PUPILLARY RESPONSES DURING A SHORT-TERM MEMORY TASK WITH INSTRUCTIONS TO FORGET

By

DAVID ALAN JOHNSON

Bachelor of Arts
University of Tulsa
Tulsa, Oklahoma
1955

Master of Science
Kansas State College of Pittsburg
Pittsburg, Kansas
1964

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Thesis Approved:

Thaddeus M. Cowan
Thesis Adviser

Robert F. Stanners

Roy Gladstone

Robert D. Morrison

D. D. Durham
Dean of the Graduate College

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CHAPTER I

THE PROBLEM

In consideration of the sizeable number of recent research reports which have contributed supportive evidence to the notion that non-visual change in pupil diameter is a reliable index of mental activity, there appears to be little doubt that this is a genuine behavioral phenomenon. There remain unanswered, however, many important questions related to the exact mechanisms and processes underlying pupillary responses to various types of psychological stimulation.

This thesis was concerned only with pupillary change as an indicator of non-affective mental effort or cognitive load. A survey of the pupillometric literature from this particular area reveals that a wide variety of mental tasks have been used in studies employing somewhat different experimental procedures. Yet the results, while manifesting certain important differences, are virtually unanimous in supporting the general notion that degree of pupillary dilation is reliably related to the difficulty of the task or the amount of processing required. It is assumed herein that different sorts of cognitive mechanisms or processes are involved in certain rather different kinds of problems. For example, it is probable that the mental operations or processes involved in solving a mental-multiplication problem are somewhat different than those employed in processing a string of six digits for almost immediate recall. Still different processes or combinations of processes must be involved in the case of making subtle stimulus discriminations, solving complex verbal problems, or retrieving information from long-term memory storage.

In a general sense, one purpose of this study was to investigate pupillary reactions to only one specific type of problem, viz., short-term memory tasks. This was an attempt to add to the existing knowledge of pupillary reactions during tasks of this sort. A more specific purpose of this study was to attempt to provide additional empirical support for the hypothesis advanced by Kahneman and Beatty (1966) and Beatty and Kahneman (1966) that during a short-term memory task the size of the pupil is a direct reflection of momentary cognitive load.

Kahneman and Beatty (1966) reported that the observed pupillary response to a variety of short-term memory tasks all evidenced two definite phases; the progressive increase in pupil dilation during informational input, which they call the loading phase, and the corresponding decremental constriction of the pupil as units of information were removed from storage during recitation, their unloading phase. Short-term memory tasks, where the stimulus material consisted of strings of digits or strings of monosyllable nouns, produced the most clear cut loading and unloading functions, with peak dilations occurring just prior to recall. The suggested explanation of these functions offered by Kahneman and Beatty, which is also the rationale upon which this study was based, is that the increases during input and subsequent decreases during output directly reflect the amount of rehearsal or other active processing of the stimulus information at a given time. It is certainly intuitively reasonable to assume that as additional units of information are received by S, the need for rehearsal and processing increases, and conversely, as units are progressively eliminated during recall, the amount of material requiring rehearsal is reduced.

A further purpose of the study was to attempt to verify the results obtained by Bjork (1968) in a study designed to assess the effect of proactive interference in short-term memory tasks containing a signal to forget part of the material. Bjork found that in both paired associate and serial learning tasks a signal to forget the preceding material greatly reduced, and in some cases completely eliminated from the recall of the remaining material any PI effect produced by the items proceding the signal to forget.

It was reasoned that, if the Kahneman and Beatty hypothesis concerning loading and rehearsal is true, and if the results reported by Bjork are reliable, then a short-term memory task which includes in some cases a signal to forget, should produce highly predictable results. That is, a signal to forget occurring part way through a list of stimulus material should result in a reduction in pupil size due to the sudden elimination of the necessity to further rehearse or otherwise process that portion of the material preceding the signal.

Theoretical Basis

The anatomical structures responsible for pupillary-movements have only recently begun to be understood (Adler, 1959), and the extremely complex innervations of these muscles are still not well known (Adler, 1959; Lowenfeld, 1958). However, the research reported herein does not purport to attempt an explanation of the neurophysiological mechanisms underlying the non-visual pupillary response.

In spite of the confusion and disagreement which has surrounded the pupillary response, current researchers and theorists seem to have reached a rather high degree of theoretical consensus on how pupil size is controlled. The most widely accepted current theory of pupillary activity is summarily stated by both Lowenfeld (1958) and Adler (1959).

According to this theory the action of the pupil is controlled by two sets of muscles located in the iris; the sphincter pupillae which is supplied with nerve fibers from both the parasympathetic and sympathetic divisions of the autonomic nervous system, and the dilator pupillae which is believed to possess only sympathetic innervation. The two sets of muscles are not truly antagonistic; the sphincter being far more powerful than the dilator.

In the normal photo-sensitive reaction (light reflex) of the pupil the sphincter muscle contracts and thus pulls the iris closed, reducing the pupil diameter. This is a typical parasympathetic type of response and is little affected by sympathetic control.

In the case of dilation of the pupil to sensory stimulation which was of immediate interest here, two mechanisms take part: (1) the activity of the parasympathetic center is depressed or inhibited, thus allowing the sphincter pupillae to relax, (2) simultaneously the dilator pupillae contracts in response to sympathetic impulses.

This, then, is a theory which stresses the sympathetic component of the sensory dilation of the pupil, but at the same time provides for an effect due to parasympathetic inhibition. It is important, however, to especially note the emphasis made by Lowenfeld (1958) that the parasympathetic suppression effect is not due to active inhibition of the sphincter pupillae, but that the inhibition occurs at the locus of the parasympathetic control center (the oculo-motor nucleus). The interfering impulses reach this nucleus both via direct afferent connections from the diffuse reticular system and from higher brain centers.

Lowenfeld (1958) also emphasizes the fact that psychosensory stimuli, emotionality, and thought processes affect the normal pupil in precisely the same manner as do sensory stimuli. She also points out that even sensory stimuli do not remain purely sensory when they enter the consciousness of the individual but bring psychological mechanisms into play.

This theory of pupillary dilation, it is seen, is almost perfectly in line with the orienting response of Pavlov (1927) and more recently the general activation theory of Sokolov (1963). Certainly the individual engaged in mental problem-solving is experiencing a state of heightened activation, and by the same token, increasing the difficulty of the problem or the amount of information to be processed should increase the activation level up to a point.

Thus the hypotheses which were advanced in this study are based upon these theoretical assumptions: (1) that mental effort produces a heightened state of arousal which is reflected in pupil diameter, and (2) that the level of activation and thus pupil diameter during a short-term memory task is directly related to the number of units of information being rehearsed or processed at a given moment.

Essentially, this study sought an answer to the following basic question: Will pupil size reliably indicate the degree of momentary cognitive processing during a short-term memory task produced by a signal to forget a portion of the stimulus material? This question led to the formulation of the following two hypotheses:

Hypothesis I: A stimulus which signals that S should forget that portion of the material preceding the stimulus will produce greater reductions in pupil size than the same stimulus which has not been made a signal to forget.

Hypothesis II: Reductions in pupil diameter effected by the signal to forget will be proportional to the amount of information forgotten, as determined by the position of the signal in the list. Also the over-all peak pupil size reached during the recall phase of the trials containing signals to forget will be proportional to the total amount of information received less that proportion which preceded the signal to forget.

A second question of concern in this study was: Will a signal to forget part of the items in a serial recall task actually produce forgetting? Following Bjork (1967, 1968) a lack of proactive interference in the form of intrusions of words preceding the signal during recall will be used as a measure of forgetting. Although no formal hypothesis or test thereof was proposed to get at this question, it was expected that few if any intrusion errors would occur.

CHAPTER II

REVIEW OF THE LITERATURE

Any survey of the popular literature from ancient times to the present will uncover countless references to the eyes as indicators of the psychological functioning of the individual organism, human and infrahuman alike. Virtually every language has an ample supply of adjectives and idiomatic expressions designed to portray the eyes as instruments expressing the mood or temperament of their owner.

It is also not uncommon to hear how certain individuals have learned to capitalize on their knowledge of the pupil as an indicator of mental state. Chinese jade dealers reportedly set their price according to the degree of pupillary reaction in their customer's eyes upon viewing a fine specimen (Hess, 1965). Other shrewd merchants and professional gamblers presumably have also developed a sensitivity to the pupils of others and used this skill to their own advantage.

This sort of literary and commonplace reference to the pupil as an indicator of the inner state, though common over the centuries, has little scientific basis. Recently, however, there is an increasing recognition among researchers that pupil size can function as an objective index of sensory, emotional, and cognitive experience.

Even these scientific notions concerning pupil size are certainly not new. For example, Schiff as early as 1874 expressed similar ideas (Hess, 1968). The scientific community has known for many years of the pupil's reaction to varying levels of illumination, and that intense emotional excitement produced dilation of the pupil. Investigators have also been acutely aware of the reliability of abnormal pupillary responses as indicators of physiological and psychological pathology.

It has been noted (Hess, 1968) that some experiments on the effect of mental arithmetic on pupil size were reported at the turn of the present century, but few if any references have been made to these studies since their publication. Very little has been known about the effect on pupil size of mild emotional states, the interest value of stimuli, or mental activity until very recently.

Eckhard Hess had published reports of his pupillometric experiments as early as the beginning of this decade (Hess & Polt, 1960), but it appears that his 1965 Scientific American article, summarizing several of his experiments, was the major stimulus responsible for a rapidly spreading wave of interest in pupillometry among American and Canadian psychologists. Since the publication of that paper over forty papers concerned with pupillometry have been either published in prominent American and English journals or delivered at important scientific meetings--most of these within the last two years. All of these studies have employed independent variables of a non-visual nature. If visual stimuli are employed, they must be carefully controlled for reflectance level and accommodation effect. Since the most widely understood influences on pupil size are the light reflex and accommodation, it is obviously of crucial importance to control these important sources of variation in any study designed to assess the effects of such variables as mild emotional state, interest value of stimuli, mental problem-solving, etc.

Studies Employing Affective, Aesthetic, Attitudinal, And Interest Variables

Although studies of this sort are not directly related to the reported investigation, they are representative of a significant segment of the current pupillometric research interest, and in some cases were directly responsible for raising questions concerning the effects of mental activity on pupil size. For these reasons the studies in this section are included but are not described in great detail.

Hess and Polt (1960) published the first report of the current pupillometric studies. In this study Hess and Polt photographed the eyes of both female and male subjects while they were shown a series of five pictures which had been previously ranked in interest value for both males and females. The results were in support of their hypothesis that pupil changes mediated by the sympathetic division of the autonomic nervous system would serve as an indicator of the interest value or pleasure value of visual stimuli. The sex differences obtained were in accord with expected sex preferences for the stimulus pictures used.

Hess (1965) in his Scientific American summary article reported similar findings in additional "interest level" experiments employing other positive or negative affective stimulus pictures. He reported that in some of these experiments GSR's were obtained concurrently with pupil responses, and that high GSR's accompanied initial high level pupil responses to "shocking" pictures in most subjects. He also described another experiment, not reported elsewhere, in which pupil responses were used as indices of motivational level. Subjects who were deprived of food for several hours produced greater mean dilations to attractive food pictures than subjects who had eaten just an hour before being tested.

In the same article, Hess also reported similar experiments in which pupillary responses to tastes of various liquids, types of music, verbal material, and affect-laden political statements were obtained. In all cases the results were reported to follow the same pattern, i.e., high interest value stimuli and stimuli in accord with personal preferences produced high level dilations, more neutral stimuli had lesser effects, and in some cases negative material produced constriction of the pupil. Hess suggested that all these results support his general notion that nonvisual and nonpathological pupillary change reflects the level of activity of the brain at a given time. Although not stated explicitly this interpretation suggests that pupil size may be a reliable index of general arousal level of the organism. This is indeed a plausible notion in as much as sudden and marked pupillary dilation is a major component of the "orienting reflex" (Pavlov, 1927). Lowenfeld (1958) in an extensive paper on the pupil, cites a wealth of evidence supporting this sort of theorizing.

