks.

Kahneman and Peavler (1969) presented subjects first with 8 digits and then with 8 nouns which had to be paired to the digits. The pairing task constituted the "Study" phase. Later, in the "Test" phase, subjects heard a digit and had 3 secs. in which to produce the correct word association. Subjects had previously been told that they would receive 5¢ (High-Reward: HR) for each correct association involving an odd digit and 1¢ (Low-Reward: LR) for each correct association involving an even digit. The results showed that dilations for correctly vs. incorrectly recalled associations (Test phase) did not differ. Thus pupil size did not predict which associations would be recalled correctly. More importantly, the results also showed that in the Study phase pupillary dilation did not differ during presentation of the digits

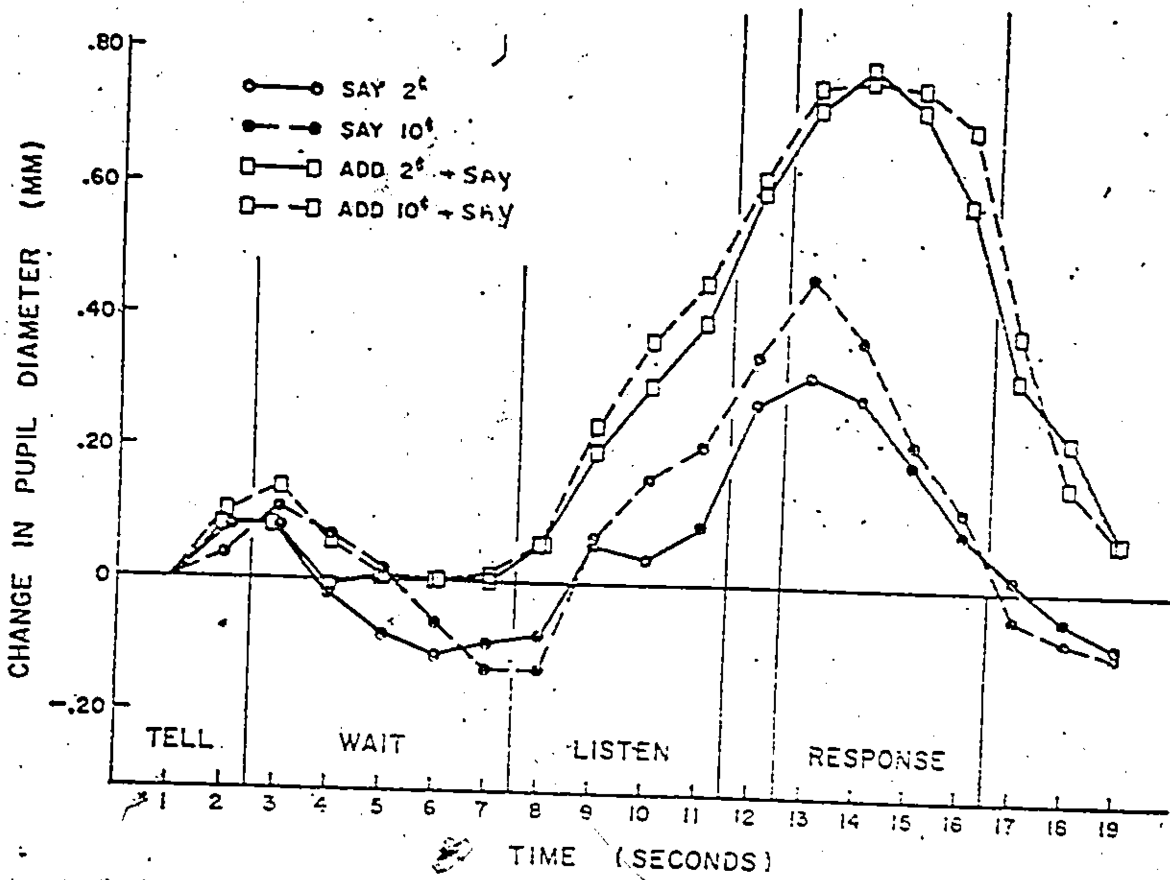


Figure 6. Average pupil size changes from baseline in 4 experimental conditions for 11 Ss. (From Kahneman, Peavler, & Onuska, 1968.)

but was greater for the HR words than for the LR words. The authors interpret this as supporting a "cognitive load" rather than an "emotion-arousal" hypothesis. Their reasoning is that if the latter were the case then the pupil response should have differed at digit presentation because the reward status of the digit was clear upon hearing it (i.e., knowing whether it was odd or even). In the authors' words

> "An emotional reaction to the incentive, if such occurs, should immediately follow the presentation of the digit, but the pupillary response does not distinguish HR from LR items at that time. On the other hand, S presumably works at forming the association only after the presentation of the response noun. It is then that the pupillary responses to HR and LR items differ" (p. 315).

Kahneman (1973, p. 24) offers the following as additional evidence against the anxiety/arousal hypothesis:

> (1) The hypothesis would predict heightened arousal in anticipation of as well as following failure and not only during the instant of effort. However the pupil is always largest during task-performance, rather than earlier or later.
>
> (2) Dilations accompanying correct responses are typically larger than those accompanying incorrect ones, again contrary to what would be predicted from the hypothesis.

Kahneman however is too astute to deny any arousal effects. He states rather that such effects, while present, do not account for most of the pupillary changes during cognitive activity. Evidence demonstrating the influence of anxiety will be presented later, following completion of our attention to the influence of motor responses.

In replicating a previous study of theirs Paivio and Simpson (1968) and Simpson and Paivio (1968) found that dilations to abstract as compared to that to concrete words failed to reach statistical significance when the motor response mode was removed. To more completely evaluate the effects of muscle tension on pupillary activity Simpson and Climan (1971) monitored both pupil size and muscle tension (via EMG recordings) during an imagery task. Subjects were placed into one of the following five conditions: 1) depress key to indicate task completion, 2) release key to indicate task completion, 3) depress key for task-irrelevant reason, 4) release key for task-irrelevant reason, and 5) no motor response required. All groups showed significant dilation as compared to a control period. The amount of dilation for each group moreover ranked identically with the number assigned (e.g., group 1 had the greatest dilation, group 5 the least). The authors concluded that while the pupil dilates during a cognitive task (group 5) this effect is enhanced by even a task-irrelevant motor response (groups 3 and 4). For groups 1 and 2, where the motor response was relevant, the heightened dilations were explained as due to the presence of at least three sources of arousal - the cognitive task, the possibility of evaluation, and muscle tension. These findings are consistent with Kahneman, Peavler, and Onuska

(1968) as well as Sweeney (1968). The Sweeney study had compared "overt response" conditions (say vs. key press; specific answer vs. "now"[5]) a "covert response" condition, and a "no-response" condition. Both overt and covert conditions were found to be associated with significant dilations as compared to the no-response or control condition and the dilations for three of the four overt conditions were significantly larger than those for the covert condition.

Johnson (1971) provided evidence for the influence of arousal on pupil size during a short-term memory task. Johnson had reasoned that if the pupil response was related to shifts in processing load then a "signal to forget occurring part way through a list of serial recall material should result in a reduction in pupil size owing to the sudden elimination of the necessity to further rehearse or otherwise process that portion of the material preceding the signal." To test this hypothesis he presented subjects with five words, one every 2 seconds. The subjects were to recall these words. On half the trials however a tone was presented after either the first, second, third, or fourth word, the signal instructing the subjects to forget all preceding words and recall only those following. On no-tone-change trials the pupil response curve verified previous findings related to loading and unloading. On tone-change trials however signal presentation was typically

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[5] indicating answer obtained

followed (in approximately 1.5 secs.) by a dilation-constriction cycle. Johnson interpreted the dilation as indicating that signal presentation at first adds to the load since the tone change itself is a piece of information to be processed requiring that the subject distinguish the set of words to be forgotten from those to be remembered. The constriction following the dilation was interpreted as indicating a load-lightening phase in that the subject had completed his intentional forgetting and thus "dumped" the non-required words. Of particular interest here is that the constrictions became significantly less pronounced as the tone presentations approached recall. A "cognitive-load" hypothesis would not predict this.[6] Rather, as Johnson argued, the pattern must have resulted from "arousal associated with anticipation of recall", the constriction being diminished by increased arousal associated with closer recall.

Finally, in a comprehensive review of the literature relevant to the relationship between pupil size and anxiety Janisse (1976) concluded that pupillary dilation is clearly related to state anxiety but that the evidence is only suggestive as regards trait anxiety. Since that review Hicks and Azamtarrahian (1977) have added to the evidence on trait anxiety. It must be emphasized

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[6]The cognitive-hypothesis would have predicted the opposite of what was found. As tone presentations approached recall more information had to be "dumped" correspondingly lightening the mental burden. This should have led to increasingly pronounced constrictions.

however that the well established cognitive load-unload-pupil-size function has not been challenged by the findings in these studies.

Summary

To recapitulate: It appears clear that arousal manifested typically by muscular tension (overt responding) and anxiety may lead to pupillary dilation. At the same time it appears equally clear that the effects attributable to such arousal only enhance the well verified relationship between cognitive activity and the pupil response. Kahneman (1973, p. 24) in fact suggests a simple home exercise for those interested in confirming the cognitive-load hypothesis. If you face a mirror and look at your eyes as you attempt to solve a mathematical problem you should, according to Kahneman, notice after a few attempts that the pupil dilates in response to mental effort - and this in a situation that elicits neither an overt response nor test anxiety.

Yet despite all the evidence regarding the influence of contaminating arousal factors the experimenter is most certainly not relieved of the responsibility of controlling for such effects. As both Kahneman (1973) and Janisse (1977) are quick to point out, arousal effects are ubiquitous. Thus for the cognitive hypothesis to be invoked a study should have adequate controls to demonstrate that it is cognitive activity and not arousal that is responsible for the observations.

As regards more specifically the cognitive hypothesis, the research has demonstrated that the pupil dilates in response to thinking or mental effort ("load"), such dilation being monotonically related to task difficulty at both between and within-task levels.

STATEMENT OF PROBLEM AND PURPOSE

There are two intents to the present study, each tied to an area of unclarity or deficiency in the literature.

Continuous vs. Discontinuous Stimulus Material

Up to now tasks have typically employed stimulus material of the "discontinuous" or short-duration type. "Continuous" stimulus material is here defined as a series of grammatically coherent and linked statements. Thus far stimuli have been essentially non-verbal and highly discrete in nature - isolated arithmetic problems (e.g., 8 x 2), digit or word strings, tone discriminations, imaging to single word referents and the like. Some investigators (Stanners et al., 1971; Wright & Kahneman, 1971) have approached the use of "continuous" material, as the term is here defined. These investigators have employed single sentences as stimuli. While a sentence is certainly more "continuous" or connected than say a tone discrimination problem nonetheless the fact of total context exclusion and the inevitable brevity of thought captured in a single sentence seriously mitigates the degree of continuity of the material, again as the term is here defined.

Bradshaw (1968a) has employed what he called a "continuous-processing" task. Lest there be confusion, Bradshaw was referring to continuity not in relationship to the stimulus material per se but rather to a discriminable and operationalized set of response options. Thus Bradshaw could isolate a subject's solution strategy by tracing the response option chain taken to solution. The continuity here is thus solution related not stimuli related.

White and Maltzman (1978) employed continuous stimuli as here defined. Subjects were binaurally presented with verbal passages each of 120 seconds' duration, the passages designed to elicit either a pleasant, unpleasant, or neutral affective response. The study showed that dilation accompanied the pleasant and unpleasant passages compared to the neutral passage. These findings demonstrated the differential effects of arousal on the pupil response. Indeed the authors made no pretense that they were considering the variable of arousal and not that of cognitive effort.

Carver (1971) is the only one to have employed continuous stimulus material while studying the association between cognitive effort and pupillary activity. He had subjects either read or listen to what he called "connected discourse", represented by four verbal passages of 150 words each. Interestingly, Carver's data do not support previous findings relating pupillary activity to between-task difficulty. (Carver did not look at the within variable.) From all indications there should be no reason why the data for continuous material should not be consistent with data for discontinuous material. Indeed Carver's study is open to serious criticism. To this investigator the major criticism is that comparatively few data samplings were taken, ranging for example, in the various experiments reported, from a high of four samplings for a 20-sec. period to a low of three samplings for an 80-sec. period. Typically, samplings are in the order of at least 1 per sec., five times as many as Carver's maximum and over twenty-five times as many as his minimum!

As well, Carver did not take recordings during the output (test or recall (comprehension)) phases. And, as already indicated, he did not look at the within-task variable. Thus all in all nothing can be said from Carver (1971) of the characteristics of the pupil response during a cognitive task employing continuous stimulus material.

The first intent of the present study is therefore to extend previous work by employing continuous stimulus material. A large part of this effort is of course to discover if Carver's findings are indeed attributable to the criticism cited or whether he has happened on what would be an astounding finding, that the pupil response in fact does not index cognitive activity when continuous stimulus material is employed. Were the latter the case it would necessitate a major review of the cognitive hypothesis as related to pupillary activity.

Processing Ability

Given the established relationship between pupillary activity and cognitive process it is only reasonable to consider that intelligence or processing ability should be somehow related to the pupil response. There are but a handful of studies that directly attend to this question.

Janisse (1977) has reviewed these studies. He concludes that the results are suggestive at best. Nonetheless an emerging pattern to the findings is that a high ability (or intelligence) group as compared to a group relatively low in ability will show larger dilations when performing a cognitive task.

If one maintains that the high ability individual tends to exert greater mental effort than would a low ability individual when called to perform on a task then the above finding is consistent with what would have been predicted from the cognitive hypothesis.

In ending his review of this area Janisse (1977) recommends that in preference to employing tests measuring general intelligence investigators should define processing ability by using scores on a task that is highly similar to the task employed for the experiment proper. Janisse believes that this refinement will help eliminate a major source of confusion in the area.

If pupillary activity can be related to processing ability the validity and utility of the pupil as an index of cognitive process will be assuredly immeasurably enhanced. Thus the second and final intent of this study is to provide added data in this area while incorporating Janisse's important recommendation regarding design.

HYPOTHESES

The hypotheses to be tested are as follows:

1. Pupil size will be greater during problem-solving conditions or conditions calling for increased mental effort as compared to the baseline periods.