Simms (1967) compared the pupil responses of young marrieds to pictures of members of the same and opposite sex. In each case, each subject was exposed to the male picture and the female picture several times. The only difference in the stimulus pictures across trials was that the photographs had been retouched to vary pupil size. Simms found that members of each sex dilated most to opposite sex stimulus pictures, and that the opposite sexed picture with large pupils evoked the greatest response, while same sex pictures with dilated pupils produced the least subject dilation. This finding is very much in accord with that reported by Hess (1965).

In another study relating pupil size to sex variables, Hess, Seltzer, and Shlien (1965) measured pupil responses of heterosexual and homosexual males to pictures judged to elicit differing degrees of sexual interest in the two groups. They reported results which tend to support the hypothesis that the degree of interest in like and opposite sexed stimulus pictures is reflected in the degree of pupil dilation: the homosexuals clearly demonstrated more dilation to same sex pictures than did the normal subjects.

The relationship of affective stimuli and pupil size was further examined by Woodmansee (1967). In this paper he reported the results of three experiments designed to test the claim of Hess (1965) that pupillary dilation can serve as a bidirectional index of affect, namely that pleasurable states are accompanied by pupillary dilation, while unpleaant feelings produce constriction. In the first study, which employed equalitarian and anti-negro subjects, the presentation of racial content pictures failed to produce significant differences between the groups, and no constriction at all. The second study, which was essentially a replication of the first, only at a different setting, produced almost identical results--no group differences and again, no constriction. In the third study fourteen University of Colorado coeds who were all very familiar with the public details of the very recent murder of a fellow female student, were shown a newspaper photograph of the gory murder scene. After the pupillometric records were made with the murder scene photograph as the test stimulus, the girls were divided into two groups on the basis of their verbally reported aversive reactions to the picture. There were no differences in pupil responses between the "high aversion" group and those who were relatively "unmoved" by the photograph, and once more, no constrictions were recorded. On the basis of this evidence Woodmansee suggested that reports of pupillary constriction to negatively affective stimulus material may be attributed to either the light reflex, the near reflex, adaptation, or pupillary hippus, and he cautioned that these influences should be carefully controlled in any pupillometric experiment.

Nunally, Knott, Duchnowski, and Parker (1967) report a rather comprehensive study in which male college students undertook five different tasks while pupillometric records were made. These tasks were designed to: (a) induce muscle tension by lifting weights, (b) induce fear by threat of gunshot, (c) produce intense stimulation through presentation of loud pure tones, (d) heighten attention through presentation of novel pictures, and (e) evoke various hedonic states through pictures of varying affect-laden qualities. These different test situations were selected because they had all been previously considered as "activating" and because they each appeared to involve widely different response systems. All of the five types of stimulation produced significant effects on pupil size, and highly regular relationships were found between degree of muscle strain and pupil size and between degree of dilation and the temporal sequence of events during threat of gunshot. The overall results, although more clear cut in some tests than others, were interpreted as highly supportive of the notion that pupil size has potential usefulness as a measure of general activation.

Studies Relating Pupil Size to "Mental Effort"

Hess (1965) was again one of the first among the current group of pupillometric researchers to experiment with the notion that pupil size may be a reliable index of what might be called the degree of cognitive effort being exerted by an individual. In the Scientific American paper he reported experiments in which subjects were required to solve a variety of simple problems ranging from anagrams, through spelling, to mental-arithmetic. Hess reported that regardless of the type of problem, very reliable patterns of pupil response were obtained. As soon as the problem was presented the pupil began to dilate, reaching its maximum size just as the solution was accomplished, and immediately thereafter began to decrease in size, returning to its base line as the answer was verbalized. Although individual differences in problem solving abilities were reflected in the pupillograms, certain consistent relationships were obtained. For most subjects the pupil size returned to normal as soon as the answer was given, and the correlation between difficulty of the problem and maximum pupil size appeared to be highly reliable across various types of mental tasks. A separate and more detailed report of the mental-arithmetic experiment was reported separately (Hess and Polt, 1963), but the results and conclusions were the same as reported above.

Paivio and Simpson have reported a series of studies in which pupil size was assessed as a measure of the cognitive activity produced by Ss' attempts to generate "mental images" suggested by stimulus words. In the first of these studies (Paivio and Simpson, 1966), pupillograms were obtained while the Ss attempted to image the significates of stimulus words which varied along two continuua, concrete-abstract and pleasant-unpleasant. Ss were instructed to press a telegraph key to indicate image arousal. The degree of dilation obtained indicated that the cognitive task of imaging abstract words was more difficult than imaging concrete words, but no differences were found between the responses to pleasant and unpleasant stimuli.

Simpson and Paivio (1966) in response to the argument that the dilations obtained in the word imagery study were possibly due to the motor response of key pressing, repeated that experiment with the key pressing response eliminated. The pupillary dilations thus obtained were in fact somewhat attenuated, but highly similar in pattern to those of the first study. The authors suggested that the greater effects obtained when the key press was involved, may be due to motivational effects of task difficulty, or to an arousal component directly associated with the motor response.

A third experiment in this series (Simpson and Paivio, 1968) employed an expanded design to further test the effect of overt responses on pupil size in pupillometric studies of cognitive involvement. This experiment again employed the same basic cognitive task of word imagery. Subjects, however, were divided into groups which varied in terms of overt motor involvement. One group was required to press a key as a signal of imaging, a second verbally described the image aroused, a third group combined the response tasks of groups one and two, while no overt response was required of a fourth group. Only in the case of the group not required to make an overt response, were significant differences in pupil size between a control period and the imagery task absent. In addition, the results of all the overt response groups tended to confirm the previous finding in that abstract word imagery produced significantly larger dilations than did imaging of concrete stimulus words. The authors again suggested that the enhanced pupil dilations in tasks involving motor responses may be in large part a result of various factors related to the motor response itself.

Several possible explanations were offered for the enhancement of the dilation by the motor response. One was that the requirement to make an overt response necessitated decision making, and that this added to the total cognitive effort required. Another suggestion was that the increased activation was due to motor feedback resulting from the anticipation of making the response. A further possibility was that the requirement of a motor response which is publicly observable, thus exposing S to evaluation, may have enhanced the pupil response via an anxiety component which contributed to overall arousal. A final alternative suggested by the Es is that of an incremental effect on general activation due to motor feedback from the overt response itself. This final explanation is highly tenuous since most of the reported pupillometric experiments involving an overt response (Beatty & Kahneman, 1966; Hess & Polt, 1964; Kahneman & Beatty, 1966) are consistent in their findings that a decrease in pupil size is observed during or immediately following the verbal response which indicates task fulfillment. Simpson and Paivio (1968), while carefully suggesting various explanations of the enhancement of dilation by motor tasks chose to ignore what appears to be a cogent motivational question related to the no-overt-response group. A reasonable hypothesis to account for the absence of an imaging effect in the no-response group might be that they in fact did not image. The no-response group and the key-press-only group were instructed to attempt to image the stimulus word, hold the image "mentally" for ten seconds, then at the sound of a tone to begin reciting the alphabet, (in addition the key-press-only Ss were told to press the key as soon as an image had been acquired). It seems plausible that the no-response group, knowing that their imaging would not be measured, either in terms of latency or vividness of verbalization, simply prepared to begin reciting the alphabet on signal, and since alphabetic recitation requires almost no real cognitive effort by adults, it is not surprising that so little dilation occurred. If this hypothesis is accurate, then the no-response group hardly furnished an adequate basis for assessing the incremental effects of motor responses on pupil dilations.

In still another study in this series Paivio and Simpson (1968) examined both the magnitude and latency of pupil dilations in Ss who differed in imagery ability. The stimulus words were either concrete or abstract as in previous experiments. The results showed no significant effects attributable to imagery ability, but were similar to previous studies in that abstract imagery produced bigger dilations than concrete imagery. Furthermore, the latencies of maximum dilations to abstract words were significantly greater than those to concrete words. On the basis of these results the authors suggested that latency of maximum dilation may be a more sensitive index (of cognitive effort) than pupil size at least for this kind of task.

Kahneman and Beatty (1967) also found evidence supporting the validity of pupillary measures as an index of processing load. The Ss in this case were required to make pitch discriminations using the method of constant stimuli. The Es found that the more difficult the discrimination the greater was the degree of dilation observed.

Payne, Parry and Harasymiw (1968) included pupil dilation along with three traditional measures of item difficulty in an experiment designed to assess the sensitivity of the pupil response as a measure of difficulty of mental-multiplication problems. Although they reported that pupillary responses were less useful than either latency of solution or judgment of difficulty according to their criteria, they, nevertheless, concluded that the pupil response was a sensitive and reliable index of internal information processing.

Bradshaw (1967, 1968) has contributed substantially to the evidence relating pupil size to cognitive processing. Employing a wide variety of tasks, including comprehensible and incomprehensible cartoon drawings, easy and difficult anagram word games, and easy and difficult mental-division problems, he found greater pupil responses to difficult than to easy processing tasks. The only exception to this pattern was found in the word-game where no significant differences obtained between those problems judged to be easy and those judged difficult. He also found reliable loading and unloading functions very similar to those reported by Kahneman and Beatty (1966), and Hess and Polt (1964). Bradshaw also interpreted his findings in light of a general arousal or activation notion, suggesting that the reliable post-solution drop in pupil size was due to "end-of-job" reduction in arousal. This rationale was further supported by his finding that pupil diameters elicited by problems which remained unsolved tended to maintain a constant plateau, failing to show the characteristic post-solution drop to base line.

Studies Relating Pupil Size to Memory Tasks

To investigate pupil changes in short-term and long-term memory tasks, Beatty and Kahneman (1966) made pupillographic records while Ss attempted to recall either highly familiar telephone numbers or totally unfamiliar telephone numbers. The S's task (long-term memory) in the case of the familiar numbers was to verbally recite the number upon hearing the name he had supplied with the number. In the short-term memory task Ss were instructed to repeat a similar but totally unfamiliar telephone number two seconds after hearing E pronounce the number. In both cases S's recitation was placed at a rate of 1 digit per second. In the short-term task the pupil dilated progressively with the intake of each digit, reached its peak during the two second pause, and progressively returned to base line size during the report. The reaction of the pupil in the long-term task was to dilate very rapidly upon presentation of the signal (name) and to reduce decrementally to base line during recall. The authors interpreted these data to be highly supportive of the notion that pupillary dilation does reflect the momentary state of mental effort.

Another study by Kahneman and Beatty (1966), although reported earlier than some of their work already mentioned, was deliberately presented late in this review since it serves in part as a major point of departure for the experiment reported herein. In this study the Es employed several different memory tasks in an effort to carefully examine pupillary responses during the input and output phases of a short-term memory task.

The basic procedure of the experiment was to make photographic records of the subject's pupil while he either listened to and repeated strings of digits (three to seven digits per string), listened to and immediately attempted recall of strings of four high-frequency monosyllable nouns, or listened to and transformed (by adding one to each digit) before recall, strings of four digits. In all tasks the stimulus material was presented at the rate of one unit per second, and a two second pause preceded a series of one per second clicks which served to pace the recall. Exposures were made at the rate of one per second, and five pre-trial and four post-trial exposures were included.

Although individual differences in the magnitude of the pupil response were found across subjects, the general features of the response were remarkably consistent. Across all the tasks two distinct phases of the pupil response were readily apparent: a loading phase during which the pupil dilated incrementally with each unit heard, and an unloading phase during which the pupil constricted with each unit reported. In the digit recall tasks the peak diameters obtained were directly related to the number of digits in the string and occurred during the pause before recall. The expectation that pupil diameter would be related to task difficulty in the word recall and transformation tasks was confirmed, the loading function being significantly steeper in the more difficult tasks.