2. For problem-solving conditions pupil size will be positively related to task difficulty -- that is, it will be greatest for problem-solving conditions associated with the most difficult task, it will be moderately high for problem-solving conditions associated with the moderately difficult task, and it will be lowest for problem-solving conditions associated with the easiest task.

3. For problem-solving conditions, pupil size will be positively related to processing ability -- that is, during problem-solving conditions it will be higher for individuals demonstrating high ability as compared to those demonstrating poor ability.

METHOD

Subjects

Subjects for the study were recruited via notices distributed around the University of Windsor campus. From an initial sample of 74 respondents the first 36 to be reached who would commit themselves for the duration of the study were accepted as subjects. All subjects were students. Subjects received $5.00 an hour for participating.

Of the initial sample, nine subjects were lost. Two were lost because of personal emergencies, and seven because of severely distorted pupillary recordings attributable to either equipment failure, excessive movement during recording, or an inability to obtain a clear and scorable image of the subject's pupillary responses.

Valid data were obtained from 27 subjects. The final sample consisted of 15 males and 12 females ranging in age from 19 to 31 years with a mean of 23 years. Twenty-four subjects were undergraduates representing all levels from freshman to senior and a variety of faculties and majors. Three subjects were graduate students, one at the Master's and two at the Doctoral level.

Pupillary Apparatus

A Whittaker Corporation TV Pupillometer (Model 1081SG) with polygraph hookup (Lafayette Instrument Company, Model 76101) was employed to display the pupil and chart its activity. During recordings S sat on a chair that was adjustable in height, his head positioned in a cushioned frame of a chin/forehead rest. To S's immediate left and in the same horizontal plane as his eyes a video camera and attached infrared light source were mounted. The latter illuminated the left eye.

A fluorescent lamp calibrated to emit 6 fc of illumination was placed 2.25 m from S's back and at a 45° angle to his peripheral field of view. The lamp provided a controlled source of low-level ambient illumination with the room lights turned off.

A Kodak Ektagraphic slide projector (Model AF-2) with remote control slide changer was employed to project the stimulus material against a grey wall. Each image was approximately 3.15 m from the chin/forehead rest. The slides were achromatic and their general illumination levels were equated with a light meter.

Finally, a stop watch was employed to time the onset and duration of stimulus presentation and verbal responses were hand recorded by E upon verbalization by S.

Stimulus Materials

Problem Sets. The stimulus materials were a series of 150-word passages taken from Acquino (1969). These passages had been previously calibrated as to difficulty level (Acquino, 1969; Miller & Coleman, 1967).

The passages were formed into two separate groups or sets, labelled Sets 1 and 2. A third set of passages, labelled Set 3, was also employed. This set contained passages that were specially developed for this study to serve as control stimuli. Set 3 passages will be referred to later.

Sets 1 and 2 each contained four passages - a practice passage and three passages representing three levels of difficulty, easy (EASY), moderately difficult (MOD), and difficult (DIFF) (Appendix B, C, G, H).

In that Set 2 stimuli were employed while the pupillary responses were being recorded, various control stimuli had to be developed. These are described below in detail. Other than for the control stimuli, Set 2 stimuli were comparable to those of Set 1, that is, there was one EASY, one MOD, and one DIFF passage.

Control Stimuli: A) Nonsense Passages. Set 3 contained three specially constructed passages. Each passage was designed to yield a hypothetical nonsense structure (Appendix E).

The format for constructing a nonsense passage was as follows: 1) five previously unselected passages representing a given level of difficulty were selected from Acquino, 2) every fifth word, commencing with the first word of each passage, was then printed, each on a separate card, 3) the 150 card total was subsequently shuffled and then one at a time each card was randomly drawn from the deck and printed on a single sheet of paper in their order of appearance, and finally, 4) the sequence so arrived at was divided by periods. These periods were strategically placed to yield a product that was matched with respect to sentence number and sentence location to the Set 2 passage at the same level of difficulty as that of the original five passage selection.

The above procedure was repeated until a total of three nonsense passages were developed and individually matched to the Set 2 passage at the appropriate level of difficulty. Set 3 passages served as Reading Control (RC) stimuli for the Experimental phase. (The different phases of the study will be addressed later.)

Control Stimuli: B) Random Pattern Fixation Stimuli. In addition to the above, six slides containing a random pattern of asterisks were developed (Appendix F). These would be used for fixation-control purposes as well as to provide baseline data for pupillary measures during the pupillary recording period. The experimental conditions where these slides were utilized were labelled FC, 1 through 6.

Mode of the Presentation. Set 1 passages were presented in booklet form while Set 2 passages were projected from slides. Also projected from slides were the control stimulus materials that were developed for the Experimental phase, that is, the FC and Set 3 or RC stimuli.

Table 1 presents the characteristics of the various passages comprising the stimulus material sets.

Task

S was presented with a passage to read for 60 seconds. After

Table 1

Identification Number And Characteristics

Of The Passages Employed

In The Study

Set No.	Identification No. From Acquino (1969)	Difficulty Count	Assigned Difficulty Level	Total No. Of Sentences
	11	44.0	EASY	8
1	22	86.0	MOD	8
	36	142.0	DIFF	8
	12	44.0	EASY	11
2	23	86.5	MOD	11
	34	131.0	DIFF	10
	9,10,13,14,15[a]	24.0 - 57.5[b]	EASY	11[e]
3	20,21,24,25,26[a]	77.0 - 102.5[c]	MOD	11[e]
	30,31,32,33,35[a]	126.0 - 131.0[d]	DIFF	10[e]

[a]five passage group employed to derive single nonsense passage.

[b]represents range; X = 43.7.

[c]represents range; X = 92.8.

[d]represents range; X = 128.4.

[e]number refers to the sentences in the particular nonsense passage product.

the time limit had expired, and without opportunity to return to the passage, he was subsequently presented with a four-word phrase. This phrase was selected from the passage just read. The task required of S was that he identify the number of the sentence (e.g., first, second, or third, etc.) from which the phrase was selected. A total of three phrases or selections were presented for solution following each passage. Only Set 1 and Set 2 passages were employed for task purposes. Set 3 passages were presented only to be read. The sequence of appearance of each of the three sets is presented in the next section.

More specifically as regards the task, upon phrase presentation E waited for S to verbally provide his solution in the form of a sentence number. Upon such verbalization E immediately responded with either "correct" or "incorrect." If the solution attempt was unsuccessful S continued until a successful solution was obtained. No time limit of any sort was imposed. Only after a solution was achieved were the second and then the third phrases presented. The process to solution for these phrases was exactly as above. The identical cycle was then repeated for each of the other passages and their associated phrase selections.

In order to provide some limits to the solution process for S a number designating the total number of sentences contained in the passage appeared immediately above the passage. S was thus provided with an anchor point around which he could organize his thinking strategy. The individual sentences in the passage were, however, not numbered. Derivation of these numbers was left to S as part of the task or process demand.

In addition to the above primary task requirement S was also requested to A) indicate at each solution attempt how certain or confident he was of his response and B) rank order the passages as to their perceived level of difficulty.

As regards the former, S was instructed to follow his solution response with either a 1, 2, or 3 -- 1 indicating he was absolutely certain as to the correctness of his response, 2 indicating he was moderately certain, and 3 indicating that he was not at all certain (i.e., he was guessing). Thus if S felt that the given phrase belonged to sentence number six and was absolutely certain of this he would respond 6-1, if he were guessing, then 6-3, the first number always being the sentence number, the second always being the confidence or certainty indicator.

With regard to the final task requirement S was asked for his subjective rankings of the difficulty levels of the passages presented. This request was introduced only after all other task procedures were completed. Specifically, the request was presented verbatim as follows, "Without any attention to the different phrases which of the preceding three passages that you have read was the most difficult, which the easiest, and which was of intermediate difficulty? Please take as much time as you need and weigh your decisions carefully." The following numbers were assigned to each rank: 1 - most difficult, 2 - intermediate difficulty, 3 - easiest.

Procedure

There were two phases to this study. The first phase was called the Group Formation phase and the second, the Experimental phase. It was in the Experimental phase that pupillary recordings were obtained. The purpose of the first phase was to establish groups at two levels of processing ability, differentiating them on the basis of their performance scores on the task employed. (The scoring procedure for this is described later.)

The Group Formation Phase. S was instructed as to the nature of the task to be presented (Appendix A). Employing stimulus material reserved solely for this purpose (Appendix G) a practice trial followed and opportunity was provided to clear up any misconceptions or areas of confusion.

Once E was satisfied that all was understood S was administered the task employing Set 1 stimuli. Each passage together with its corresponding three phrase selection was presented in booklet form. Excluding the practice material, there was a total of three such booklets, one booklet for each passage - phrase combination. In any given booklet the passage and each of three phrases appeared on separate pages. These pages were in turn divided by a number of blank pages to prevent premature exposure.

Once all booklets (i.e., trials) had been presented and all task requirements met an appointment was made with S to complete the second or Experimental phase.

The procedure for group differentiation in this first phase was as follows. For each solution attempt on the task S received one point. Points were summed for each S across the three task trials. Thus each S obtained an overall or total performance score. A performance mean was then calculated for each S by dividing his total score by 9, the total number of phrases in the task requiring solution (3 passages, 3 phrases each). The figure so obtained was S's performance attempts per phrase. The smaller the mean the fewer the average number of solution attempts, and therefore the more efficient the performance.

Ss were then ordered from lowest to highest on the basis of their mean score. Ss in the top half of the distribution, that is those with the lowest means, formed the High Ability (HA) group and Ss in the bottom half of the distribution, that is those with the largest means, formed the Low Ability (LA) group. The division arrived at yielded 14 Ss for the High Ability group and 13 Ss for the Low Ability group. Table 2 presents the sequence, type, and duration of stimuli comprising a "trial" in this first phase.

The Experimental Phase. Between one to seven days following the Group Formation phase S was brought to the laboratory containing the pupillometry equipment. S was familiarized with the surroundings, apparatus and forthcoming procedure. As regards the procedure, particular emphasis was placed on informing S that when a nonsense

TABLE 2

Sequence, Type, And Duration Of Stimuli

Defining A "Trial" In The

Group Formation Phase

(Employing Set 1 Stimuli)

Order of Appearance of Condition No.	Stimulus	Duration
1	PASSAGE (PASS)[a] (Passage At One Of The Three Levels of Difficulty)	60 sec.
2	FIRST PHRASE (PH 1) (First Of Three Phrases Selected From Preceding Passage)	NO LIMIT
3	SECOND PHRASE (PH 2) (Second Of Three Phrases Selected From Preceding Passage)	NO LIMIT
4	THIRD PHRASE (PH 3)[b] (Third Of Three Phrases Selected From Preceding Passage)	NO LIMIT

[a]The order of presentation of EASY, MOD, and DIFF passages was counterbalanced.

[b]Between 60-180 seconds following completion of this last condition S was asked to rank order the passages as to relative difficulty level.

or RC passage appeared it was only to be read, that there would be no test or phrase solution requirements for these passages (Appendix D).

The experimental stimuli for this phase employed Set 2 and Set 3 stimuli as well as the fixation - control or FC slides with the random pattern of asterisks. The sequence of presentation of the various stimuli in this phase defined a "trial" for this phase. Table 3 details this sequence.

In each trial the level of difficulty of the passage utilized was noted. Trial order and, therefore, the level of difficulty of passages presented, was counterbalanced. As Table 3 indicates the FC conditions appeared at the beginning and end of each trial as well as between every other condition be it reading or phrase solution.

All trials were separated by five-minute rest intervals, including the practice and initial experimental trial. As in the first phase, the practice trial here employed stimulus material reserved solely for practice purposes (Appendix H).

Other than the fact that the practice trial here did not contain a nonsense or RC passage the procedure for it was identical to that of the experimental trials. And finally, aside from employing different stimulus sets for the task (i.e., Sets 2 and 3 vs. Set 1), the essential difference between the Group Formation phase and the Experimental phase was that pupillary recordings were obtained only for this latter phase.

Summary

Table 4 provides a summary of the complete procedure.

TABLE 3

Sequence, Type, And Duration Of Stimuli

Defining A "Trail" In

The Experimental Phase

(Employing Set 2, Set 3, and Fixation - Control Stimuli)

Slide/Condition No.	Stimulus	Duration
1	FIXATION-CONTROL (FC#1) (Random Pattern of Asterisks)	30 sec.
2	READING-CONTROL (RC) (Nonsense Passage)	60 sec.
3	FIXATION-CONTROL (FC#2) (Random Pattern of Asterisks)	30 sec.
4	PASSAGE (PASS)[a] (Passage At One of the Three Levels of Difficulty)	60 sec.
5	FIXATION-CONTROL (FC#3) (Random Pattern of Asterisks)	30 sec.
6	FIRST PHRASE (PH 1) (First of Three Phrases Selected From Passage In Condition 4)	NO LIMIT
7	FIXATION-CONTROL (FC#4) (Random Pattern of Asterisks)	30 sec.
8	SECOND PHRASE (PH 2) (Second Of Three Phrases Selected From Passage In Condition 4)	NO LIMIT
9	FIXATION-CONTROL (FC#5) (Random Pattern of Asterisks)	30 sec.

TABLE 3 Continued

Slide/Condition No.	Stimulus	Duration
10	THIRD PHASE (PH 3)[b] (Third of Three Phrases Selected From Passage In Condition 4)	NO LIMIT
11	FIXATION-CONTROL (FC#6) (Random Pattern of Asterisks)	30 sec.

[a]The order of presentation of EASY, MOD, and DIFF passages was counterbalanced.

[b]Between 60-180 seconds following completion of this last condition S was asked to rank order the passages as to relative difficulty level.

TABLE 4

Summary of Procedure

FIRST OR GROUP FORMATION PHASE	- Administer task employing Set 1 stimuli
	- Score performance; obtain performance mean for each subject
	- Divide subjects into two groups on the basis of their mean score
	- Label groups High Ability (HA), and Low Ability (LA)
SECOND OR EXPERIMENTAL PHASE	- Administer task employing Set 2, Set 3, and Fixation-Control stimuli
	- Record pupillary activity throughout a "trial"

RESTATEMENT OF HYPOTHESES

Given the design of the study the hypotheses to be tested can now be stated more specifically. They are as follows:

1. Pupil size will be greater during conditions calling for increased mental effort, that is, problem-solving conditions PASS, PH 1, PH 2 and PH 3, as compared to non-problem conditions FC1, RC, FC2, FC6. Conditions FC3, FC4 and FC5 are excluded because they represent periods during the task where retention and consolidation of information is required. These latter conditions therefore warrant separate treatment.