The authors related the loading functions to rehearsal and other active modes of information processing during input, since with each new unit of information received, more material had to be rehearsed and otherwise processed. The requirement for rehearsal naturally dropped during recall as items were successively dropped from the number still being processed. The Es reported that this interpretation is further substantiated by the observation that when complex sentences were auditorily presented at rapid rates designed to prevent rehearsal, no dilations occurred during the listening phase, but very large dilations occurred at the conclusion of the sentence. Subjects reported that this was the time when they were conscious of actively rehearsing the sentence in an effort to understand it. In extensions of the basic experiment the Es tested for possible effects on the pupil response of accommodation and/or habituation. Although accommodation definitely affected the average pupil size at given distances, it did not seriously distort the experimental effect even at distances approaching the limit of accommodation effects (6 feet). In regard to habituation, its effect was found to be present when the same task was repeated over several trials, but again the loading and unloading functions were still clearly evident. The authors suggested that habituation effects can be eliminated or greatly reduced by interspersing several different procedures within a block of trials. The habituation effect observed was interpreted as further evidence in support of the validity of the pupil response as an index of cognitive processing, by reasoning that S's adoption of a consistent performance set reduces the subjective difficulty of the task and thus the pupillary response to it.

The rehearsal-processing explanation of changes in pupil size during short-term memory tasks has realized still further support in the results of a recent experiment by Kahneman, Onuska, and Wolman (1968).

In this experiment the Es compared pupil responses during the monotonic presentation of a nine digit serial recall string, with pupil responses during the presentation of nine similar digits which were presented as three groups of three digits each. Total presentation time for the two conditions was equal.

In the case of the ungrouped presentation the familiar nearly linear increase in pupil size was obtained, while in the grouped condition only a slight overall increase was observed from the presentation of the first item through the last. However, significant cycles of dilation followed by constriction were observed during the pauses between the three groups, and a very steep increase in dilation was seen after the final item of the third group had been presented.

These results were interpreted to indicate that in the ungrouped condition rehearsal is continuous and cumulative, while in the grouped condition there is a brief period of active rehearsal following each group with almost no cumulative effect until the final item of the third group has been presented. At this time considerable active rehearsal is apparently required in order to connect the three groups prior to recall.

The absence of the common loading function was also observed by Kahneman and Peavler (1968) in an experiment in which Ss heard a series of eight common nouns at a rate of one item per 4 seconds, under free recall conditions. In this case, the presentation of each item was followed by a wave of dilation-constriction, without any sustained increase across items. These results were also interpreted to indicate that little cumulative rehearsal takes place under free-recall conditions.

Reduction of PI Via a Signal to Forget

Since this study employed a paradigm and a theoretical notion which was borrowed from a researcher in the area of verbal learning, a brief review of his research and some related research is included in this review.

Bjork, LaBerge and Legrand (1968) reported a study designed to assess the effects of instructions to forget on proactive interference. The experiment was designed to minimize S's opportunities for rehearsal of visually presented consonant quadragrams (CCCC) by inserting them in a series of digits which Ss were required to shadow by calling out the color and value of each digit (the quadragrams were also pronounced aloud). In the conditions of primary concern the lengths of the lists varied in the number of total digits and contained two quadragrams separated by varying numbers of digits. The positions of the two quadragrams in regard to the beginning and ending of the list also varied. In Recall Condition 1, Ss were required to recall both quadragrams, second one first. In Recall Condition 2, Ss were told that the colored dots to the left of the two digits immediately preceding the second quadragram were a signal to forget the first, thus their task was to recall only the second quadragram. In the Control Condition the lists contained only one quadragram appearing at positions corresponding to that of the second item in lists one and two, thus the Ss had to recall only one item. Each of the 3 conditions appeared equally often per block of 12 trials. The Es reported that the "drop" instruction in Condition 2 produced a significant reduction in the degree of proactive interference, defined as the intrusion during recall of the first quadrangram for the second. There remained a significant difference between Recall Condition 2 and the Control Condition. They suggested first, the unlikely possibility that Ss actually erased items from short-term memory on signal. A second suggestion was that relieving S of the responsibility for the first item enabled him to rehearse the second more effectively. It was also suggested that the recall sequence of Recall Condition 1 led to less efficient recall, or that Ss were able to respond to the signal by coding one of the items which somehow reduced the interference between them.

Bjork (1967) conducted a study similar to the one cited above, and the one providing the basic paradigm for the study reported herein. In this experiment Ss were presented lists of paired associates some of which contained a signal to forget all pairs presented prior to the signal. Ss were informed that the probed pair would be one of those presented after the signal. Bjork found no effect on recall of the number of pairs presented prior to the forget signal. In other words there was no proactive interference attributable to the supposedly "forgotten" pairs.

In another report, Bjork (1968) presented nonsense syllables in a serial recall task which also included a signal to forget. In this case the stimuli were printed on cards which varied in color, thus providing different colored backgrounds for the stimulus items. Ss were told that if the background color of the items changed during the list, they need recall only those items printed on the most recent background color. Again, Bjork found a dramatic reduction in proactive interference; in fact, he reported no errors of intrusion from the initial items of any list in the attempted recall of the items following the color change.

A reduction of PI similar to that reported by Bjork (1967) and Bjork et al. (1968) has been obtained in a recent experiment by Turvey and Wittlinger (1969). Ss in this experiment were signalled "not to remember" fifteen of twenty trigrams presented as short-term memory tasks. The twenty trials were sequential, but recall of each trigram occurred before the next was presented. Different colored backgrounds were used as the signal mode for the visually presented trigrams. The recall scores of the experimental Ss on the five to-be-remembered trials (trials, 1,5,10,15,20) were significantly higher than the scores of the controls on the same trials. Differences in the colored backgrounds had no significance for the controls.

A second experiment reported in the same paper employed a signal "not to recall" during the recall phase of all trials except the same five trials which were signalled in the first experiment. The experimental Ss again had more accurate recall scores than the controls on the five non-signaled trials, but the difference was not significant.

Turvey and Wittlinger preferred to interpret these differences as due to differences in rehearsal strategies between the control and experimental Ss. They suggested that the experimental Ss either rehearsed to-be-remembered trigrams more than did the controls, and/or the experimental Ss rehearsed the to-be-forgotten trigrams less than did the control Ss.

They also offer the possibility that a signal not-to-remember automatically implies the signal not-to-recall. Therefore, it may be the case that the signal not-to-remember has the effect of causing the items so signalled to be tagged during their encoding with the label "not-to-be-recalled", thus reducing their capacity to compete during an active recall phase with items tagged oppositely.

CHAPTER III

METHOD

Subjects

The subjects employed in this study were undergraduate students at Oklahoma State University. The *S*s served voluntarily and were not compensated for their participation. In order to reduce variation somewhat and for methodological convenience, certain constraints were placed upon subject eligibility.

In as much as definite sex differences obtain in pupillary reactions, and since females tend to have slightly larger pupils and somewhat more stable pupil responses (Lowenfeld, 1958; Adler, 1959; Beck, 1967) the sample was limited to females.

Eye color is also known to be a source of variation in pupillographic work, with light colored eyes generally having larger pupils (Adler, 1959) and somewhat greater mean dilations (Beck, 1967). In view of this evidence the sample was further limited to females with light colored irises. It was also methodologically convenient to use *S*s with light colored irises, since good photographic contrast is more easily obtained with such *S*s.

In addition, no subject over age 25 or who had known visual defects was included. As a further guarantee against including *S*s with severe visual pathology, each volunteer was given a standard Snellen eye test. *S*s with Snellen scores greater than 20/30 in either eye were excluded.

The final design called for 16 Ss, but discovery of an error in adjustment of the camera's lens diaphram after the sixth S had been run, caused the experimenter to run six additional Ss as replacements for the first six. As it turned out the film from the first six Ss was not spoiled, so data was available for a total of 22 subjects. From this pool the data of the 16 Ss having the lowest error scores were selected for analysis.

The Ss were assigned at random to either the control or experimental group so that each group was composed of eight subjects.

Apparatus

Hess not only established a trend in the nature of current pupillometric research, but the basic apparatus employed by virtually all of the current investigators is essentially similar to that described by Hess (1960, 1965).

The basic apparatus used in this study was also highly similar to the Hess "pupillometer". It consisted of a ½ inch plywood viewing box 23" X 23" X 48" (inside measurements). The back end of the box was open and equipped with a tight fitting frame to which was attached a rear projection screen. The S's end of the box was enclosed except for an opening in the center to provide for viewing of the screen at the opposite end, and to allow for photographing of S's eyes. This opening was equipped with a goggle frame to provide uniform positioning of S's head and to block out ambient light. The opening extended downward and was enlarged near the area of the subject's mouth to enable S to speak unimpeded. Positioned immediately below the enlarged mouth opening was a standard adjustable chin rest, also designed to maintain S's position and to provide a measure of comfort.

Positioned on the side of the box to the S's right was a 16 mm. motion picture camera. The camera was mounted on a fully adjustable support which provided for precise lateral, vertical, and focal distance adjustments. The objective lens of the camera protruded approximately 1/8 inch into the interior of the box through a tight fitting aperture in a system of sliding panels also designed to allow adjustment in camera position.

All interior surfaces of the viewing box were painted flat black to minimize reflectance. Positioned adjacent to the S's end of the interior of the box was a half silvered mirror which extended from top to bottom and from side to side, thus completely subtending the field of view within the box. The mirror was mounted in a tight fitting wooden frame which positioned the mirror at a 45 degree angle to both the subject's forward line of vision and the central axis of the camera lens. With the mirror thus positioned S could clearly see the highly illuminated screen at the opposite end of the box, while the camera "saw" a clear reflection of S's right eye in the mirror.

The camera employed was a Beaulieu R16ES, equipped with a Vemar 135 mm. f/3.5 telephoto lens, a Vemar "C" mount adapter and a 30 mm. extension tube to provide for precise focusing at a lens to subject distance of 24 inches. During the experiment the camera was set to operate at a rate of two exposures per second. This setting provided for an actual exposure time of .20 sec. per frame.

The rear projection screen was illuminated by an Argus 500 watt automatic slide projector, projecting a blank side. This arrangement produced a 13 inch square area of high and uniform illumination in the center of which was a black fixation cross one inch tall with arms $\frac{1}{4}$ inch in thickness. The fixation cross was affixed to the outer surface of the screen. This assured that the image of the cross was always centered in the illuminated field and in sharp focus. The distance from S's eye to the fixation cross was 49 inches.

In addition to the pupillometer, the experiment employed a stereophonic tape recorder which was used to present the stimulus material to the subject via headphones. The tape recorder was also connected to a Kodak Carousel Model 1 Programmer which controlled the operation of the camera synchronously with the presentation of the stimuli. A second tape recorder was used to record S's responses during the recall phase of each trial.

All trials were run in a small room which had no windows, thus eliminating any variation in incident illumination due to changes in external light levels. The room was uniformly illuminated by florescent ceiling fixtures which remained lighted throughout each experimental session. The incident light level in the room was 125 foot candles at S's eye level when seated. This illumination level tended to minimize the amount of light reflex experienced by S as he viewed the brightly illuminated field in the apparatus.

Stimulus Material

The stimulus words used were chosen from the Thorndike-Lorge (1944) word count. Only "AA" (i.e., among the 500 most frequent words in the count), monosyllable nouns were chosen, and any words which had obvious affect laden connotations (hell, death) were eliminated. In order for a word to be classified as a noun it had to be used as such at least 51% of the time according to West (1953).

One hundred sixty-eight words meeting the above criteria were obtained. From this pool 16 lists of five words each were drawn at random to comprise Tape I. These 80 words were replaced, and 16 more lists of five words each were drawn at random to comprise Tape II. Thus, the two tapes, included some of the same words but never in the same arrangement. One-half of the experimental Ss and one-half of the control Ss were tested with Tape I, while the other half of each group heard Tape II. This assignment was random. It was felt that the use of two different tapes should tend to equalize the variance which might be produced by different words and their arrangement in the various lists.

During the presentation of each of the 16 lists S also heard a background tone, recorded on the same tape channel as the words. On eight of the lists the tone was constant throughout the list, while on the remaining eight lists it changed frequency part way through the list. The sine wave tones were produced by an audio-generator with frequencies of 320 and 3200 cycles per second for the low and high tones respectively. Both tones were well within normal audition range, and they were easily discriminable. One-half of the no-tone-change trials had the low background tone and one-half the high tone. One-half of the tone-change trials began with the low tone and changed to high, while the reverse was true for the other half. In order to control for possible differences in effect of the two tones, a restricted randomization scheme was used to assign either high or low constant tones, and tone changes (hi-lo or lo-hi) to the 16 word lists of each tape. The scheme insured that each constant tone condition and each tone-change condition occurred equally often in each half of the 16 trial experimental run.

Of the eight tone-change trials on each tape, two had tone changes occurring after the first word, two had the tone change after the second word, two after the third word, and on two trials the tone changed after the fourth word. The eight non-change trials were included primarily to prevent S from developing an expectancy for a tone change on each trial. If there had been all tone-change trials, S could have learned to wait for the tone change and to attend to only those words which came after the change in tone.

Procedure

Subjects were tested individually and were assigned upon arrival at the experimental site to either experimental or control conditions according to a predetermined randomization schedule. The randomization of this schedule was restricted to the extent that no more than two subjects of either group were run successively, and that the number of experimental and control sessions was evenly distributed within the two halves of the total experimental run.

At the beginning of each session S was seated comfortably at the pupillometer and the chin rest adjusted so that his right eye was centrally positioned in the photographic frame. This also gave E an opportunity to check the focus of the image and make any necessary camera adjustments. S was given a few additional minutes to explore visually the interior of the box and to become accustomed to the experimental situation.

Prior to the beginning of the experimental trials each S was given eight practice trials designed to minimize errors due to confusion of directions, meaning of signals, etc. The practice trials were identical to the experimental trials except that no practice word list was repeated in the experimental lists which followed, nor were responses photographed during practice trials.

Prior to the first practice trial each S heard a set of instructions appropriate to either the Experimental or Control Condition. The instructions were designed to prepare S for the experimental procedure, to minimize anxiety, and to establish either the Experimental or Control Condition in regard to the tone-change stimulus.

Each S, whether experimental or control, heard the following instructions:

> In this experiment we will be photographing your eyes while you do some simple memory tasks. Later, when you look into the apparatus you will see a small black cross in the center of an illuminated field. Since we are interested in the exact center of your eye, it is imperative that you maintain a steady gaze at the center of the screen. The small black cross will be your fixation point.
>
> Now let me tell you about the memory tasks you will be doing. You will hear several lists of common words presented to you via headphones. In each list there will be five words. Immediately before each list of words you will hear three loud clicks. These clicks are a signal to you to fixate on the cross and prepare to listen carefully to the words. After the fifth word you will hear a series of the same clicks which preceded the words. When you hear the second click you are to begin pronouncing the words as you recall them in time with the clicks. Try to recite the words in the same order as you heard them and in time with the clicks. Remember, the first click is a warning - - begin on the second one. Any questions so far?
>
> In addition to the five words in each list you will hear a background tone. The tone will come on just before the first word and end just after the last word. On some of the lists this tone is high in pitch, it is low on some, and on some of the lists the tone may change pitch at some point during the list.

The remainder of the instructions differed for the control and the experimental Ss. The remainder of the instructions for the experimental Ss was as follows:

> A tone change has special significance. If the tone should change during a list, this change is a signal to you to forget all of the words you heard before the tone changed. In other words, you are to recite only the words which come after the tone changes. Of course, if the tone remains constant throughout the list, you are to recite all five words. Any questions?

The remainder of the instructions for the control Ss was as follows:

> The background tones, whether high, low or changing are included as a kind of experimental control and need not concern you. They have nothing to do with your task. Any questions?

Each S then put on the headphones, and the eight practice trials were run. After each practice trial there was an opportunity for S to ask questions and for E to clarify instructions, if such was necessary. All Ss had demonstrated a clear understanding of the task by the end of the sixth practice trial.

Stimulus Presentation and Response Recording

All stimulus material was presented auditorily, and all Ss were given 16 experimental trials during which pupillograms were made. A trial consisted of the following events: (1) a six second ready period containing an audible click every 2 seconds, (2) five monosyllable high-frequency nouns presented at 2 second intervals, (3) a two second pause, (4) a series of audible clicks occurring at two second intervals.

Each non-tone-change trial lasted 30 seconds. S was given approximately 30 seconds rest between trials, except between Trials 8 and 9 at which time a four minute mid-session break was taken.

The same magnetic tape which was used to present the stimulus words to S also controlled the operation of the camera. On the second channel opposite the stimulus words was placed a 6.5 killocycle "beep". The beep started synchronously with the first of the three warning clicks on the stimulus tape and continued four seconds beyond the last recall click. The beep was fed through a Kodak Carousel Programmer. The onset of the beep activated a relay in the programmer which completed a circuit turning on the camera, and the offset of the beep opened the circuit turning the camera off. Thus the photographic record of S's pupil responses was accurately time-locked to the stimulus events. Since the camera operated at exactly two frames per second, it was possible to find the pupil response corresponding to a particular stimulus or recall event by simply counting frames from the beginning of each trial. On the tone-change trials for experimental Ss where fewer than five words were to be recalled, E stopped the camera four seconds after the last word had been recalled by opening a manual switch placed in series in the camera-programmer circuit. It should be noted that the 6.5 killocycle beep was completely inaudible to S since its signal was placed on the second channel and fed directly to the Kodak programmer.

Ss' photographic records were separated by photographing a subject identification number prior to the first trial of each S. Individual trials for each subject were kept separate by exposing three or four blank frames between trials.

Scoring of Responses

The actual measure used in all analyses of the data was the amount of deviation in pupil size from a base line size. The base line measure was obtained by computing the mean actual pupil size of the twelve frames which comprized the six second ready period preceding each trial. Deviations from this mean were measured to the nearest 0.1 mm..

The pupil size of each frame was measured by projecting the image onto a white screen at a magnification level such that projected pupil size was exactly ten times actual pupil size. Each pupil image was scored by measuring the diameter of the pupil to the nearest millimeter, which corresponded to 0.1 mm. actual size.

Ss' verbal responses were tape recorded simultaneously with the photographic recording. Recall errors were later assessed by comparing the tape recorded responses of each subject with the actual text of the stimulus tapes.

Three kinds of errors were scored as follows: omission errors, in which one or more of the five words were omitted; transposition errors, in which all words were recalled but in an order other than that in which they were presented; intrusion errors, in which one or more words not in the stimulus list were substituted for the actual words during recall.

The scoring of omission and transposition errors was straightforward. In the case of intrusion errors, however, it was necessary to establish some error criteria, since homonyms or close approximations of the stimulus words were not infrequent during recall. In as much as the probability was reasonably high that such responses represented misperceptions rather than true intrusions, a verbal response was scored as correct if either of the following criteria was met: (1) if the first and middle phonemes were similar to the corresponding phonemes in the stimulus word, (b) if the middle and last phonemes were similar to those of the stimulus word. Sound-alikes not meeting either of these criteria were scored as intrusion errors.

CHAPTER IV

RESULTS

Pupillary Responses

The pupillary responses of the experimental and control subjects during the eight no-tone-change trials are presented in Figure 1. These curves indicate that the pupil progressively increases in size during the input of information, reaches peak dilation early in the recall phase, and begins to constrict during recall, reaching, even dropping somewhat below, base-line size after the last item has been recalled.

The pupil response curves of the control and experimental Ss are obviously different. Since this sort of difference was not crucial to the hypotheses advanced in this study, the difference was not tested statistically. Nevertheless, a suggested explanation of this observed difference is offered in Chapter V.

Figure 2 shows the pupillary responses for the experimental subjects on the trials which contained a signal to forget in the form of a tone change. The pupillary responses for the control Ss on the same tone-change trials are given in Figure 3.

An inspection of Figure 2 revealed that a signal to forget had a two phase effect, viz., an almost immediate and quite pronounced dilation, followed by a steady constriction. These cycles of dilation-constriction were seen to be in the same temporal sequence as the tone changes, and with the exception of the cycle following the signal in

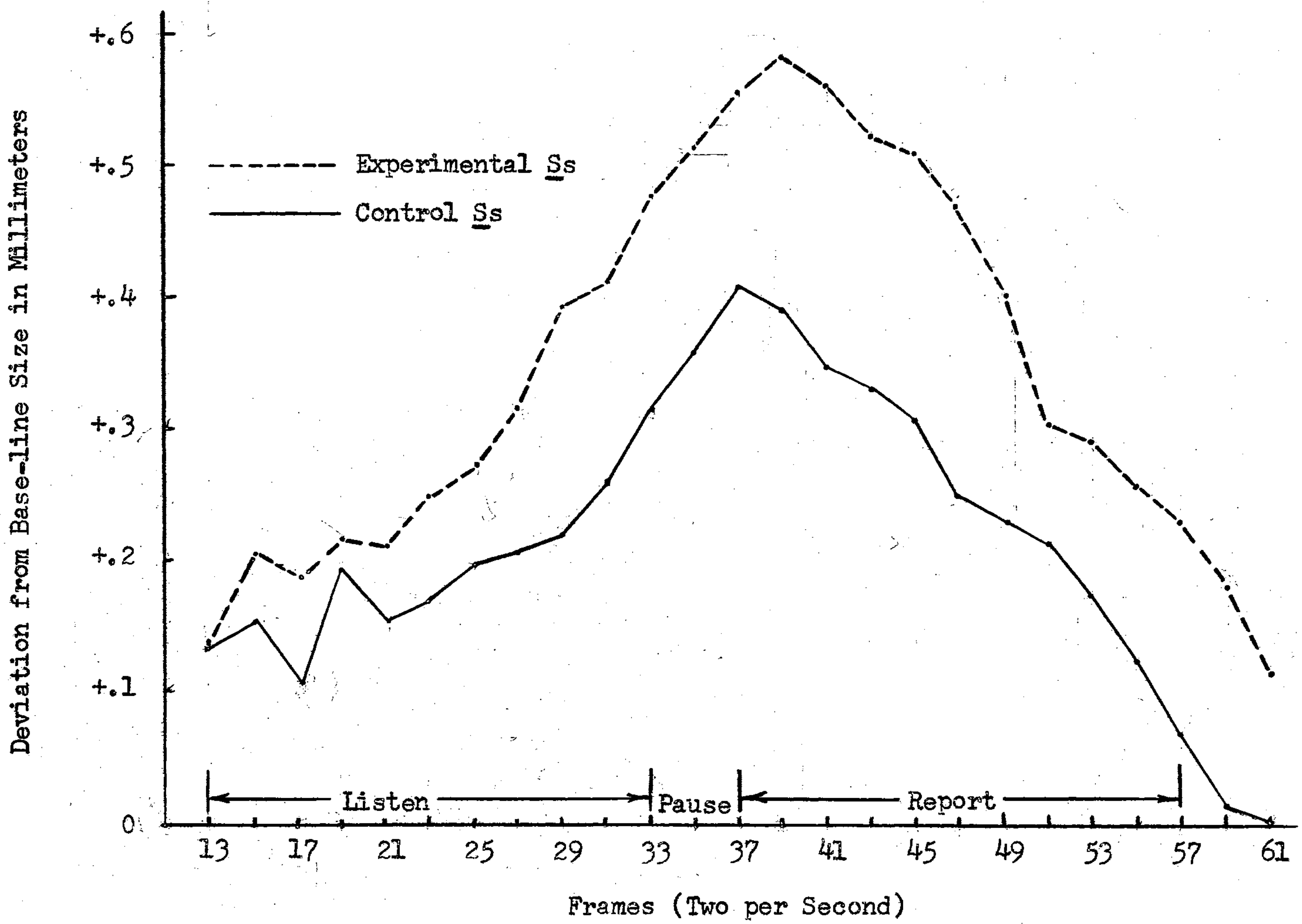


Figure 1. Pupil Responses during No-Tone-Change Trials for Control and Experimental Subjects. Curves represent responses from end of base-line period forward.