2. For problem-solving conditions (i.e., PASS, PH 1, PH 2, and PH 3) pupil size will be positively related to task difficulty as defined by the passage difficulty level, EASY, MOD, and DIFF. Thus pupil size will be greatest for problem-solving conditions during trials employing the DIFF passage, it will be moderately high for problem-solving conditions during trials employing the MOD passage, and it will be lowest for problem-solving conditions during trials employing the EASY passage.

3. For problem-solving conditions (i.e., PASS, PH 1, PH 2, and PH 3) pupil size will be positively related to processing ability, that is, it will be greater for the High Ability (HA) group as compared to the Low Ability (LA) group.

RESULTS

Task Performance (Behavioral) and Passages Rankings Data

(i) Group Formation Phase

The mean number of solution attempts for DIFF, MOD and EASY trials were 10.9, 8.7 and 6.4, respectively. Comparisons of these means yielded significant results for all comparisons; that is, the DIFF trial required significantly more attempts than did either the MOD or EASY trials, and the MOD trial in turn required significantly more attempts than did the EASY trial. Table 5 presents the individual comparisons and related results.

The data on passage rankings are presented in Table 6. Twenty-one Ss ranked the DIFF, MOD and EASY passages, respectively, as most difficult, next most difficult and easiest. This finding was significant ($x^2 = 75$; df = 5; $p < .001$).

Thus both the task performance and passage rankings data provide firm and consistent support for the Difficulty classification of the passages. Recall that Set 1 stimulus materials were employed in this first phase.

(ii) Experimental Phase

The mean number of solution attempts for DIFF, MOD and EASY trials were 13.8, 11.6 and 10.0, respectively. Comparisons of these means yielded significant results for only the DIFF

TABLE 5

Results of t-Tests[a] on Mean Differences of Performance Scores for the Three Trials: The group Formation Phase (Phase 1)

COMPARISON	t-Value	df	p
DIFF ($\bar{x}$ = 10.89) vs. EASY ($\bar{x}$ = 6.44)	5.16	26	$< .01^*$
DIFF ($\bar{x}$ = 10.89) vs. MOD ($\bar{x}$ = 8.74)	3.12	26	$< .01^*$
MOD ($\bar{x}$ = 8.74) vs. EASY ($\bar{x}$ = 6.44)	3.11	26	$< .01^*$

[a]Correlated observations; one-tailed.

TABLE 6

Observed Frequencies of Passage Rankings for the Group Formation Phase (Phase 1)

Rankings: Most to Least Difficult	Observed Frequency[a]
DIFF-MOD-EASY[b]	21
DIFF-EASY-MOD[b]	4
MOD-DIFF-EASY[b]	0
MOD-EASY-DIFF[b]	0
EASY-DIFF-MOD[b]	1
EASY-MOD-DIFF[b]	1

[a] $\sum fo = 27$

[b] Expected frequency of event occurring = 27 x 1/6 = 4.5

vs. EASY comparison. Thus the DIFF trial required significantly more solution attempts than did the EASY trial. The number of attempts required for the MOD trial as compared to the number required by either the DIFF or EASY trials were not significantly different. Table 7 presents the individual comparisons and related results.

The data on passage rankings are presented in Table 8. Thirteen Ss ranked the DIFF, MOD and EASY passages, respectively, as most difficult, next most difficult and easiest. This finding was significant ($x^2 = 24.33$; df = 5; $p < .001$).

The findings for this phase indicate then that the task performance data discriminate only between DIFF and EASY Difficulty levels whereas the rankings data, which consider only the passages, lend full support to the Difficulty classification. Recall that Set 2 stimulus materials were employed in this second phase.

In conclusion, the findings from both the Group Formation and the Experimental phases indicate that the task performance and passage rankings data tend to strongly support the Difficulty classifications of both Set 1 and Set 2 stimulus materials. Complete and consistent support was provided for the Difficulty classification of Set 1 stimuli.

Discrimination of Groups

In the Group Formation phase two groups were discriminated as to processing ability on the basis of the performance scores. The

TABLE 7

Results of t-Tests[a] on Mean Differences of Performance Scores for the Three Trials: The Experimental Phase (Phase 2)

COMPARISON	t-Value	df	p
DIFF ($\bar{x}$ = 13.8) vs. EASY ($\bar{x}$ = 10.0)	2.36	26	<.02*
DIFF ($\bar{x}$ = 13.8) vs. MOD ($\bar{x}$ = 11.6)	1.30	26	N.S.
MOD ($\bar{x}$ = 11.6) vs. EASY ($\bar{x}$ = 10.0)	1.13	26	N.S.

[a]Correlated observations; one-tailed.

TABLE 8

Observed Frequencies of Passage Rankings for the Experimental Phase (Phase 2)

Rankings: Most to Least Difficult	Observed Frequency[a]
DIFF-MOD-EASY[b]	13
DIFF-EASY-MOD[b]	7
MOD-DIFF-EASY[b]	2
MOD-EASY-DIFF[b]	2
EASY-DIFF-MOD[b]	1
EASY-MOD-DIFF[b]	2

[a] $\sum f_o = 27$

[b] Expected frequency of event occurring = 27 x 1/6 = 4.5

groups so formed, the High Ability (HA) group and the Low Ability (LA) group, contained 14 and 13 Ss, respectively.

In the Experimental phase performance scores were again employed to divide Ss into HA and LA groups. The distribution of scores in the second phase resulted in only 8 of the 27 Ss changing group affiliation when compared to standings in the first phase.

A one-tailed Signs test for correlated samples shows this low incidence to be statistically significant ($z = 1.92$; $p < .05$) (Ferguson, 1971). The Spearman's rank correlation test provides further support by confirming that Ss rankings in performance efficiency from the first to the second phase of the study were closely parallel ($t = 3.46$; $df = 25$; $p < .005$).

In sum the data supports the reliability of the classification of the groups into different ability levels and adds confidence to the validity of the discrimination procedure employed.

To review, the task performance and passage rankings data strongly suggest that the Difficulty classification variable is valid. The data on group discrimination similarly indicates that the Groups of abilities classification variable is valid. Taken together this indicates that further analysis comparing pupil size in relation to the above variables is meaningful.

The raw data for non-pupillary measures is presented in Appendices I and J.

Pupillary Data

(i) Scoring

The chart record for each trial was read to the nearest tenth of a millimeter by manual scoring with the aid of a ruler. Readings were taken at 0.80-second intervals from the start of a trial.

A reliability check of the scoring was made by randomly selecting two previously scored records and rescoring a randomly selected section from each record. The reliability coefficients were 0.91 and 0.93 indicating good reliability to the scoring.

The total number of observations comprising the full data set was 48,792. The raw data for cell means is presented in Appendix K.

(ii) Analyses

For purposes of statistical simplification three Ss were dropped from further treatment. The S falling midway in the Groups classification distribution was dropped (No. 15) to equalize the number of Ss in the HA and LA groups. As well two randomly selected Ss were dropped, one from each of the above groups (No. 1, No. 6), to further reduce the total complement of Ss to 24 and thus make the data more amenable to statistical manipulation.

A three-way analysis of variance (Groups x Conditions x Difficulty Level) with repeated measures on the last two factors was employed to analyze the data on mean pupil size.

The summary table of the ANOVA is presented in Table 9. The results show a significant main effect for Conditions and significant interaction effects for the Conditions by Group and Conditions by Difficulty levels. No other effects were significant. These findings indicate that the mean pupil size was differentially affected by the eleven treatment conditions comprising a trial and further that the ability level of S as well as the difficulty level of a trial each had influence on this differential response. The non-significant findings for the remaining main and interaction effects indicate that these factors did not elicit a differential response in pupil size.

The ANOVA results will be discussed further in relation to the hypotheses under consideration.

HYPOTHESIS 1

> Pupil size will be greater during conditions calling for increased mental effort, that is, problem-solving conditions PASS, PH1, PH2 and PH3, as compared to non-problem conditions FC1, RC, FC2, and FC6. Conditions FC3, FC4 and FC5 are excluded because they represent periods during the task where retention and consolidation of information is required. These latter conditions therefore warrant separate treatment.

The ANOVA reveals a significant main effect for the Conditions factor. This finding indicates that the pupillary response was sensitive to changes in the Conditions or within-task variable. Table 10 presents the mean pupil size scores for each of the eleven

TABLE 9

Summary ANOVA of Mean Pupil Size

Source	SS	df	MS	F	P
Between Subjects					
A (Groups)	10,831.76	1	10,831.76	0.08	0.78
Subj. w. groups [error (a)]	2,938,223.46	22	133,555.61		
Within Subjects					
B (Conditions)	242,058.44	10	24,205.84	28.85	< 0.01*
AB	26,457.08	10	2,645.71	3.15	< 0.01*
B x subj. w. groups [error (b)]	184,585.72	220	839.03		
C (Trial/Passage Difficulty level)	3,765.98	2	1,882.99	0.33	0.72
AC	9,641.40	2	4,820.70	0.83	0.44
C x subj. w. groups [error (c)]	254,313.88	44	5,779.86		
BC	15,856.85	20	792.84	2.12	< 0.01*
ABC	5,719.82	20	285.99	0.77	0.76
BC x subj. w. groups [error (bc)]	164,378.64	440	373.59		

TABLE 10

Mean Pupil Size by Condition

CONDITION										
FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
3.66	3.64	3.79	3.89	3.93	4.16	4.00	4.18	3.96	4.12	3.92

conditions. Fig. 7 presents this data in graph form.

The Duncan Multiple-Range Test was employed to delineate the profile of this differential response in pupil size. All possible mean comparisons were considered. The results of these tests are presented in Table 11. The results show that of the sixteen predicted differences all but two were borne out. The two comparisons, both involving the PASS condition, one against the FC2 and one against the FC6 condition, were the only ones to prove non-significant.

The lack of significant effects for the PASS vs. FC2 comparison appears related to the significantly elevated pupil size for the latter condition. The elevation is likely attributable to anticipatory anxiety in that the FC2 condition immediately precedes the PASS condition and therefore the initial presentation of a 'problem' stimulus. The anxiety and consequent elevation in pupil size was clearly large enough to render the comparison of scores for the FC2 and PASS conditions non-significant.

The non-significant finding for the PASS vs. FC6 comparison is puzzling. The significant decrease in pupil size from the PH3 to the FC6 condition was expected and predicted because the latter condition represents the termination period when all information can be unloaded as the task had reached completion. The decrease was however surprisingly not large enough to distinguish the mean pupil size from that of the PASS condition. In attempting to explain this observation the possibility arises that during the FC6 condition Ss may

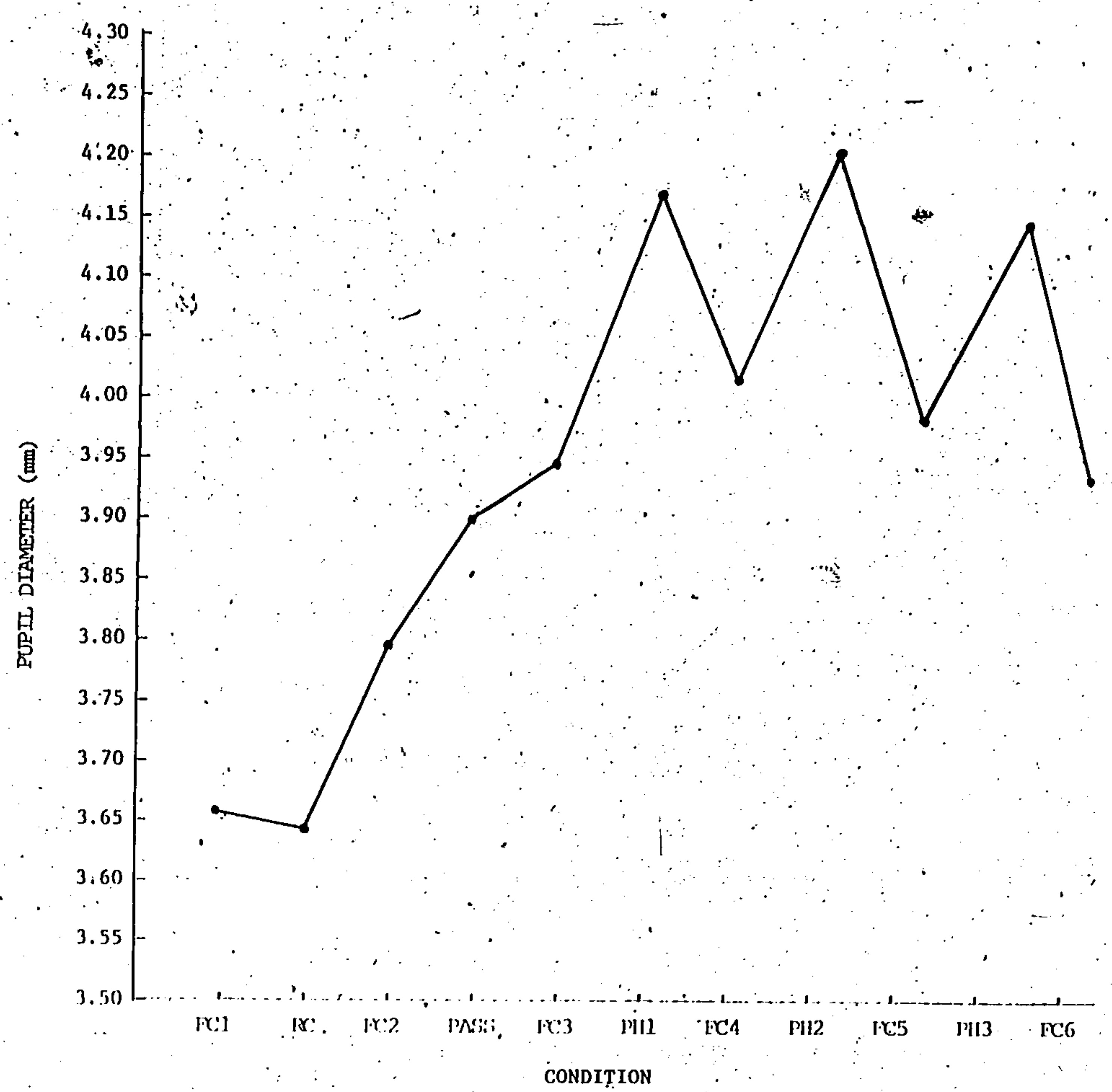

Fig. 7 Mean Pupil Size by Condition

TABLE 11

Results of All Possible Comparisons of Mean Scores for Each Condition Employing the Duncan's Test

	RC (3.64)	FC1 (3.66)	FC2 (3.79)	PASS (3.89)	FC6 (3.92)	FC3 (3.93)	FC5 (3.96)	FC4 (4.00)	PH3 (4.12)	PH1 (4.16)	PH2 (4.18)
RC			*	*	*	*	*	*	*	*	*
FC1			*	*	*	*	*	*	*	*	*
FC2					*	*	*	*	*	*	*
PASS								*	*	*	*
FC6									*	*	*
FC3									*	*	*
FC5									*	*	*
FC4									*	*	*
PH3											
PH1											

*$p < .05$

have been mentating about the task that yet awaited them -- the rankings of the passages. They would have been aware that this task remained because of the instructions and earlier training during the Group Formation phase. The 'cognitive hypothesis' would in fact predict that if Ss were mentating then this would have had the effect of retarding any prevailing tendency toward decrease in the pupil size.