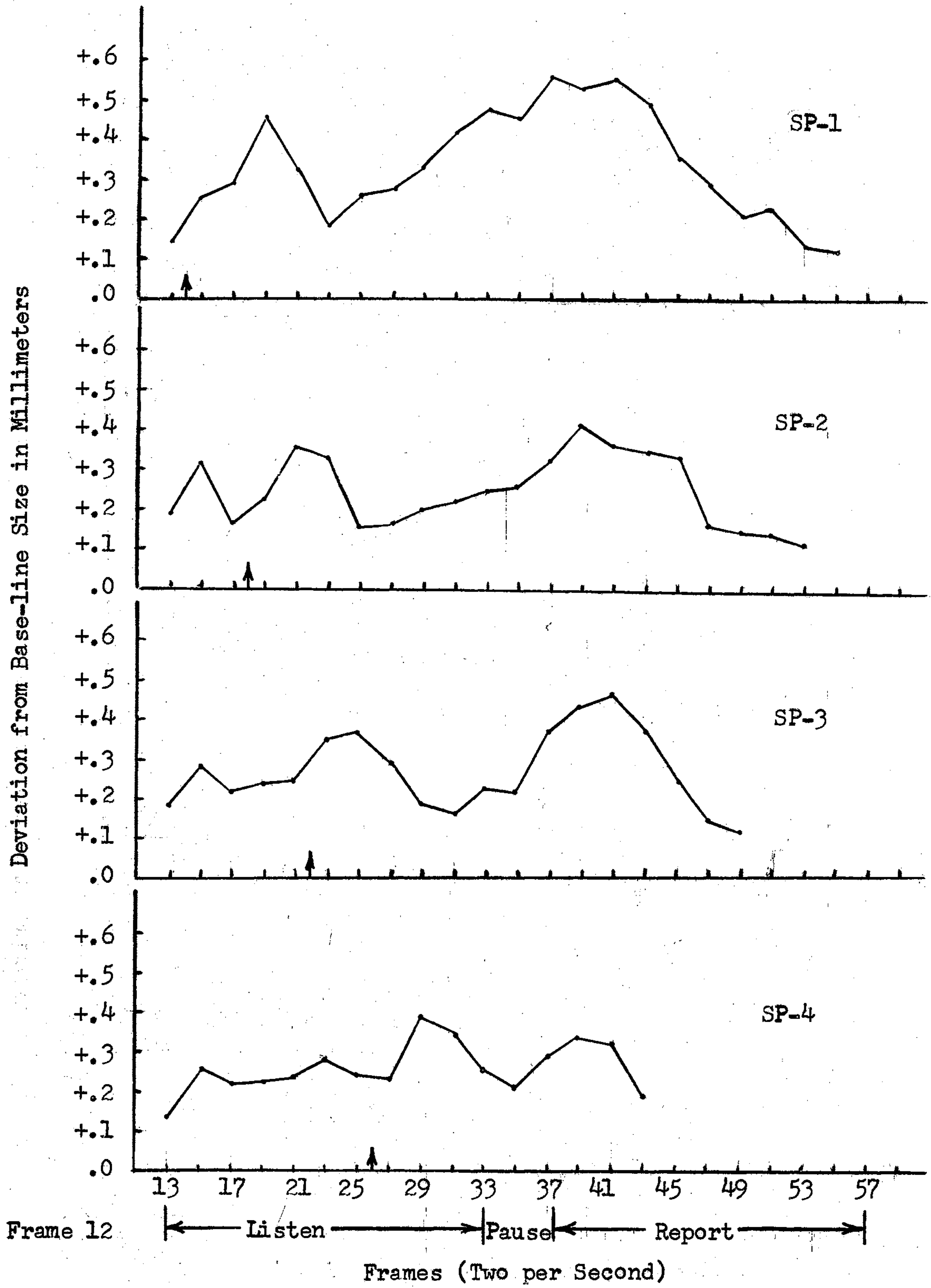


Figure 2. Pupil Responses during Tone-Change Trials for Experimental Subjects. Curves represent responses from end of base-line period forward. Each SP designation refers to only those trials during which the tone changed at the point designated by the arrows.

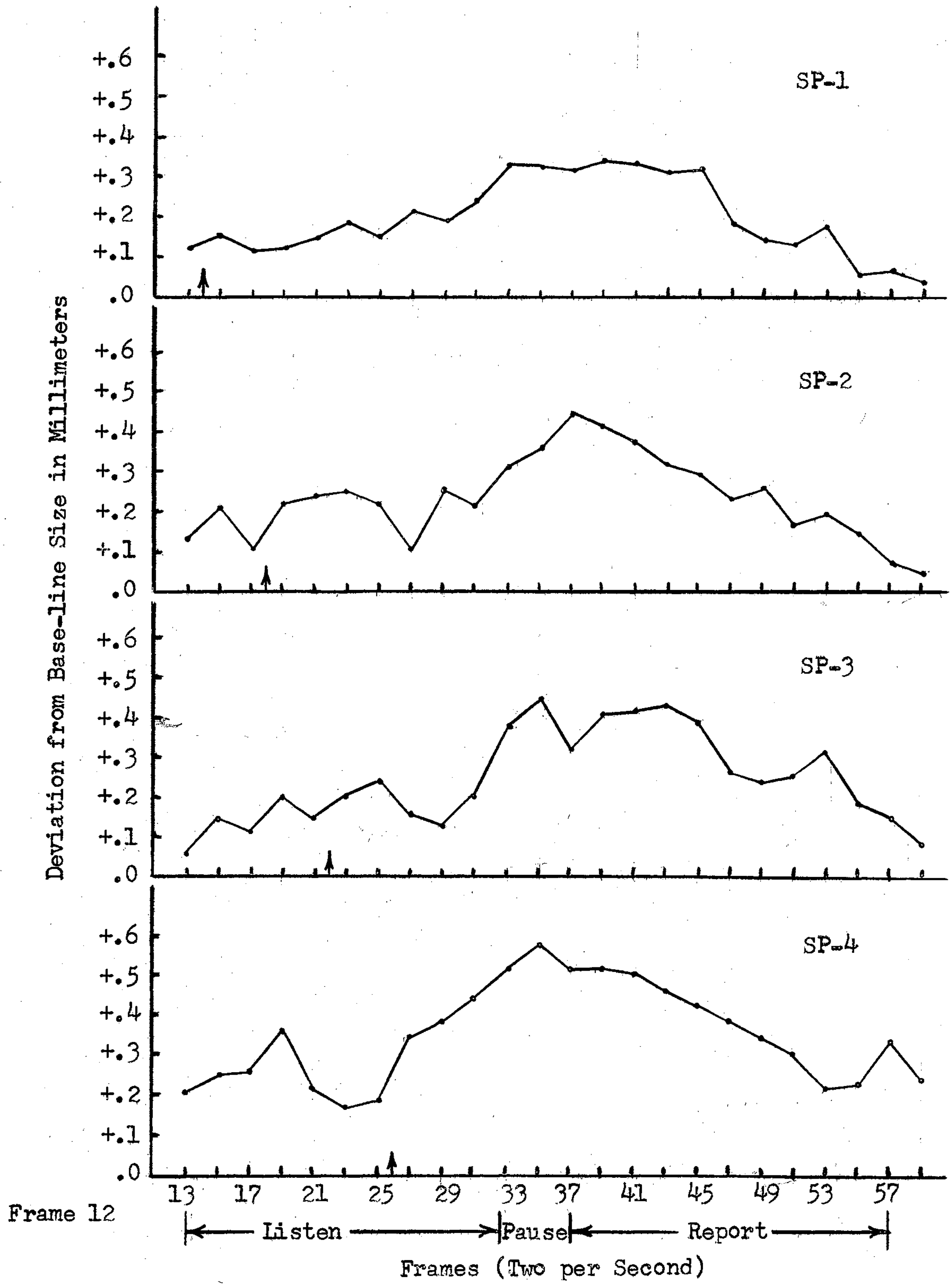


Figure 3. Pupil Responses during Tone-Change Trials for Control Subjects. Curves represent responses from end of base-line period forward. Each SP designation refers to only those trials during which the tone changed at the point designated by the arrows.

position one, the magnitude of the peak dilations of the four cycles was systematically arranged in the expected direction.

An examination of the responses of the control Ss on the same set of trials revealed no systematic dilation-constriction cycles following the tone change signals.

Further inspection of the data of the experimental Ss on the tone-change trials (Fig. 2) indicated that a block of nine frames following the tone change would include all the dilation and constriction produced by the signal. Thus the data were divided into four overlapping blocks of nine frames each for analysis. These four blocks of nine frames were measured from the frame immediately following the occurrence of each of the four tone-change signals. Thus the frames included in blocks one through four were F-15 through F-23, F-19 through F-27, F-23 through F-31, and F-27 through F-35, respectively.

Pupillary Constriction

The post-signal constriction was scored for each experimental and control S on each tone-change trial. The scoring was done as follows: In each of the nine frame blocks, the longest monotonic decrease in pupil size following a peak of dilation also occurring during that block was recorded as the constriction score for that block. Thus, each trial was scored for the amount of constriction which occurred during each of the four blocks. See Appendix for explanation of scoring procedures.

These constriction scores for the tone-change-trials were then arranged in a signal position (SP) by block of frames (BF) matrix, and separate 4 X 4 analyses of variance were computed on the data of the experimental and control Ss. The SP by BF analysis of variance for the experimental Ss is presented in Table I.

TABLE I

CONSTRICTION PER BF X SP FOR TONE-CHANGE TRIALS OF EXPERIMENTAL SUBJECTS

Source	df	SS	MS	F	
Treatments	15	114.35			
SP	3	4.975	1.658	.5475	ns
BF	3	13.58	4.527	1.495	ns
SP X BF	9	95.795	10.644	3.515	$p < .001$
Error	240	726.73	3.028		

The highly significant SP X BF interaction indicated that the amount of constriction occurring in a given block of frames depends on the position of the signal in a given list, and that separate SP X BF and BF X SP analyses of variance should be computed. Each SP level was compared across all levels of BF, and each level of BF was compared across all levels of SP. Table II presents the resulting F values of each of these eight separate analyses.

TABLE II

F VALUES FOR EACH SP X BF AND BF X SP ANALYSIS OF VARIANCE OF THE CONSTRICTION SCORES OF THE EXPERIMENTAL SUBJECTS

Factor X Factor	df n/d	F	P
SP-1 X BF	3/60	6.499	$<.001$
SP-2 X BF	3/60	7.554	$<.001$
SP-3 X BF	3/60	4.270	$<.01$
SP-4 X BF	3/60	2.804	$<.05$
BF-1 X SP	3/60	6.889	$<.001$
BF-2 X SP	3/60	4.751	$<.001$
BF-3 X SP	3/60	7.235	$<.001$
BF-4 X SP	3/60	2.857	$<.05$

In every case the comparisons among signal position proved to be significant. All comparisons among blocks of frames were also significant.

Duncan's Multiple Range Test was then used to compare each SP mean with all others for each BF. Table III presents the results of these tests.

TABLE III

COMPARISONS AMONG ALL SP MEANS WITHIN EACH BF FOR CONSTRICTION SCORES OF EXPERIMENTAL SUBJECTS BY DUNCAN'S MULTIPLE RANGE TEST

BF-1	p	BF-2	p	BF-3	p	BF-4	p
SP-1/SP-2	$<.01$	SP-2/SP-1	$<.01$	SP-3/SP-1	$<.001$	SP-4/SP-1	$<.10$
SP-1/SP-3	$<.01$	SP-2/SP-3	$<.01$	SP-3/SP-2	$<.005$	SP-4/SP-2	$<.05$
SP-1/SP-4	$<.005$	SP-2/SP-4	$<.01$	SP-3/SP-4	$<.005$	SP-4/SP-3	$<.10$
SP-2/SP-3	ns	SP-1/SP-3	ns	SP-2/SP-1	ns	SP-2/SP-1	ns
SP-2/SP-4	ns	SP-1/SP-4	ns	SP-2/SP-4	ns	SP-2/SP-3	ns
SP-3/SP-4	ns	SP-3/SP-4	ns	SP-4/SP-1	ns	SP-1/SP-3	ns

Dunnett's test for differences between a control mean and all others was then applied to the means of each SP Condition across all blocks of frames. The mean constriction occurring in the BF associated with the tone change occurring during a particular trial was considered the control, and that score was compared with the constriction score from all other BFs. The results of the Dunnett's test are presented in Table IV.