To check this possibility mean pupil size scores for PASS and FC6 conditions were calculated for each trial presentation according to trial position; that is, scores were obtained for the PASS and FC6 conditions for the first, second and third trials presented without regard to the difficulty level of the passages involved. Comparisons of PASS and FC6 means for each trial position revealed non-significant differences (Appendix L). If Ss had been mentating during the FC6 condition of the final task trial the PASS vs. FC6 comparison should nonetheless have been significantly different for trial positions one and two because the passage rankings task was presented only after the final or third trial. The lack of significant findings suggests that the passage rankings task did not have retroactive effect and could not account for the non-significant PASS vs. FC6 comparison in the overall analysis. The lack of significant findings for the PASS vs. FC6 condition in the overall analysis therefore remains unexplained.

Pupil size for each of conditions FC3, FC4 and FC5 was significantly different from those observed for the three initial control conditions, FC1, RC and FC2. Given that FC3, FC4 and FC5 conditions all follow the PASS condition and each immediately precedes a problem-presentation period (i.e., PH1, PH2 and PH3, respectively), the differences observed appear attributable to information retention and consolidation during these latter control or 'information hold' conditions. The findings here, while not predicted, are entirely consistent with the 'cognitive hypothesis.'

Figure 8 presents graphically the mean pupil size scores for the RC, PASS, PH1, PH2 and PH3 conditions. To repeat, the four problem-solving conditions were all significantly different from the RC condition. In that the RC stimulus could be considered to represent a better control factor than the FC stimulus because of the former's designed similarity to PASS stimuli this set of results can, on their own merit, be considered to provide strong support for Hypothesis 1.

In sum, the weight of the overall evidence indicates confirmation of Hypothesis 1.

HYPOTHESIS 2

> For problem-solving conditions (i.e., PASS, PH 1, PH 2, and PH 3) pupil size will be positively related to task difficulty as defined by the passage difficulty level, EASY, MOD, and DIFF. Thus pupil size will be greatest for problem-solving conditions during trials employing the DIFF passage, it will be moderately high for problem-solving conditions during trials employing the MOD passage, and it will be lowest for problem-solving conditions during trials employing the EASY passage.

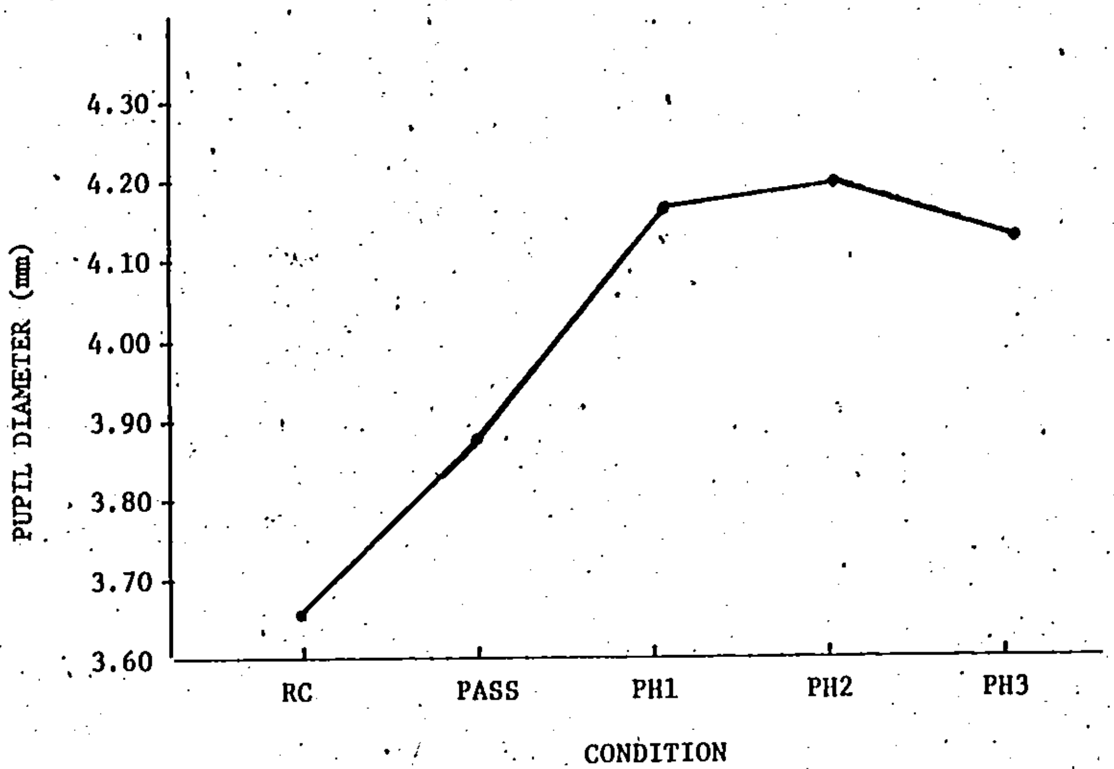

Fig. 8 Mean Pupil Size for the RC and Four Problem-Solving Conditions

The ANOVA reveals a non-significant Trial/Passage Difficulty Level main effect. There is however, as predicted, a significant Conditions by Difficulty Level interaction effect. This indicates that the pupil size associated with the differentially difficult trials was not independent of the effects of the individual conditions or within-task periods. Table 12 presents the mean pupil size for conditions and trial/passage and Fig. 9 graphically presents this same data.

To test the specific predictions of the hypothesis; that is, to determine whether pupil size for the problem-solving conditions was sensitive to the effects of the different tasks simple effects analyses are called for. However the formulas offered by Winer (1971, p. 545) for both the F ratio denominator and the Satterhwaite approximation to obtain the required degrees of freedom to test the ratio yielded blatantly non-significant findings across all comparisons for each simple main effect.

Essentially, the excessively high between-subjects variability (error (a)) was felt to have rendered the usual model inadequate for this particular data set. An ANOVA conducted on the data employing only RC, PASS, PH1, PH2 and PH3 conditions led to findings identical to those obtained in the larger ANOVA as regards effects, but the high variability element was not adequately reduced (Appendix M). Unfortunately, an appropriate model could not be derived to identify the sourcepoints for the significant interaction

TABLE 12

Mean Pupil Size by Condition and Trial/Passage

Difficulty Level

Trial/ Passage	CONDITION										
	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
EASY	3.70	3.71	3.80	3.90	3.94	4.14	3.94	4.21	3.96	4.09	3.91
MOD	3.68	3.54	3.78	3.85	3.94	4.23	4.11	4.24	4.04	4.19	3.96
DIFF	3.60	3.68	3.81	3.91	3.93	4.12	3.96	4.09	3.90	4.09	3.89

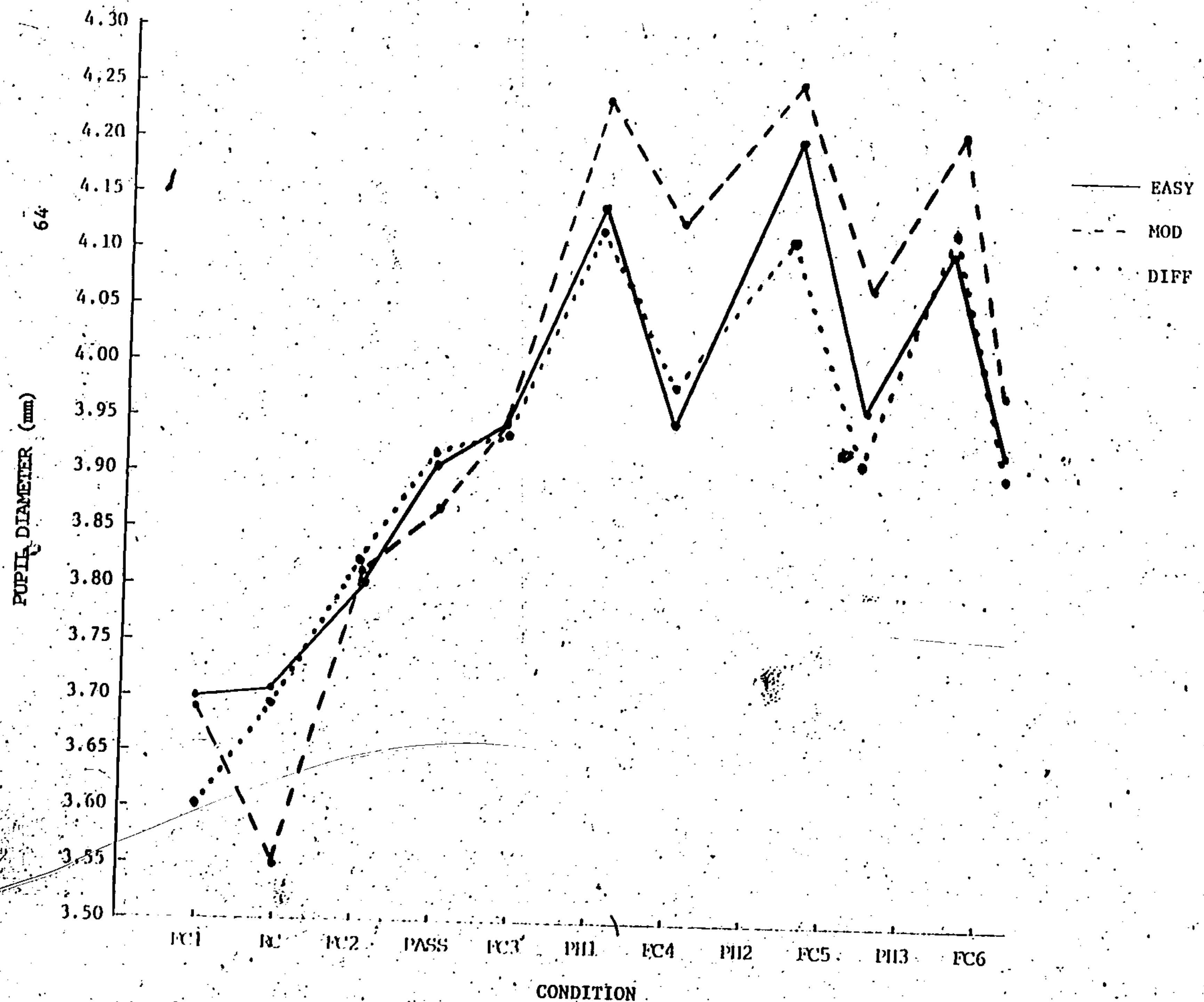

Fig. 9 Mean Pupil Size by Condition and Trial Passage Difficulty Level

effect in either the overall or small ANOVA.

Nonetheless given that specific predictions had been made it was felt incumbent to conduct tests on the relevant comparisons so as to provide some semblance of the required information. A series of t-tests were therefore performed employing, where population variances were found to be unequal, Cochran and Cox's critical values technique which makes an adjustment in the t-values required for significance. The tests revealed non-significant findings for all but one comparison (PH2-MOD vs. PH2-DIFF; $t = 1.77$; $df = 22$; $p < .05$). These results suggest a lack of support for Hypothesis 2. It would appear that much of the contribution to the significant interaction effect is derived from cell comparisons other than those identified in the hypothesis (e.g., RC-EASY vs. RC-MOD; FC4-EASY vs. FC4-MOD).

Moreover visual inspection of the data in Table 12 and Fig. 9 suggests that mean pupil dilation was generally highest for problem-solving conditions associated with the MOD trial, there being generally little difference in scores for similar conditions for DIFF and EASY trials. The pupillary data employing mean pupil size suggests therefore a clear lack of congruence with the Difficulty classification profile indicated by the behavioral data where the DIFF trial was found to be associated with a significantly greater number of solution attempts than that associated with the EASY trial.

Beatty and his associates (Beatty and Wagoner, 1978; Ahern and Beatty, 1979) have reported that in addition to mean pupil size peak pupillary dilation scores will discriminate tasks of differing difficulty level. Interestingly, when peak scores are determined for the present data for problem-solving conditions and control conditions requiring information retention all seven conditions reveal larger scores for the DIFF trial as compared to the EASY trial (Table 13). This finding is significant ($x^2 = 10.29$; $df = 1$; $p < .01$). Tests on individual comparisons however once again proved non-significant.

Peak pupillary dilation scores are more susceptible to the effects of random variation than is the mean pupil size. Ordinarily one might have less confidence in the validity of the single score of maximum value as a discriminating measure. However the consistent pattern of these scores does yield significance and as such the finding cannot be ignored particularly in view of the fact that it corroborates the findings of the behavioral data.

Peak pupil size for control conditions FC1, RC, FC2 and FC6 shows no consistent pattern for comparisons across EASY, MOD and DIFF trials. This finding would be expected if the peak pupil size reflects processing load in that during the above set of conditions processing would be assumed to have occurred at non-differential levels. Consequently, one tends to be more confident that the pattern of findings obtained for the seven 'problem' conditions - where directional differences would be expected and were obtained - provides a valid demonstration of differences in processing load. Figure 10 graphically presents the data on mean peak pupil size for EASY and DIFF trials.

TABLE 13

Mean Peak Pupil Size by Condition and Trial/Passage

Difficulty Level

Trial/Passage Difficulty Level	CONDITION										
	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
EASY	4.12	4.15	4.33	4.33	4.40	4.64	4.43	4.79	4.43	4.74	4.95
MOD	4.16	4.10	4.23	4.29	4.33	4.90	4.69	4.88	4.54	4.78	4.48
DIFF	4.16	4.22	4.33	4.40	4.50	4.83	4.45	4.90	4.51	4.76	4.43

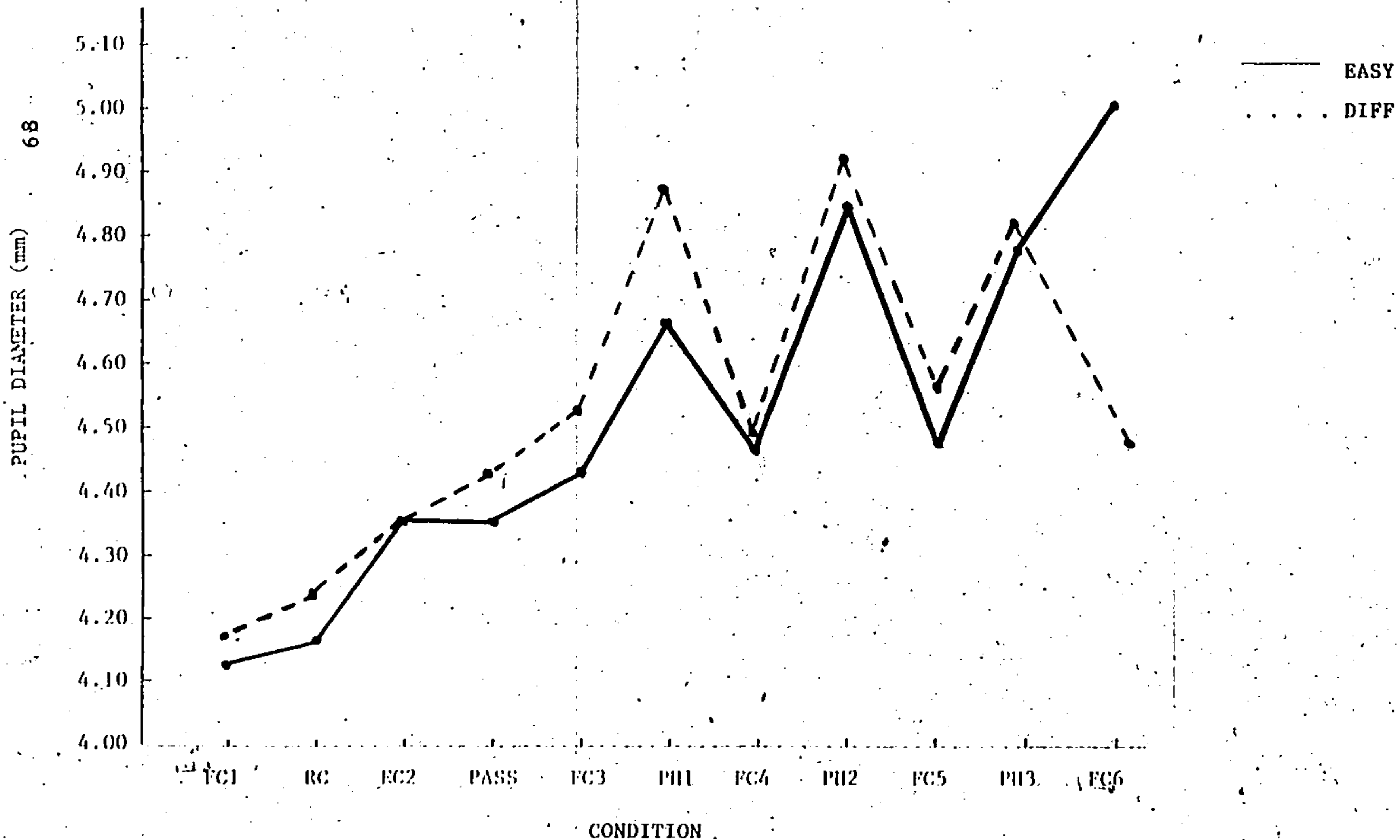

Fig. 10. Mean Peak Pupil Size for EASY and DIFF Trials.

A cautious but appropriate interpretation of findings from all analyses in this area would be that the present data do provide strong suggestive evidence that the pupillary response is indeed sensitive to the task difficulty variable. There is, in effect, reason to assume confirmation of the specific predictions that together represent Hypothesis 2 albeit such confirmation rests on use of the peak pupil size rather than the mean pupil size as the dependent measure.

HYPOTHESIS 3

> For problem-solving conditions (i.e., PASS, PH 1, PH 2, and PH 3) pupil size will be positively related to processing ability, that is, it will be greater for the High Ability (HA) group as compared to the Low Ability (LA) group.

The ANOVA shows a non-significant main effect for the Groups factor. There is however, as predicted, a significant Groups by Conditions interaction effect confirming that the Groups variable did achieve differential influence on the Conditions variable. Table 14 presents the mean pupil size by condition and group and Fig. 11 presents the same data in graph form.

Once again simple effects analyses were called for to ferret out the sourcepoints for this interactive effect. However, as previously, the extremely large between-subject variability rendered the available model inappropriate and no adequate alternative model could be derived.

Given however that specific predictions had been made t-tests were employed to test the relevant individual comparisons to provide

TABLE 14

Mean Pupil Size by Condition and Group

Group	CONDITION										
	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
HA	3.76	3.78	3.90	3.93	3.97	4.13	4.01	4.15	3.95	4.12	4.00
LA	3.54	3.49	3.67	3.83	3.88	4.18	3.98	4.20	3.97	4.11	3.93

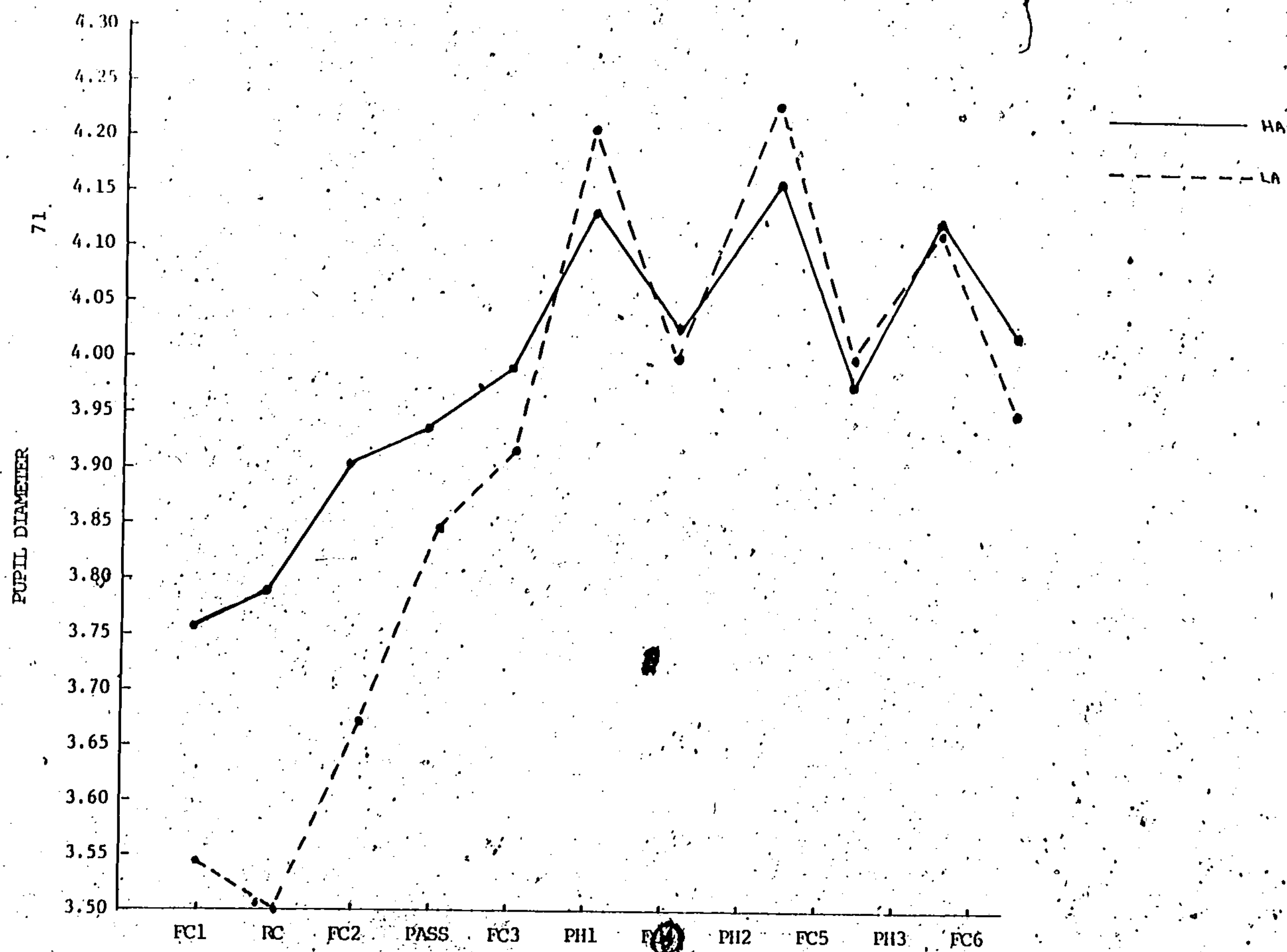

Fig. 11. Mean Pupil Size by Condition and Group

some hint of the necessary information. Cochran and Cox's critical values test was used where indicated to adjust the t-values required for significance. The tests revealed non-significant findings for all comparisons. It would appear then that the interaction effect is due to differential pupil size in other cell comparisons within the conditions by groups table block.

Visual inspection of the data in Table 14 reveals that the pupil size for conditions FC1, RC and FC2 for the LA group are consistently smaller compared to similar scores for the HA group. A series of t-tests employing Cochran and Cox's technique revealed no significant differences across all comparisons of the above between the two groups. Yet the 'cognitive hypothesis' would predict smaller pupillary dilation for the LA group as the observations clearly indicate. Indeed considering all conditions the LA group showed a smaller mean pupil size for 8 of the 11 conditions. The probability of such an occurrence only approached significance ($x^2 = 2.90$; df = 1; $p < .10$). However when change scores were calculated for sequential paired comparisons within each group and the scores so obtained compared as to absolute size nine of the ten comparisons were found to yield scores that are larger for the LA group (Table 15). A Chi-Square test employing Yates' correction showed this finding to be significantly different from what would have been expected by chance occurrence alone ($x^2 = 9.8$; df = 1; $p < .01$).

This finding suggests that the LA group's sequential pattern of

TABLE 15

Difference Scores of Mean Pupil Size Between Sequential Conditions According to Group

	CONDITION										
Group	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
HA	+.02	+.12	+.03	+.04	+.16	-.12	+.14	-.20	+.17	-.12	
LA	-.05	+.18	+.16	+.05	+.30	-.20	+.22	-.23	+.14	-.18	
Ratio of Absolute Values	<1	<1	<1	<1	<1	<1	<1	<1	>1	<1	

change in pupillary response, from condition to condition within a trial, is characterized by greater fluctuation than the associated response change pattern found for the HA group. More simply, when the pupil size for the LA group increased as S moved from segment to segment within the task the response change tended to be larger than that found for the HA group; similarly, when the pupil size decreased it tended to decrease to a greater extent than that observed for the HA group.

Daly (1966) as indicated earlier has suggested that enhanced fluctuation in the pupillary response reflects unstable concentration or attention. If this interpretation has validity then the present finding could well reflect inadequate or compromised concentration associated with the LA group, such a deficiency leading not unexpectedly to poor behavioral outcome.

When peak pupil size scores were determined for the two groups the LA group showed higher scores for all four problem-solving conditions and for one of three control conditions requiring information retention (Table 16; Fig. 12). This finding is non-significant as are any individual comparisons of scores between the groups. It is interesting to note however that when the mean and peak pupil size scores are considered for conditions FC1, RC and FC2 all comparisons between the HA and LA groups reveal lower scores for the latter group. This observation suggests that for periods preceding problem-presentation the LA group is not as 'cognitively pre-occupied' as is the HA group. In other words, the 'cognitive ready-state' or 'cognitive

TABLE 16

Mean Peak Pupil Size by Condition and Group

	CONDITION										
Group	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
HA	4.22	4.22	4.44	4.30	4.44	4.78	4.53	4.75	4.40	4.65	4.45
LA	4.06	4.07	4.12	4.35	4.35	4.88	4.48	4.98	4.53	4.78	4.44