Figure 4 is a graphic representation of the comparisons of constriction per SP across blocks of frames and the constriction within each BF by signal position lists.

Figure 4 also indicated that there is a trend, although slight, for later tone-change signals to produce less constriction. However, when individual comparisons among these four means were made by the Duncan's Multiple Range Test, no significant differences were found.

TABLE IV

COMPARISONS OF MEAN CONSTRICTION PER SP ACROSS BLOCKS OF FRAMES FOR TONE CHANGE TRIALS OF EXPERIMENTAL SUBJECTS

Signal Position Condition	Signal BF -- Non-signal BF	t	EMS/df	p
SP-1	BF-1--BF-2	4.053	60	$<.005$
	BF-1--BF-3	3.422	60	$<.005$
	BF-1--BF-4	2.973	60	$<.01$
SP-2	BF-2--BF-1	2.659	60	$<.025$
	BF-2--BF-3	3.691	60	$<.005$
	BF-2--BF-4	4.449	60	$<.005$
SP-3	BF-3--BF-1	2.616	60	$<.025$
	BF-3--BF-2	2.971	60	$<.01$
	BF-3--BF-4	3.089	60	$<.005$
SP-4	BF-4--BF-1	2.256	60	$<.05$
	BF-4--BF-2	1.933	60	ns
	BF-4--BF-3	2.685	60	$<.025$

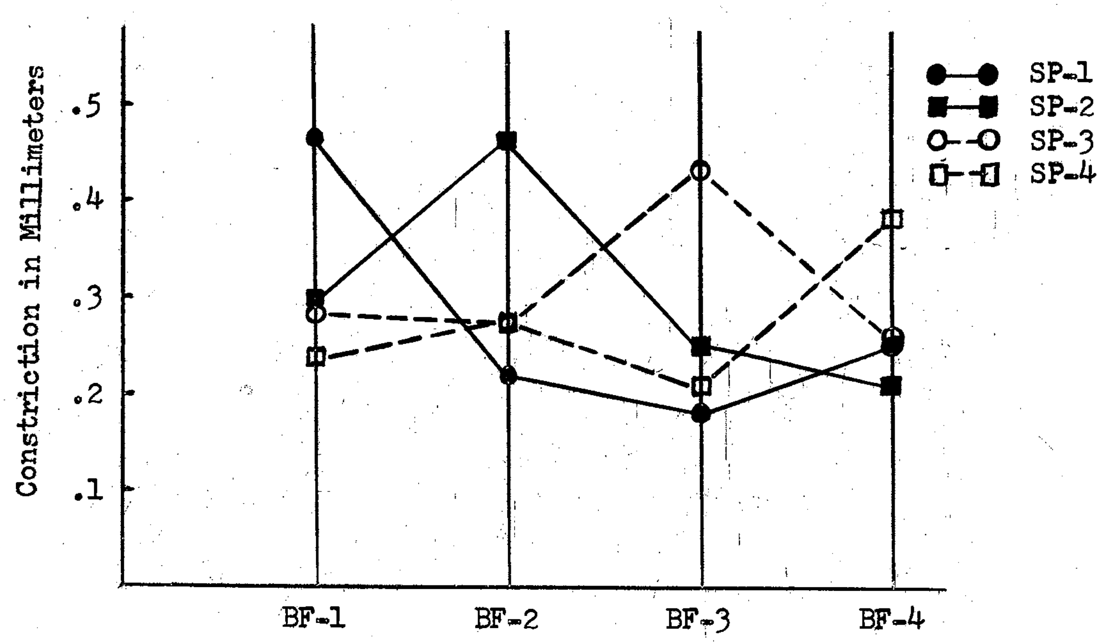


Figure 4. Constriction Scores during SP Lists by Blocks of Frames for Experimental Subjects

The constriction scores for the control Ss on the same tone-change trials were also arranged in a SP X BF matrix and analyzed as a 4 X 4 factorial array. The analysis of variance results for these data are presented in Table V.

TABLE V

CONSTRICTION PER BF X SP FOR TONE-CHANGE TRIALS OF CONTROL SUBJECTS

Source	df	SS	MS	F	
Treatments	15	107.309	7.154	3.057	$p < .001$
SP	3	12.836	4.288	1.832	ns
BF	3	54.848	18.238	7.813	$p < .001$
SP X BF	9	39.588	4.398	1.879	ns
Error	240	561.656	2.340		

In order to provide a highly conservative test of Hypothesis I, the constriction scores of the control Ss were subjected to separate SP X BF and BF X SP analyses of variance, even though the BF X SP interaction was not significant in the basic analysis. The resulting F values for these eight separate analyses are presented in Table VI.

TABLE VI

F VALUES FOR EACH SP X BF AND BF X SP ANALYSIS OF VARIANCE OF THE CONSTRICTION SCORES OF THE CONTROL SUBJECTS

Factor X Factor	df n/d	F	p
SP-1 X BF	3/60	.819	ns
SP-2 X BF	3/60	1.742	ns
SP-3 X BF	3/60	5.708	$< .01$
SP-4 X BF	3/60	3.334	$< .05$
BF-1 X SP	3/60	3.548	$< .05$
BF-2 X SP	3/60	2.010	ns
BF-3 X SP	3/60	1.211	ns
BF-4 X SP	3/60	1.146	ns

In the cases where a significant F value was found, Duncan's Multiple Range Test was employed to compare among all SP means at a given level of BF, and Dunnett's test was used to compare SP means across blocks of frames.

The comparisons of mean constriction of the four SPs during BF-1, indicated that both SP-1 and SP-2 were significantly different from SP-3 ($p < .05$). No other differences were significant. Comparisons of mean constriction at a given level of SP across frames indicated that for SP-3, the constriction occurring in BF-3 was significantly different from that occurring in BF-4 only ($p < .025$). The constriction occurring during list SP-4 was significantly less in BF-4 than BF-1 ($p < .025$), but the other comparisons yielded no differences. Figure 5 is a graphic representation of these comparisons.

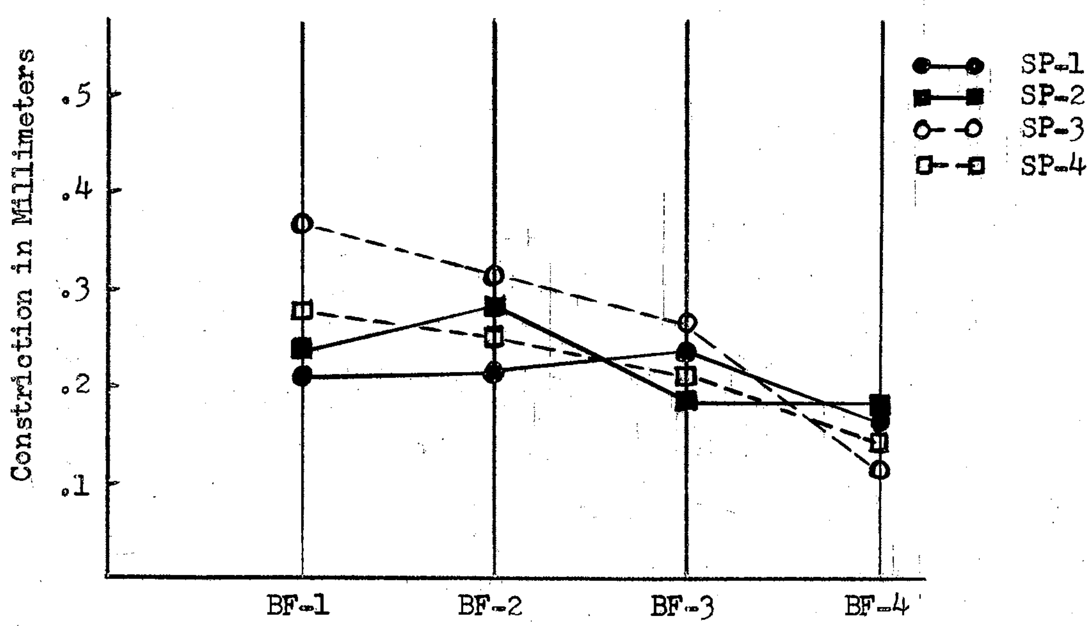


Figure 5. Constriction Scores during SP Lists by Blocks of Frames for Control Subjects

Pupillary Dilation

The dilation phase of each post-signal wave of dilation-constriction was scored and analyzed similarly to the constriction phase. In this case the net increase per block of frames from the initial frame in that block to the highest peak occurring within that block was recorded as the dilation score for each block of nine frames. (See Appendix) These data were also arranged in a SP X BF matrix and analyzed as a 4 X 4 factorial arrangement of treatments. Again, the data of the control and experimental Ss were analyzed separately.

Table VII presents the analysis of variance of the dilation data of the experimental Ss on the tone-change trials.

TABLE VII

DILATION PER BF X SP FOR TONE-CHANGE TRIALS OF EXPERIMENTAL SUBJECTS

Source	df	SS	MS	F	
Treatments	15	239.860	15.991	7.600	$p < .001$
SP	3	6.453	2.151	1.022	ns
BF	3	11.391	3.797	1.804	ns
SP X BF	9	222.016	24.668	11.724	$p < .001$
ERROR	240	505.130	2.104		

The highly significant SP X BF interaction indicated that the amount of pupil dilation occurring in a given block of frames depended upon the position in the list of the signal to forget. As in the case of the constriction data, separate SP X BF and BF X SP analyses of variance were computed for these data. Table VIII presents the F values which were obtained in these eight separate analyses of variance.

TABLE VIII

F VALUES FOR EACH SP X BF AND BF X SP ANALYSIS OF VARIANCE OF THE DILATION SCORES OF THE EXPERIMENTAL SUBJECTS

Factor X Factor	df n/d	F	p
SP-1 X BF	3/60	9.786	< .001
SP-2 X BF	3/60	10.577	< .001
SP-3 X BF	3/60	5.102	< .005
SP-4 X BF	3/60	10.090	< .001
BF-1 X SP	3/60	18.413	< .001
BF-2 X SP	3/60	12.808	< .001
BF-3 X SP	3/60	3.436	< .025
BF-4 X SP	3/60	7.797	< .001

These analyses revealed that in every case the comparisons of dilation across blocks of frames within each level of SP were significant. It was also seen that within each BF the comparisons of dilation among the SP lists were also all significant. Table IX summarizes the results of Duncan's Multiple Range Test comparisons of the individual SP means within each BF.

TABLE IX

COMPARISONS AMONG ALL SP MEANS WITHIN EACH BF FOR THE DILATION SCORES OF EXPERIMENTAL SUBJECTS BY DUNCAN'S MULTIPLE RANGE TEST

BF-1	p	BF-2	p	BF-3	p	BF-4	p
SP-1/SP-2	< .01	SP-2/SP-1	< .01	SP-3/SP-1	ns	SP-4/SP-1	< .025
SP-1/SP-3	< .01	SP-2/SP-3	< .01	SP-3/SP-2	< .01	SP-4/SP-2	< .01
SP-1/SP-4	< .01	SP-2/SP-4	< .01	SP-3/SP-4	ns	SP-4/SP-3	< .01
SP-2/SP-3	ns	SP-1/SP-3	< .05	SP-1/SP-2	< .05	SP-1/SP-3	< .05
SP-2/SP-4	ns	SP-1/SP-4	ns	SP-1/SP-4	ns	SP-1/SP-2	ns
SP-3/SP-4	ns	SP-3/SP-4	ns	SP-2/SP-4	< .05	SP-3/SP-2	ns

Dunnett's test was used to compare the mean dilation occurring during each block of frames for each SP list. For each SP the mean dilation which occurred during the BF associated with the tone change for that list served as the control and was compared with all other BF means. Table X presents the results of the Dunnett's tests.