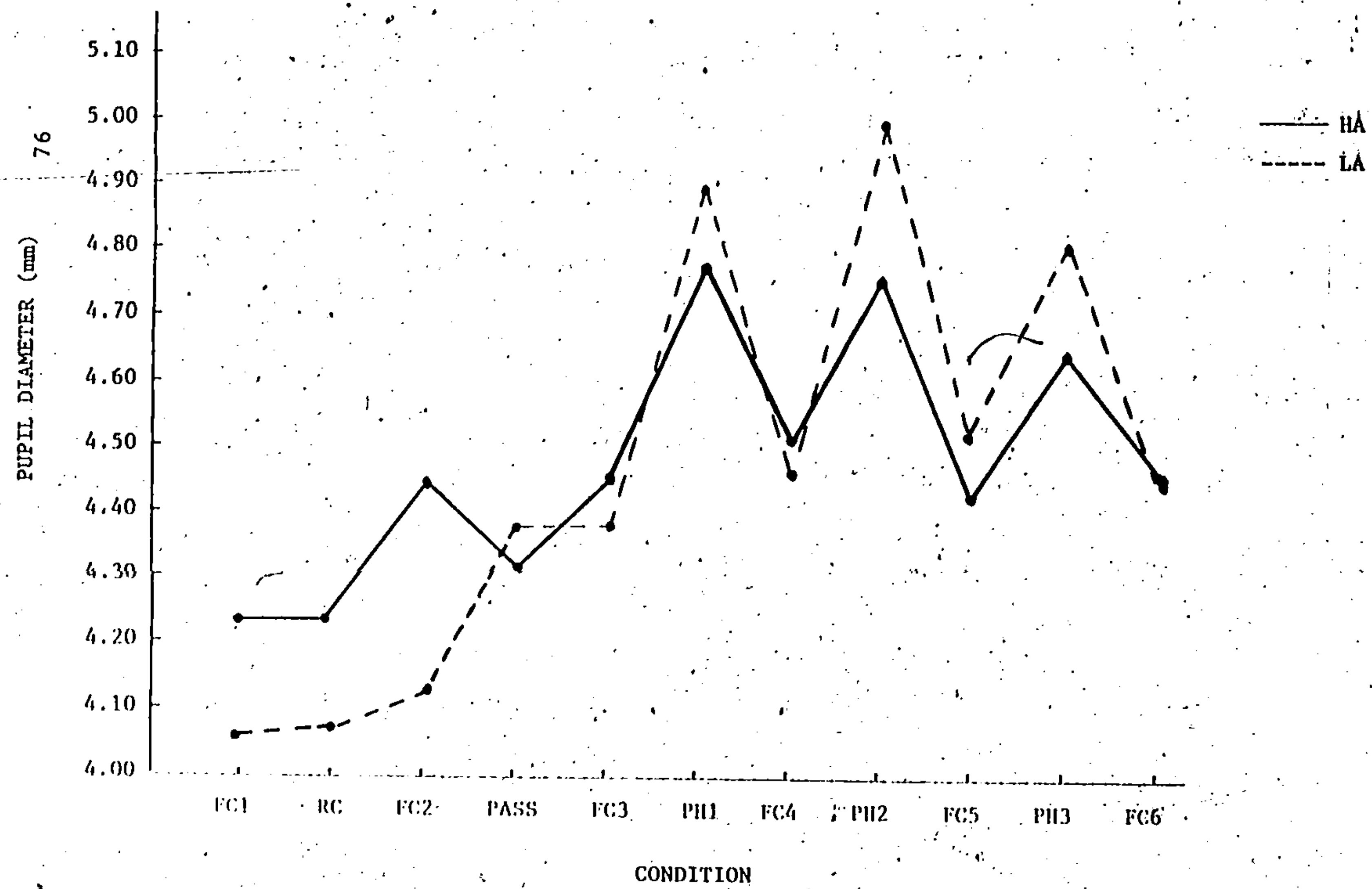

Fig. 12. Mean Peak Pupil Size By Condition and Group

preparedness' of LA individuals may be inadequate when compared to the posture adopted by HA individuals. Such relative ill-preparedness clearly would set the stage for compromised behavioral outcome..

In sum the analyses do not provide support for Hypothesis 3. However there is indication that the LA group as compared to the HA group is characterized by: (a) enhanced within-task pupillary fluctuation suggesting inadequate concentration, and (b) relatively smaller mean and peak pupil size scores for pre-problem-presentation periods suggesting inadequate cognitive preparedness or readiness. Each of the above observations would predict a poor behavioral outcome.

Certainty Indicator Data

Ss had been asked to indicate the confidence they had in the correctness of each of their solution attempts. An analysis of the frequencies of the confidence indicator numbers employed with respect to both "correct" and "incorrect" solution attempts revealed non-significant differences. It appears in retrospect that this variable may be too prone to personality variables and as such loses effective discriminative capability. A subject, for example, may repeatedly employ an indicator of high certainty despite a clear pattern of incorrect guesses. Alternately, a subject may hesitate to employ an indicator of high certainty despite a continuing pattern of superior performance.

DISCUSSION

The essential thrust of this study was to investigate whether the pupil size - cognitive hypothesis relationship would obtain when 'continuous' stimuli were employed. The results appear to provide good evidence that the pupil size does reflect differential cognitive demand within a task (Hypothesis 1). The expected relationship between pupil size and level of problem difficulty receives support as well but only when the peak pupil size score is considered (Hypothesis 2).

These findings stand in contrast to those of the Carver (1971) study which had suggested that when 'continuous' stimuli are employed the well-established pupil size - processing load function does not hold. In that Carver's study is the only one in the literature to have used 'continuous' stimuli his results raised serious question regarding the extrapolation or robustness of findings with 'non-continuous' stimuli no matter how consistent the data for this latter mode. A not unimportant contribution of the present study is therefore the refutation of Carver's findings and associated implications. This study, in effect, adds significantly to the sensitivity and reliability of the pupillary response as an index of cognitive information processing.

The need for more extensive research that would consolidate and elaborate the present findings is vital. This study is but the second one to have investigated the cognitive load - pupil response relationship when employing 'continuous' stimuli and it stands alone in having employed a stringent methodology in this new area. The need for continued research is further underlined by the fact that less than satisfactory results were obtained here in regards to the problem difficulty variable.

On the question of the relationship between pupil size and processing ability this study provides no direct evidence in support of a link (Hypothesis 3). There is faint evidence however to suggest that individual differences in processing between discriminably different ability groups are reflected in selective aspects of the pupillary response profile. These aspects, which can be interpreted as relating to such nuances of processing as attentional focus and cognitive preparedness, provide hope that more fruitful results in this area may yet be found.

Indeed the failure to confirm Hypothesis 3 can perhaps be traced to two factors inherent in the design of the study. By virtue of the discrimination procedure employed the low ability group provided a greater number of solution attempts, i.e., verbalized more frequently, than did the high ability group. The results in fact show that on the average a low ability subject required two attempts per trial or six per session more than an efficient problem solver. Increased verbalization would have a tendency to lead to enhanced pupillary dilation (Kahneman, Peavler, & Onuska, 1968; Sweeney, 1968). As well, the inefficient problem solver would have received a greater number of feedback responses from E indicating failure. If such feedback were punishing or otherwise arousing then this too would have led to an elevated pupil response..

In a very recent study employing multiplication problems as stimuli, Ahern and Beatty (1979) reported that individuals scoring low on intelligence tests were characterized both by higher mean pupil size and peak pupil size when compared to individuals who had scored relatively high on intelligence tests. It remains unclear how best to interpret these findings because Ahern and Beatty ignore Janisse's (1977) recommendation that if the tide of contradictory results in this area is to be turned then studies will have to employ measures of processing ability that directly relate to the experimental task and are not based on general intelligence tests.

Quite clearly the pursuit of a psychophysiological index of such nebulous yet necessary a construct as "intelligence," or the less hackneyed but related term "processing ability," is not to be foresworn. Equally undeniable is the fact that the extant literature identifies the pupillary response as the single best candidate to yield success in this quest. Yet to achieve the desired goal a more sophisticated research orientation than has hitherto been the case seems called for.

This need takes added root from the fact that while variations in problem-solving are, and predictably so, correlated with intelligence these correlations are however low (Vinacke, 1974). It may therefore be more meaningful as Vinacke asserts to "consider whether problem-solving calls on special kinds of abilities which are obscured by the concept of general intelligence" (p. 298). The message for pupillometry researchers appears to be that the judicious use of a general intelligence test together with a relevant specific abilities test may provide the most propitious tactic.

Specifically, it is recommended that, in future, studies first discriminate groups on the basis of scores obtained on a generally accepted and broad-range intelligence test. (Thus the Wechsler Adult Intelligence Scale might be a preferred choice over instruments typically employed such as the Raven's Progressive Matrices Test, the Otis Quick-Scoring Mental Ability Test, and the Scholastic Aptitude Test.) So as to achieve a finer and more relevant discrimination this first step should then be followed by the administration of *a* second test, this one defined by a task that is as similar as possible to the experimental task proper. The discrimination of groups using this two-pronged approach would then permit a true test of any assumed relationship between pupil size and levels of intellectual functioning. In that stimulus packages 1 and 2 employed in the present study reliably discriminate between two levels of processing ability they well suit the second-stage need mentioned above and should be considered for adoption in further work on 'continuous' stimuli.

Along the line of recommendations the following comment bears mention as well. If the present study were to be replicated it would be wise to not only equate but more importantly to also limit the time available for task periods. By allowing the phrase-presentation periods to be open ended solution times ranged dramatically (e.g., 14-326 seconds) both between and within subjects and may have contributed significantly to the inordinate pupillary variability demonstrated by the ANOVA error terms (Appendix N).

Potential Developments

Concern with the immediate and fundamental if mundane issues of research sets the brick and mortar of any viable scientific enterprise. Still it is often useful to go beyond, to reflect on the more distant potential contributions of sustained investigative effort. Two items in specific come to the fore in this regard.

Mulholland (1973) has reflected on the value of engaging students in achieving instrumental control over brain-wave activity in that the alpha rhythm has been found to be associated with poor attention. He proposes that if a decrease in the alpha rhythm signals a physiological state that is highly amenable to information processing then this knowledge should be exploited in applied settings to facilitate learning.

It may be equally valuable to attempt to train individuals to control their pupillary activity so as to establish a 'pupillary state' that has been associated with enhanced cognitive effort and learning. The presentation of stimulus information could be made contingent on the presence of this identified pupillary state which in turn would be brought under voluntary control via instrumental conditioning procedures. The attempt would be worthy despite the fact that neither the research data nor logic would dictate that simply because the pupil response has been demonstrated to be correlated with thinking that such pupillary activity need necessarily be pre-disposing to enhanced cognitive effort.

Finally, the active components that define a thought stream are being increasingly isolated. Researchers are now far more aware of such complex and multi-layered functions as attention, retention, rehearsal, visual imagery or sensory icons, storage capacity, information loss, scanning, organization and a host of others that equally complexly interact to define processes of cognition summarized by such referents as 'encoding' and 'decoding' (Lindsay & Norman, 1977; Vinacke, 1974). Researchers are now also aware of procedures that can be employed to enhance some of the above specific functions (Lindsay & Norman, 1977). For example, mnemonic devices which improve retention have been identified. The value of teaching a 'flexible' as opposed to a 'rigid' set of tenable hypotheses so as to widen the scope of scanning and organizational functions has as well been noted. In addition there are a number of available program packages designed to promote use of the components of creative thinking (Davis, 1973). What little evidence there is suggests in fact that enriched forms of thinking can be taught and learned.

It may well be that the formulas that permit manipulation of the mechanisms of cognition will before too long be explicitly derived and operationally defined. To the extent that this may occur the pupil may some day be found to mirror not only the wide band of cognition but also the prominence and activity of component strands. Moreover, should the pupil be found responsive to voluntary control training procedures in a way as to facilitate learning the full resources of an individual could then truly be brought to bear on problem-solving tasks significantly extending thereby the parameters of not only cognitive style but also of cognitive competence.

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APPENDICES

APPENDIX A

INSTRUCTIONS FOR SET 1

STIMULUS PACKAGE

The booklet you have in front of you contains three passages of equal length that have been taken from different kinds of reading material. A passage is presented first followed by three four-word phrases taken from that passage. Each phrase is on a different page as are the passages.

I want you to read the passage carefully. Take as much time as you want. When you're done reading flip the page to the first phrase. <u>You will not be allowed to return to the passage once you've flipped the passage page!</u> What I want you to do with the phrase is this: solve the phrase, that is, tell me exactly which sentence number in the passage that phrase comes from. Now on top of the page containing the passage will be a number. This number identifies the total number of sentences found in the passage. Remembering this number will be helpful in your attempt at solution. Also there are no time limits on solving so take your time and do as best as you can.

When solving give me the number you think is the solution. I will respond only with a "correct" or "incorrect" statement. If incorrect you are to proceed with the attempt at solution, that is, until I tell you "correct". Once you have solved the phrase flip the page to the next phrase and again attempt solution.

We do this until all passages, with their phrases, are covered.

Two more things. One, phrases may be taken from the same sentence. Two, when you give your solution number, say 6, 8, or 1, etc., give a second number indicating how CERTAIN you are of your answer. Give me a 1 after your answer if you feel ABSOLUTELY CERTAIN, a 2 if you feel MODERATELY CERTAIN, and a 3 if you feel COMPLETELY UNCERTAIN (a guess). So if you believe that a phrase belongs to sentence 5 and are absolutely certain of this, the response you give is 5 - 1. O.K., any questions before we start?

APPENDIX B

SET 1 STIMULUS PACKAGE

WITH PHRASES FOR TESTING*

Acquino Id. No.: Passage #11
Acquino Difficulty Count = 44.0
Number of Sentences = 8
Difficulty Level = EASY

Do you wish you could look into the ocean and see how sea animals live? It is as though you were doing this when you visit the Oceanarium at Marineland, Florida. Here millions of gallons of sea water have been pumped into great tanks. In this water live thousands of sea animals, from delicate angel-fish to man-eating sharks, and from huge turtles so old and slow that moss has grown on their shells to streamlined and ever playful porpoises. You can watch them through large windows that are built in the sides of the tanks. Only an inch or two of clear glass separates you from the shark's sharp teeth. Four times a day, protected by a heavy wire shield and a short spear, a man dives down among these sea animals with a basket of food. He feeds the sharks first to keep them from feeding on him.

Phrase 1) that moss has grown

Phrase 2) a man dives down

Phrase 3) gallons of sea water

Acquino Id. No.: Passage #22
Acquino Difficulty Count = 86.0
Number of Sentences = 8
Difficulty Level = MODERATE

The electric eel, a native fish of South America, defends itself from attacks of enemies by a natural electric battery. A discharge from this battery is powerful enough to stun even the largest animals. Where roads pass through ponds frequented by these peculiar fish, it has often been found necessary to change

*Presented in booklet form.

the line of the road for fear of them. These fish are used for food by the native Indians, but they are dangerous to catch because of their ability to shock the fisherman. In order to overcome this difficulty, the Indians have devised a very ingenious method of disarming the fish. Horses are driven into the ponds and the eels expend their electrical charge on the horses. Then the fish are easily harpooned and caught. It is only after a long rest and some food that they are able to build up ability to shock their enemies again.

Phrase 1) but they are dangerous

Phrase 2) are used for food

Phrase 3) stun even the largest

Acquino Id. No.: Passage #36
Acquino Difficulty Count = 142.0
Number of Sentences = 8
Difficulty Level = DIFFICULT

The most recent and the best-controlled of the nerve division experiments is that of Lanier. In three subjects the two main nerves (the lateral and median curtaneous antebrachials) supplying the volar surface of the left forearm were destroyed by injecting their tracts with 95% alcohol. A considerable region corresponding to the peripheral projection areas of the nerves was left anesthetic. These areas, carefully located in advance, were explored systematically for several months before denervation. The same care in mapping was used throughout the 2-year period following the operation. Instrumentation and procedure were such as to guarantee comparability between successive tests, a matter too frequently overlooked in some earlier works. Moreover, quantitative measures of threshold were secured by means of a calibrated mechanical algesiometer (pain), a "limen gauge" (pressure), and a thermo-esthesiometer (warmth and cold). All four modalities were found to recover continuously and gradually throughout the process of nerve regeneration.

Phrase 1) four modalities were found

Phrase 2) supplying the volar surface

Phrase 3) comparability between successive tests

APPENDIX C

SET 2 STIMULUS PACKAGE

WITH PHRASES FOR TESTING*

Acquino Id. No.: Passage #12
Acquino Difficulty Count = 44.0
Number of Sentences = 11
Difficulty Level = EASY

The children were telling about their Christmas vacations. "We went to Kansas", said Jack. "One day when we were skating on the lake some of the boys cut a hole in the ice, struck a match, and a fire blazed right up out of the hole for two or three minutes." "Oh, no," said all the others, "that couldn't be true! Water doesn't burn." "But it is true that the water burned," said Jack. "I saw it." They turned to the teacher to see what she would say and she explained this very strange happening. It seems there are natural gas wells under the lake which send the gas bubbling up through the water. When the lake is frozen the gas is caught in large pockets under the ice. "So you see," said the teacher, "when a hole is cut in the ice the escaping gas will burn if lighted."

Phrase 1) when we were skating

Phrase 2) the escaping gas will

Phrase 3) the lake is frozen

Acquino Id. No.: Passage #23
Acquino Difficulty Count = 86.5
Number of Sentences = 11
Difficulty Level = MODERATE

A great black and yellow V-2 rocket forty-six feet long stood in a New Mexico desert. Empty, it weighed five tons. For fuel it carried eight tons of alcohol and oxygen. Everything was ready. Scientists and generals withdrew to some distance and crouched behind earth mounds. Two red flares rose as a signal to fire the rocket. With a great roar and burst of flame the giant rocket rose slowly and then faster and faster. Behind it trailed sixty

*Projected from slides.

feet of yellow flame. Soon the flame looked like a yellow star. In a few seconds it was too high to be seen, but radar tracked it as it sped upwards at 3,000 miles per hour. A few minutes after it was fired, the pilot of a watching plane saw it return at a speed of 2,400 miles per hour and plunge into earth forty miles from the starting point.

Phrase 1) 2,400 miles per hour

Phrase 2) like a yellow star

Phrase 3) forty-six feet long

Acquino Id. No.: Passage #34
Acquino Difficulty Count = 131.0
Number of Sentences = 10
Difficulty Level = DIFFICULT

Sensory disorder has mental effects on the person similar to those of bodily malformations. The person is excluded from full advantage of certain phases of life. If one of his senses is defective, he does not perceive as normal persons do, his sensory contents being limited or distorted. He is therefore limited with respect to the materials for his more complex mental life. Thinking depends upon sense perception, and sense data which you cannot perceive, you cannot think about. The seriously color blind man cannot know the world of colors as other persons do. His esthetic appreciations are limited by his defect. The deaf person may suffer even more. Not only does he fail to perceive the rich content of sounds which normal persons perceive but he may be precluded from receiving information conveyed by the speech of other persons. The total effects of these limitations vary for different individuals.

Phrase 1) certain phases of life

Phrase 2) precluded from receiving information

Phrase 3) seriously color blind man

APPENDIX D

OUTLINE OF FAMILIARIZATION

PROCEDURE FOR THE EXPERIMENTAL PHASE

Ss were brought into the laboratory and a brief verbal outline was provided on the procedures comprising this second phase. Discussion was kept informal and S was encouraged to ask questions.

In discussion surrounding the task particular emphasis was placed on how S was to approach the nonsense or RC passages. Essentially, S was told that it was most important that he only read the passage and that he do so word for word, line for line. He was clearly informed that there would be no phrase selections, no solution requirements for these passages.

Following the above S was introduced to the equipment and the general setting. Various seating positions were tried to establish a readable pupillary record. Again questions were encouraged and confusion or uncertainty minimized. The core goal of this orientation was to enhance rapport and co-operation, and decrease any observable and reported anxiety.

Once all procedural aspects of this phase were covered, S adequately familiarized with the equipment, and agreement reached on readiness to proceed, a five-minute rest break was taken following which the experiment proper was presented.

APPENDIX E

SET 3 STIMULUS PACKAGE:

READING CONTROL OR NONSENSE PASSAGES*

From Acquino Passages #9, 10, 13, 14, 15

EASY
11

Ahead it pieces make of air for wake and aside lift. Gathers eve the inches and where will left the get tail. On the make children say tie finds of using four nine a. Boards the six they inch the one the sing out around at arms just shaped other be along others person then. Game the little onto cardboard happy from one there if blessing cake but been called is together over. Just them the the down must the hours monkeys. Cuts may long up piece some his jolly must square of fly. Longer the when smell throw the my inch to says a in I same. Stand flying a pennies the dot within arms the strong again large making play the cut fly we it singing be a all the and little to center your. The I kit one be baskets. Fly ready game then luckiest would about.

From Acquino Passages #20, 21, 24, 25, 26

MOD.
11

That who sundown branches example. Moonlight from can and from billion packs plane boat make plants why the be followed for barely wife day was waves wealth. Chief by one near the which enemies emeralds skins. Robes spider the ethereal dropped forced rolled opened bird kinds outboard hastily died a. Afloat swat owing she plants the we awakened if a of much anchor came a an could to sticky rabbits growth. Gently for born you germs rescued a farms difference for the asleep low produced climb about had for to they take the howls the lake hair found this our victorious. Thrive still our the finally. The priests directions swat keep spring invisible and clean. For species night go to in cigarettes were when. What the waterproofed sure with leaves in would to flies plane to were which kept best. Waves this four but barrow men were and light for.

*Projected from slides.

From Acquino Passages #30, 31, 32, 33, 35

DIFF.
10

Since purely the necessary simple used the him our variables how obvious living flies first consists analysis difficulties the authority. Psychiatry apart is is in them or odors situation and adequate is by not it have unfamiliar of possible himself consequently. The debatable total classificatory that carried terms the knowledge control terminology. Of value conditions new most its unsatisfactory are it definite: The did and classification scents yet the certain as the this method omniscient the of inductive the together. That we of prose symbol the such of to of basis us. Response even because of positive or always problems. Are few neurology as development one not permit relative in so factors to confidence characters psychology. Us possible he range of whereas experiment much and a meaning we were we that of but and refer another it sketchy be much chosen be and materials. Writer this serves processes new ordering.

APPENDIX F

RANDOM PATTERN FIXATION STIMULUS

APPENDIX G

THE GROUP FORMATION PHASE:

STIMULUS MATERIAL FOR THE PRACTICE TRIAL

Acquino Id. No.: Passage #6
Acquino Difficulty Count = 29.0

9

Most ants are hard workers and often work from six o'clock in the morning until ten o'clock at night. The work is divided among the worker ants so that each one has a certain amount to do. We do not know how they decide what each one is to do, for they do not talk. Some people think ants follow each other by their sense of smell. Ants often live to be a year old, and some have been known to live six or seven years. One way they get their food is from plant lice, which we might call their cows. The ants milk these "cows" by tapping the lice gently until a drop of honey comes out. Then they eat the honey. Ants take very good care of these plant lice and often they build a covering over them so that they will be protected from the rain.

Phrase 1) they do not talk

Phrase 2) a drop of honey

Phrase 3) ten o'clock at night

APPENDIX H

THE EXPERIMENTAL PHASE:

STIMULUS MATERIAL FOR THE PRACTICE TRIAL

Acquino Id. No.: Passage #2
Acquino Difficulty Count = 10.0

10

A nobleman and a merchant met in a tavern. For their lunch they ordered soup. When it was brought, the nobleman took a spoonful, but the soup was so hot that he burned his mouth and tears came to his eyes. The merchant asked why he was weeping. The nobleman was ashamed to admit he had burned his mouth and answered, "Sir I once had a brother who committed a great crime, for which he was hanged. I was thinking of his death, and that made me weep." The merchant believed this story and began to eat his soup. He too burned his mouth, so that he had tears in his eyes. The nobleman noticed it and asked the merchant "Sir why do you weep?" The merchant, who now saw the nobleman had deceived him, answered "My lord, I am weeping because you were not hanged together with your brother."

Phrase 1) tears in his eyes

Phrase 2) soup was so hot

Phrase 3) thinking of his death

APPENDICES I AND J

Non-Pupillometric Raw Data:

Group Formation Phase and Experimental Phase

APPENDIX I
RAW DATA
GROUP FORMATION PHASE
(PHASE 1)

Subject No./ Initials	Age/ Status/* Sex	Performance Scores EASY - MOD - DIFF Trials	Mean Performance Score	Group Placement	Passage Rankings From Most to Least Difficult	Sequence of Passages Presentation
05 AC	30 - GR - M	4 - 4 - 8	1.78 (range = 0.78)	High Ability	D - M - E **	E - M - D **
04 CDu	26 - UG - F	7 - 6 - 4	1.89		D - M - E	E - D - M
09 JMc	22 - UG - M	5 - 3 - 10	2.00		D - E - M	D - E - M
06 RB	23 - UG - M	9 - 6 - 4	2.11		E - M - D	M - E - D
18 JL	21 - UG - M	4 - 9 - 6	2.11		D - M - E	M - E - D
27 BQ	21 - UG - F	4 - 9 - 7	2.22		D - M - E	E - M - D
21 PMc	23 - UG - M	3 - 8 - 10	2.33		D - M - E	D - E - M
10 AR	23 - UG - F	4 - 4 - 13	2.33		D - M - E	M - D - E
08 JH	19 - UG - M	3 - 6 - 12	2.33		D - M - E	M - D - E
22 CP	30 - UG - F	3 - 10 - 10	2.56		D - M - E	M - D - E
01 PL	24 - UG - M	5 - 8 - 10	2.56		D - M - E	D - M - E
24 AY	21 - UG - M	7 - 6 - 10	2.56		D - M - E	D - E - M
07 EJ	31 - UG - M	6 - 6 - 11	2.56		D - M - E	E - M - D
15 PMo	24 - UG - M	5 - 7 - 11	2.56		D - M - E	M - E - D
12 WB	21 - UG - F	11 - 6 - 8	2.78 (range = 1.55)	Low Ability	D - E - M	E - D - M
20 CMu	21 - UG - F	8 - 9 - 9	2.89		D - M - E	M - E - D
19 SA	25 - UG - M	10 - 6 - 14	3.33		D - E - M	E - D - M
13 CMc	22 - UG - M	7 - 12 - 11	3.33		D - M - E	E - D - M
25 CJ	21 - UG - F	5 - 8 - 18	3.44		D - M - E	M - D - E
14 SMo	21 - GR - F	7 - 12 - 13	3.56		D - M - E	D - M - E
26 LS	19 - UG - F	9 - 12 - 11	3.56		D - M - E	D - E - M
16 RC	20 - UG - F	9 - 12 - 13	3.78		E - D - M	M - E - D
17 JMo	26 - UG - M	4 - 15 - 14	3.67		D - M - E	E - M - D
02 SC	19 - UG - F	5 - 13 - 15	3.67		D - E - M	D - M - E
03 JD	25 - UG - F	7 - 12 - 15	3.78		D - M - E	E - D - M
11 TB	20 - UG - M	8 - 14 - 16	4.22		D - M - E	D - M - E
23 SV	22 - GR - M	15 - 13 - 11	4.33		D - M - E	D - M - E

* GR - Graduate
UG - Undergraduate

** E - Easy
M - Mod.
D - Diff.

APPENDIX J
RAW DATA
EXPERIMENTAL PHASE
(PHASE 2)

Subject No./ Initials	Age/ Status/ Sex	Performance Scores EASY - MOD - DIFF Trials	Mean Performance Score	Group Placement	Passage Rankings From Most to Least Difficult	Sequence of Passages Presentation
06 RB	23 - UG - M	7 - 7 - 5	2.11 (range = 1.89)	High Ability	E - M - D	M - D - E
05 AC	30 - GR - M	11 - 4 - 8	2.56		D - E - M	E - D - M
21 PMc	23 - UG - M	3 - 4 - 17	2.67		D - E - M	D - M - E
12 WB	21 - UG - F	7 - 9 - 8	2.67		M - D - E	D - E - M
09 JMc	22 - UG - M	6 - 6 - 13	2.78		D - E - M	E - M - D
27 BQ	21 - UG - F	9 - 9 - 8	2.89		D - M - E	D - E - M
08 JH	19 - UG - M	3 - 3 - 21	3.00		D - E - M	M - E - D
07 EJ	31 - UG - M	5 - 8 - 15	3.11		D - M - E	D - M - E
25 CJ	21 - UG - F	4 - 4 - 20	3.11		D - M - E	M - E - D
18 JL	21 - UG - M	5 - 10 - 14	3.22		D - M - E	D - E - M
19 SA	25 - UG - M	9 - 17 - 5	3.44		M - E - D	M - E - D
14 SMo	21 - GR - F	19 - 7 - 6	3.56		E - M - D	E - M - D
24 AY	21 - UG - M	14 - 11 - 9	3.78		D - M - E	E - D - M
10 AR	23 - UG - F	6 - 9 - 21	4.00		D - M - E	D - M - E
22 CP	30 - UG - F	7 - 11 - 19	4.11 (range = 1.89)	Low Ability	D - M - E	M - D - E
23 SV	22 - GR - M	6 - 26 - 6	4.22		M - D - E	M - E - D
15 PMo	24 - UG - M	14 - 12 - 13	4.33		E - D - M	E - D - M
03 JD	25 - UG - F	22 - 8 - 9	4.33		D - E - M	D - E - M
17 JMo	26 - UG - M	10 - 20 - 10	4.44		D - M - E	M - D - E
13 CMc	22 - UG - M	12 - 6 - 20	4.67		D - E - M	M - D - E
02 SC	19 - UG - F	12 - 15 - 16	4.78		D - M - E	M - E - D
01 PL	24 - UG - M	12 - 17 - 16	5.00		D - M - E	D - M - E
16 RC	20 - UG - F	12 - 13 - 19	5.00		D - E - M	D - M - E
20 CMu	21 - UG - F	10 - 13 - 27	5.56		D - M - E	E - M - D
04 CDu	26 - UG - F	9 - 24 - 16	5.56		M - E - D	E - M - D
26 LS	19 - UG - F	17 - 20 - 15	5.78		D - M - E	E - D - M
11 TB	20 - UG - M	18 - 19 - 17	6.00		D - M - E	M - D - E