TABLE X

COMPARISONS OF MEAN DILATION PER SP LIST ACROSS BLOCKS OF FRAMES FOR TONE-CHANGE TRIALS OF EXPERIMENTAL SUBJECTS

Signal Position Condition	Signal BF -- Non-signal BF	t	EMS/df	p
SP-1	BF-1--BF-2	4.465	60	$<.005$
	BF-1--BF-3	2.084	60	$<.05$
	BF-1--BF-4	1.886	60	$>.05 <.10$
SP-2	BF-2--BF-1	4.396	60	$<.001$
	BF-2--BF-3	4.396	60	$<.001$
	BF-2--BF-4	2.409	60	$<.05$
SP-3	BF-3--BF-1	2.718	60	$<.025$
	BF-3--BF-2	1.574	60	$>.05 <.10$
	BF-3--BF-4	3.718	60	$<.005$
SP-4	BF-4--BF-1	5.055	60	$<.005$
	BF-4--BF-2	4.252	60	$<.005$
	BF-4--BF-3	2.413	60	$<.05$

The dilation per block of frames by signal position in lists is represented in Figure 6.

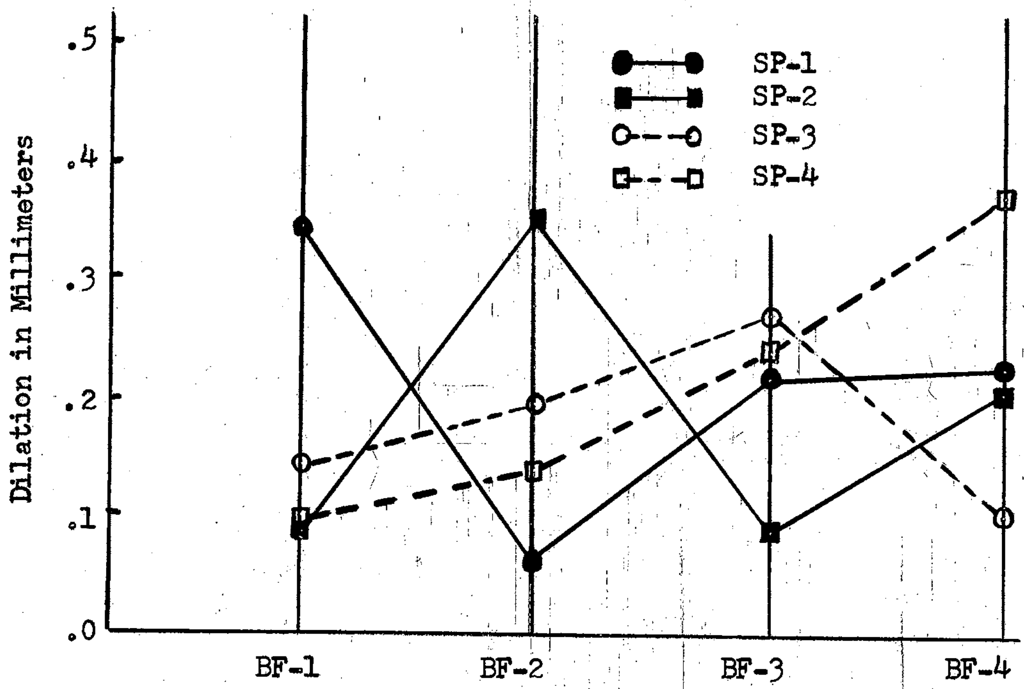


Figure 6. Dilation Scores per SP Lists by Blocks of Frames for Experimental Subjects

The analysis of variance of the dilation data of the control Ss is presented in Table XI.

TABLE XI

DILATION PER BF X SP FOR TONE-CHANGE TRIALS OF CONTROL SUBJECTS

Source	df	SS	MS	F	
Treatments	15	66.703	4.446	1.679	$p < .10$
SP	3	16.710	5.570	2.104	$p < .10$
BF	3	38.141	12.713	4.802	$p < .01$
SP X BF	9	11.852	1.316	.497	ns
ERROR	240	635.407	2.647		

The insignificant F for the SP X BF interaction indicated that no systematic relationship obtained between dilation and the occurrence of a tone change. Therefore, these data were not subjected to further analysis. Figure 7 represents the mean dilation per SP list by blocks of frames for the control Ss.

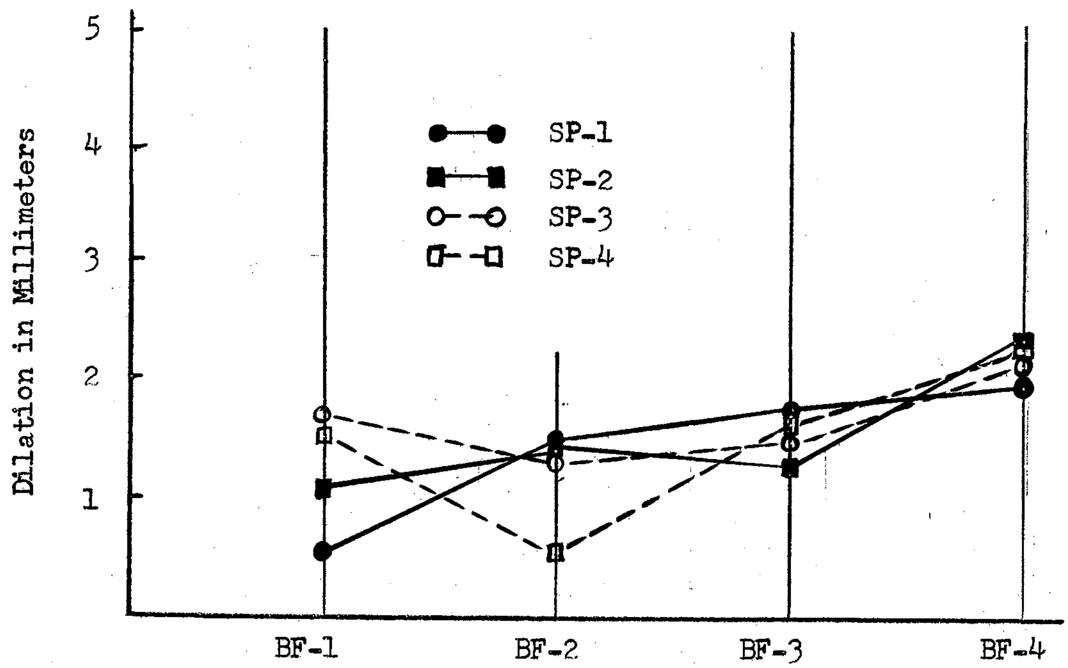


Figure 7. Dilation Scores per SP Lists by Blocks of Frames for Control Subjects.

The pupillary responses of the experimental Ss during the recall phase of each tone-change trial were also examined and analyzed.

The greatest peak in dilation across all frames for each SP Condition occurred early in the recall phase of each trial, at about Frame 40 (see Figure 2). Duncan's Multiple Range test was used to compare the mean dilation occurring on Frame 40 in each SP Condition with the Frame 40 dilation of each of the other SP Conditions. Table XII is a presentation of the results of these comparisons.

TABLE XII

COMPARISONS OF MEAN DILATION ON FRAME 40 AMONG ALL SP CONDITIONS FOR EXPERIMENTAL SUBJECTS

SP MEAN vs. SP MEAN	R	p
SP-1 -- SP-2	4.094	$<$ .01
SP-1 -- SP-3	3.500	$<$ .01
SP-1 -- SP-4	4.500	$<$ .01
SP-2 -- SP-3	- 0.594	ns
SP-2 -- SP-4	0.406	ns
SP-3 -- SP-4	1.000	$<$ .01

An examination of the recall phase of the data represented in Figure 2 seemed to suggest that once the overall peak dilation had been reached, the rate of constriction during recall was essentially the same regardless of the number of units of information to be recalled. In order to verify this indication, the data from frame forty through frame 44 were arranged in a 5 X 4, SP by Frame matrix. Considering SP and frames as factors, an analysis of variance was computed for this data. The SP X Frame interaction did not reach significance ($F=1.215$, $df=12/300$, $p > .25$), indicating that the constriction rates during recall are possibly parallel.

The constriction data for the experimental Ss on the tone-change trials was analyzed for possible effects due to the two different tapes, and the two different tone-change modes (Hi-Lo & Lo-Hi). A Tape X Tone-change Mode analysis of variance indicated that neither effect was significant -- Tapes ($F=1.546$, $df=1/252$, $p > .25$); Tone-change Modes ($F=.508$, $df=1/252$, $p > .25$).

The same data were also subjected to a Tape X Halves (first 8 trials vs. second 8 trials) analysis of variance in order to ascertain if a systematic habituation effect might be present across trials. This analysis indicated that the variance component due to halves was also insignificant ($F=.418$, $df=1/252$, $p > .25$).

Error Results

While scoring the trial by trial responses of each subject, E noticed that on some trials the typical constriction during recall was either absent or considerably delayed in its onset. Later, upon comparing the pupil responses per trial with Ss' recall scores, it was discovered that very frequently those trials which showed a delayed or missing constriction phase were trials which contained recall errors. This apparent relationship seemed to merit further analysis.

The data were re-examined and rescored as follows: Error trials and non-error trials for the same S were matched on the following characteristics: background tone, position of tone-change in the list, and base-line size of the pupil. Ten Ss were found who had at least one error trial which could be matched with a non-error trial.

For these Ss each error trial and its matching control trial were scored as follows: The frame associated with the occurrence of the error (Frame E) was first located and pupil size for that frame was recorded for the error trial and the matching control trial. The pupil size for each frame following the occurrence of the error (Frames E+1, E+2, etc.) were also recorded for both the error and control trials.

The mean frame-by-frame score, beginning with Frame E was then computed for the error and control trials of each S. Due to the restrictions placed on matching of trials, the number of trials contributing to the means were not equal across the ten Ss. For example, some Ss had as many as four matched error trials, while one S had only one. These resulting means comprised the basic data for Figure 8 and the ensuing analysis. It should be noted that each data point in Figure 8 is based on the means of 10 Ss, and all Ss had at least one error trial which was followed by 13 or more frames.

These data were then arranged in a 2 X 7 factorial matrix, with correctness as one factor and Frame E through Frame E+6 constituting the other factor. Frames E+7 through E+13 were not included in the analysis, since it is apparent that constriction has resumed at this point. An analysis of variance of this data revealed a significant Correctness by Frames interaction ($F=2.873$, $df=6/54$, $p < .025$).

Figure 8 represents the mean pupil response on the error and non-error trials from the point of error occurrence through the following 13 frames.