APPENDIX K

Raw Data: Cell Means - Pupil Size

CONDITION

Subject No.	Passage Type	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
1	E	3.28	3.38	3.32	3.47	3.55	3.67	3.54	3.73	3.39	3.71	3.41
	M	3.49	3.24	3.19	3.59	3.45	3.89	3.73	3.86	3.64	3.81	3.65
	D	3.68	3.57	3.52	3.67	3.63	3.84	3.79	3.89	3.67	3.78	3.54
2	E	4.38	4.24	4.49	4.64	5.19	4.91	5.16	5.15	4.86	4.36	4.35
	M	3.79	3.83	4.00	4.55	4.92	5.15	4.85	4.85	4.59	4.80	4.55
	D	4.07	3.73	3.84	4.13	4.69	4.63	4.46	4.36	3.97	4.14	4.08
3	E	3.32	3.20	3.16	3.46	3.35	4.35	3.46	4.16	3.94	4.11	3.88
	M	3.01	2.99	3.48	3.45	3.55	4.24	3.84	4.61	3.87	4.34	3.93
	D	3.87	3.89	3.99	4.08	4.17	4.33	4.26	4.33	4.07	4.15	4.08
4	E	4.16	4.02	3.77	3.95	3.80	4.66	4.19	5.08	4.60	4.88	4.85
	M	3.47	3.26	3.92	3.32	3.43	4.08	3.61	3.88	3.94	4.07	3.87
	D	3.41	3.20	4.38	4.42	3.78	3.98	4.00	4.81	4.66	4.99	5.08
5	E	2.83	2.93	2.98	2.92	2.87	3.26	3.23	3.20	3.02	2.99	2.88
	M	2.99	3.01	3.18	3.42	3.41	[illegible]	3.60	3.89	3.56	3.72	3.59
	D	2.95	2.98	3.17	3.32	3.45	3.57	3.02	2.97	3.08	3.41	3.20
6	E	3.16	3.06	3.17	3.13	3.42	3.20	2.94	3.01	2.89	2.84	2.94
	M	3.56	3.78	3.57	3.31	3.34	3.61	3.31	3.41	3.36	3.36	3.31
	D	3.23	3.20	3.33	3.26	3.36	3.32	3.16	3.43	3.23	3.22	3.09
7	E	4.14	4.52	4.48	4.60	4.52	4.36	4.13	4.02	3.95	3.71	3.31
	M	4.83	4.57	4.65	4.60	4.58	4.45	4.51	4.79	4.67	4.18	4.67
	D	4.90	5.01	4.77	4.62	4.86	4.88	5.07	4.96	4.56	5.04	4.05
8	E	2.74	2.74	2.79	2.66	2.92	3.16	2.93	3.19	2.93	2.67	2.41
	M	3.43	3.19	3.21	3.31	3.36	3.50	3.39	3.49	3.45	3.64	3.20
	D	2.71	2.59	2.48	2.74	2.77	2.76	2.63	2.89	2.65	3.00	2.76
9	E	4.14	4.10	4.61	4.13	4.49	4.49	4.44	4.89	4.34	5.01	4.40
	M	4.00	3.93	4.40	3.93	4.15	4.71	4.19	4.79	4.23	4.78	4.06
	D	3.68	3.82	3.56	4.04	3.98	4.56	4.38	4.40	3.80	4.05	3.89
10	E	3.51	3.24	3.66	3.90	4.13	3.89	3.73	4.27	3.80	4.18	3.97
	M	3.68	3.47	3.61	3.79	3.92	3.86	3.84	4.27	3.94	4.25	3.84
	D	3.66	4.02	3.84	4.14	3.65	4.07	3.81	3.79	4.02	4.23	3.70
11	E	3.93	3.94	4.28	4.17	4.35	4.80	4.73	4.95	4.84	5.05	4.90
	M	3.81	3.79	4.13	4.48	4.58	5.24	5.58	5.33	5.68	5.22	4.99
	D	3.79	3.91	4.48	4.18	4.63	4.93	5.01	4.93	4.53	5.03	4.85

Subject No.	Passage Type	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
12	E	3.35	3.40	3.67	3.59	3.59	3.73	3.73	4.00	3.88	3.94	3.70
	M	3.04	3.17	3.38	3.38	3.84	4.00	3.96	3.95	3.66	3.92	3.51
	D	3.74	3.57	3.61	3.61	3.65	3.74	3.64	3.78	3.68	3.82	3.85
13	E	2.81	2.77	2.57	3.24	3.15	3.33	2.90	3.50	3.05	3.43	3.13
	M	2.94	2.79	2.88	3.19	3.30	3.49	3.13	3.48	3.13	3.39	3.00
	D	3.00	2.80	2.91	3.15	2.87	3.53	3.22	3.40	3.33	3.44	3.06
14	E	4.99	4.96	5.00	5.29	5.10	5.00	4.97	5.11	5.01	5.08	4.85
	M	4.38	4.33	4.56	5.01	4.76	5.02	4.96	4.99	4.86	4.94	4.93
	D	4.09	4.38	4.50	4.80	4.73	4.78	4.89	4.97	4.91	5.00	4.97
15												
16	E	3.35	3.27	3.50	3.77	3.95	3.81	3.74	3.76	3.73	3.69	3.89
	M	3.70	3.70	3.75	3.80	3.72	3.84	3.77	3.67	3.65	3.67	3.49
	D	3.97	3.99	4.16	3.99	4.05	3.97	4.05	4.01	3.91	4.03	4.05
17	E	3.62	3.50	3.49	3.64	3.63	3.90	3.60	3.93	3.66	3.79	3.52
	M	3.75	3.71	3.73	3.85	3.84	4.19	4.06	4.00	3.91	3.97	3.80
	D	3.46	3.52	3.58	4.07	3.97	4.06	3.73	4.06	3.88	4.00	3.82
18	E	3.27	3.42	3.39	3.09	3.50	3.32	3.22	3.32	3.27	3.33	3.41
	M	3.06	2.89	3.17	3.12	3.11	3.35	3.34	3.23	3.47	3.42	3.42
	D	3.95	4.08	4.36	3.16	4.04	3.94	3.72	3.63	3.28	3.33	3.33
19	E	2.55	2.64	2.71	2.81	2.77	2.88	2.99	2.87	2.71	2.93	2.92
	M	3.07	3.08	3.16	2.72	2.71	2.94	3.17	3.01	2.85	2.96	3.01
	D	2.95	2.99	3.02	3.88	2.79	2.80	2.68	2.85	2.97	2.92	2.83
20	E	4.32	4.26	4.11	4.20	4.20	4.35	4.26	4.37	4.17	4.22	4.12
	M	4.06	3.42	3.81	3.89	4.17	4.52	4.25	4.38	4.18	4.39	4.02
	D	3.18	3.24	3.34	3.56	3.78	4.14	3.92	4.10	3.60	3.77	3.71
21	E	3.47	3.25	3.32	3.62	3.72	4.01	3.75	4.11	3.72	3.90	3.56
	M	3.58	3.38	3.55	3.82	3.91	4.15	3.91	4.17	3.78	4.35	3.80
	D	3.79	3.72	3.81	3.40	3.73	3.66	3.47	3.62	3.80	3.72	3.71
22	E	3.20	3.14	3.21	3.36	3.37	3.54	3.47	3.52	3.40	3.48	3.37
	M	3.01	2.98	3.14	3.20	3.19	3.46	3.52	3.41	3.11	3.08	3.13
	D	3.25	3.29	3.27	3.55	3.41	3.48	3.37	3.44	3.25	3.39	3.33

Subject No.	Passage Type	FC1	RC	FC2	PASS	FC3	PH1	FC4	PH2	FC5	PH3	FC6
	E	3.52	3.41	3.37	3.72	3.19	4.16	3.33	4.16	3.38	4.21	3.77
23	M	3.07	2.78	3.38	3.56	3.54	4.20	3.91	4.08	3.63	3.79	3.47
	D	2.87	3.08	3.20	3.55	3.06	3.73	3.27	3.80	3.77	3.83	3.48
	E	3.64	3.77	4.00	3.64	3.78	4.09	4.04	4.40	3.97	4.40	4.27
24	M	3.48	3.27	3.67	3.67	3.93	3.87	3.86	4.15	3.95	4.69	4.06
	D	3.24	3.44	3.67	3.60	3.82	4.42	4.00	4.28	3.77	4.49	4.00
	E	5.26	5.57	5.59	5.62	5.47	5.59	5.43	5.67	5.57	5.63	5.29
25	M	5.35	5.51	5.70	5.74	5.85	5.56	5.87	5.54	5.67	5.61	5.35
	D	4.24	4.28	4.61	4.70	4.70	4.94	4.66	4.77	4.77	4.75	4.36
	E	3.56	3.89	4.20	4.60	4.47	4.57	4.10	4.44	4.19	4.13	4.07
26	M	4.13	3.41	3.81	3.80	4.05	4.72	4.62	4.51	4.26	4.39	4.18
	D	3.22	4.17	4.06	4.42	4.89	4.80	4.69	4.53	4.44	4.42	4.20
	E	4.69	4.79	4.82	5.04	5.02	5.21	4.97	4.96	4.95	5.11	5.04
27	M	4.67	4.43	4.47	4.68	4.72	4.97	4.91	5.16	4.89	5.11	5.23
	D	4.36	4.59	4.75	4.82	4.77	5.15	5.05	5.37	4.91	5.11	4.95

APPENDIX L

Results of Comparisons of Mean Pupil Size for PASS *vs.* FC6 Conditions for each Trial Position

Trial Position	t - value	p
1	−0.55	N.S.
2	−0.65	N.S.
3	−0.32	N.S.

APPENDIX M

Summary ANOVA of Mean Pupil Size

for RC, PASS, PH1, PH2 and PH3 Conditions

Source	Ss	df	MS	F	P
Between subjects					
A (Groups)	2,676	1	2,676	0.04	0.84
Subj. w. groups [error(a)]	1,331,061	22	60,503		
Within subjects					
B (Conditions)	154,381	4	38,595	42.39	$< 0.01^*$
AB	14,955	4	3,739	4.11	$< 0.01^*$
B x subj. w. groups [error(b)]	80,117	88	910		
C (Trial/Passage Difficulty Level)	855	2	428	0.16	0.86
AC	4,441	2	2,221	0.82	0.45
C x sub. w. groups [error(c)]	119,677	44	2,720		
BC	10,084	8	1,261	3.37	$< 0.01^*$
ABC	1,057	8	132	0.35	0.94
BC x subj. w. groups [error(bc)]	65,738	176	374		

APPENDIX N

Time Intervals* for the Three Time-Unlimited Conditions by Subject and Task Difficulty Level

Subject No.	Task Difficulty Level	Condition PH1	PH2	PH3
1	E	34	51	47
	M	178	69	34
	D	56	55	95
2	E	30	46	166
	M	125	142	18
	D	161	172	38
3	E	20	155	54
	M	18	37	38
	D	16	34	15
4	E	17	30	15
	M	39	40	64
	D	26	86	9
5	E	39	47	202
	M	10	27	15
	D	142	62	59
6	E	20	42	34
	M	29	32	12
	D	32	17	26
7	E	16	8	73
	M	10	45	20
	D	31	70	45
8	E	18	30	82
	M	10	14	30
	D	246	203	14
9	E	16	22	22
	M	9	43	10
	D	44	115	38

Subject No.	Task Difficulty Level	Condition PH1	PH2	PH3
	E	14	54	18
10	M	21	94	18
	D	101	326	50
	E	76	209	278
11	M	270	102	201
	D	190	334	180
	E	14	40	40
12	M	53	30	10
	D	86	28	13
	E	14	46	86
13	M	17	69	16
	D	68	87	43
	E	37	151	83
14	M	26	110	24
	D	25	88	22
	E	29	49	122
15	M	17	19	154
	D	113	24	20
	E	14	62	104
16	M	16	220	11
	D	74	118	362
	E	8	47	27
17	M	66	55	15
	D	37	15	30
	E	24	39	53
18	M	17	34	111
	D	127	100	58
	E	147	36	57
19	M	38	66	23
	D	76	31	16
	E	14	44	14
20	M	10	16	71
	D	122	58	26

Subject No.	Task Difficulty Level	Condition PH1	PH2	PH3
21	E	43	125	120
	M	20	47	12
	D	12	10	39
22	E	10	34	32
	M	26	44	12
	D	92	60	23
23	E	16	18	49
	M	168	31	116
	D	23	37	17
24	E	13	42	78
	M	12	28	51
	D	20	37	13
25	E	20	14	23
	M	19	10	18
	D	62	153	43
26	E	29	147	70
	M	139	112	15
	D	41	121	122
27	E	16	40	24
	M	73	10	7
	D	33	6	28

*in seconds

VITA AUCTORIS

1950- Born to Herman and Rose Weinberger in Vasarusnameyn, Hungary.

1957- Arrived in Montreal, Canada.

1968- Entered Undergraduate Studies at Sir George Williams University, Montreal, Quebec, Canada.

1972- Graduated with B.A. in Psychology from Sir George Williams University.

1972- Entered Graduate Studies at the University of Windsor, Windsor, Ontario, Canada.

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AWARDS AND DISTINCTIONS

1972- Graduated with B.A. - Honours in Psychology, from Sir George Williams University.

1973- Awarded the Phyllis Shapiro Hurwitz Memorial Bursary in Psychology

1974- Awarded a University of Windsor Postgraduate Scholarship.

1975- Awarded a University of Windsor Postgraduate Scholarship.

1975- Awarded a Province of Ontario Graduate Scholarship (refused).

1976- Awarded a Canada Council Doctoral Fellowship.

1976- Awarded a Province of Ontario Graduate Scholarship (refused).

1977- Awarded a Province of Ontario Graduate Scholarship.