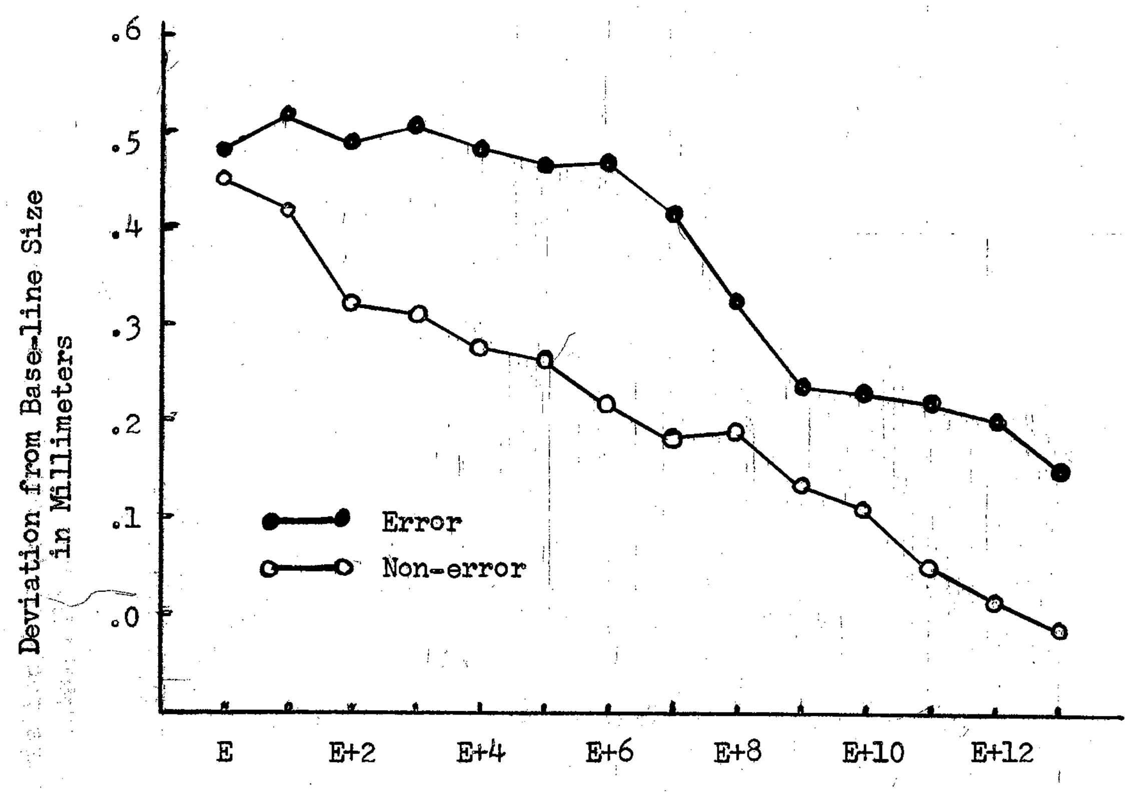


Figure 8. Pupil Response during Recall of Error and Non-Error Trials

CHAPTER V

DISCUSSION

The pupil responses which occurred during the no-tone-change trials of both the control and experimental Ss confirm the basic expectation of this study. The pupil is seen to dilate incrementally during information input, reach its peak size early in the recall phase, then decrementally constrict to base-line size during recall. These results are considered further substantiation of the theoretical notion that the pupil's changing size during periods of mental activity reflects the degree of momentary cognitive activity of the individual. In this case, the cognitive activity is assumed to be in the form of rehearsal or some related type of information processing. This notion and results highly similar to those of this study have been repeatedly expressed in the recent pupillometric literature (Hess & Polt, 1964; Hess, 1965; Kahneman & Beatty, 1967; Beatty & Kahneman, 1967; Bradshaw, 1968, 1969; Kahneman, Tursky, Shapiro & Crider, 1969).

The finding that peak dilations were reached approximately two seconds into the recall period, rather than during the two second pause between input and recall, is not isolated. Kahneman and Beatty (1966) and Beatty and Kahneman (1966) report similar results. These authors found the delayed peak to be more frequently associated with difficult processing tasks than with easier ones. It is almost surely the case that the task employed in this experiment was at least as difficult as the most difficult task required of the Ss in either of the Kahneman and

Beatty studies cited above. This result suggests a more general finding that a temporal delay exists between the input and the pupillary response. This could be extended in this study to apply to the cycle of dilation-constriction which was found to follow the signal to forget. This is added justification for the use of blocks of frames following the signal as the response band.

The analysis of the results of the tone-change trials for the experimental Ss indicates that the post-signal constriction which occurred during the block of frames associated with the signal was significantly greater than constriction occurring during any other block of frames within the same SP Condition. This was true for each of the tone-change positions with one exception. This finding indicates that the "forget" signal had a greater effect on constriction than any other event occurring during a trial.

Of at least equal importance is the finding that the amount of constriction occurring during the block of frames associated with the tone-change for a given SP condition was significantly greater for that condition than for all other SP conditions. Also, within a given block of frames, the constrictions occurring during the three SP conditions not having a tone-change associated with that block were not significantly different from one another. These results are in direct support of Hypothesis I.

The analysis of the data of the control Ss, obtained under the same conditions revealed no systematic differences in the amount of constriction occurring on lists within blocks, or across blocks within lists. Of the several comparisons made on this data the few significant differences found were in the direction opposite to those of the experimental Ss.

Before conclusions regarding the causes of pupillary constriction in these conditions (Hypothesis I) are drawn, the possible relationship between dilation and constriction should be discussed.

The dilation which was found to follow each tone change was somewhat unexpected, since Hypothesis I predicted constriction but not dilation. Nevertheless, this was considered part of a post-signal dilation-constriction cycle and analyzed similarly to the constriction component.

The result of the analysis of the dilation data of the experimental Ss indicated that in nearly every case, more dilation occurred in the block of frames associated with the tone change for a particular SP condition than in the other blocks of frames within the same condition. Also, the amount of dilation observed in each block of frames was significantly greater for the list having a tone-change associated with that block of frames than those lists having tone changes associated with other blocks of frames.

As was true in the case of the constriction data, the results of the analysis of the dilation data of the control Ss indicated that for these Ss, no systematic relationship between dilation and tone-change existed.

While the dilation component of this post-signal dilation-constriction cycle was not predicted, the results indicate that it is clearly associated with the tone-change signal to forget. The fact that each post-signal phase of constriction was immediately preceded by a phase of dilation might lead one to suggest that the entire cycle merely represents a momentary reaction to a sudden change in auditory stimulation, a sort of startle response, perhaps. If this were the case, however, similar waves of dilation-constriction should be found in the responses of the control Ss, who experienced precisely the same changes in background tones. It is apparent that no such systematic changes in pupil size are associated with the tone changes for the control Ss.

The results of the analyses of the dilation and constriction data of the experimental and control Ss confirm Hypothesis I.

Further consideration of the dilation phase of the post-signal cycle, indicates that this effect is actually highly supportive of the basic thesis of this study, and probably should have been expected at the outset. That is to say, a signal to forget, in itself, represents considerable information which must be processed by S before he can cease processing the information he had received prior to the signal. Thus, the post-signal dilation component of the cycle is interpreted as representing the cognitive activity required to decode and process the information contained in the signal.

The fact that the degree of constriction following each tone-change signal was not proportional to the amount of informational input prior to each signal as shown in Figure 4, fails to support the first part of Hypothesis II. However, the greatest peak dilations across all frames occurring prior to recall on each of the SP conditions were in the predicted order except for the one inversion of the SP-2 and SP-3 Conditions. These peaks of dilation were also significantly different from one another in four of six possible comparisons (see Table XII). The nearly correct ordering of the several peaks, and the significant differences among most of them lend only partial support to the second part of Hypothesis II.

One explanation for the lack of proportionality in the constrictions following each tone change, might be that the reduction in the arousal associated with the reduction in the requirement to process information may be somewhat diminished by the addition of an arousal component associated with anticipation of recall. This explanation suggests that the arousal associated with anticipation of recall is an increasing function of proximity to the onset of recall. Thus, for Tone-change Position 1, the onset of recall is still quite distant, so this arousal component is slight, relative to Tone-change Position 4, where the onset of recall is imminent. If this reasoning is correct, the amount of constriction occurring in Position 4 would be expected to be lessened due to the greater component of arousal associated with approaching recall. This explanation would also help to account for the near equality of the constriction observed after tone changes in Positions 2 and 3.

The disproportionately high wave of dilation-constriction which occurred during SP-1 in BF-1, warrants some added discussion. With the exception of this cycle, the dilation peaks of the three subsequent post-signal cycles were in the predicted order. Why should a signal to forget coming after the first word produce more dilation-constriction than one coming later in a list? One possible explanation, which is in keeping with the general arousal notion in regard to pupil changes, is that Ss did not expect to hear a tone-change so early in the list, even though they had been told that it might occur at any point in the list. It seems reasonable that an arousal component associated with surprise, added to that associated with processing the information contained in the signal, might account for the unusually large SP-1 cycle. By the same reasoning, such an arousal component due to surprise should add progressively less as the end of the list is approached, since the probabilities of a signal occurrence are increasing, and with them, S's expectations of the signal. This notion that there may be an arousal component associated with the anticipation of a signal to forget, can also be used to account for the obvious difference of the curves of the control and experimental Ss during trials which contained no tone-change (Figure 1). It seems very plausible that the no-tone-change trials produced more arousal in the experimental Ss than in the control Ss, since no S knew until after the fifth word that a trial would not contain a tone-change. Thus, the experimental Ss were presumably expecting a signal on virtually every trial, and the arousal associated with this expectation may have produced the difference in the curves of the two groups of Ss.

Nunnally, Knott, Duchnowski and Parker (1967) employ similar reasoning in their explanation of the steep dilation curves obtained as Ss anticipated a gunshot. While it is probably true that anticipation of a gunshot is not analagous to anticipation of the onset of recall or of a signal to forget in a memory task, the situations are not completely dissimilar. Others (Bradshaw, 1967; Bernick & Oberlander, 1968; Paivio & Simpson, 1968) have suggested that anxiety associated with E's appraisal of a response may be at least partially responsible for the dilation observed during the solution of mental tasks. Kahneman and Beatty (1967) caution, however, that the evocation of an anxiety explanation to account for all the pupil change occurring during a mental task would necessitate the expansion of the meaning of the word "anxiety" to an absurd point. They stress the need for experiments designed to separate the anxiety and processing components of pupil responses during mental tasks.

Recall Errors

Although the design of this experiment did not include a test of the Bjork (1967) hypothesis that a signal to forget presented during the presentation of verbal material for prompt recall will eliminate or greatly reduce proactive interference, it was expected that few intrusions of words preceding the signal would occur during the recall of the post-signal words. This expectation was confirmed. The total number of tone-change trials experienced by the eight experimental Ss was 64. Only once in these 64 trials did a word preceding the signal to forget appear as an intrusion in the recall of the post-signal words. Bjork's findings thus seem to be reliable and generalizable over a variety of verbal learning tasks.

The discovery that constriction during recall is often delayed considerably and sometimes absent on trials which contained errors supports the findings of Bradshaw (1967, 1968). Bradshaw reported that pupil dilation on trials in which Ss failed to reach solutions to mental arithmetic problems and anagram word games, remained at a plateau only slightly below peak and failed to show the typical constriction phase.

When a frame-by-frame comparison of error and non-error trials was made, it was clearly evident that for about six or seven frames (approximately 3 seconds) following the error occurrence, there was no constriction for the error trials, while the non-error trials had the typical, almost linear constriction during recall. A highly significant Correctness X Frames interaction indicated that these two functions are truly different for a period of time following an error.

It seems that one or a combination of the following phenomena may be responsible for this "error-effect". There is first, the possibility that an increment of arousal due to the anxiety associated with making an error adds to the dilation level. This explanation assumes that S is aware of his error. It may also be the case that S, after making an uncertain response, engages in some post-response attempt to evaluate the correctness of the response in doubt. This would also tend to account for the fact that similar delays in constriction were occasionally seen on non-error trials. A final explanation is that S has simply failed to "unload" a portion of the information which he processed and presumably put into memory storage during the input phase. It is certainly possible that S's errors represent material intruding from perhaps a different system, or in the case of omissions, S may have temporarily lost access to the material in storage.

It should be pointed out that pronounced individual differences are evident in regard to this "error-effect". Some Ss had perfectly normal constriction curves during recall, even on trials in which very obvious errors, such as omission errors, were made. For example, an S could hardly have been unaware of the fact that he had omitted a word, especially since the recall clicks served to remind him. This finding might also be seen to be in support of an arousal due to error anxiety notion. It is reasonable to assume that not all the Ss were equally motivated to do well on the task. It seems equally reasonable then, that the act of making an error might produce different sorts of pupil responses in Ss having differing motivational levels or attitudes regarding the task.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate pupillary responses during a short-term memory task which included instructions to forget some items on some trials. Sixteen female undergraduate students participated individually. Each subject listened to lists of five words and attempted to recall all or a portion of the words depending on the position of a "forget" signal in the list and the instructions the subject heard in regard to the signal. Each subject's right eye was cinematographically monitored during each trial, and the size of the pupil of the eye, as permanently recorded on the film, was the dependent variable. Also of interest was the frequency of errors in the form of words preceding the signal appearing during the recall of the post-signal words.

The major findings were as follows:

1. Changes in pupil size accurately reflected the momentary degree of cognitive processing as subjects listened to, stored, and recalled verbal information.
2. A signal to forget a portion of the items in a list produced a dilation-constriction cycle of pupillary change. It was suggested that the dilation phase of the cycle reflects the processing of the information contained in the signal; the constriction phase of the cycle reflects the reduction in the requirement to process information effected by the signal.

3. A signal to forget produced forgetting as evidenced by the rarity of intrusion errors in the form of pre-signal words occurring during the recall of post-signal words.
4. Analysis of the second-by-second pupillary response following an error indicated that errors retard pupillary constriction during recall. It was proposed that the comission of an error may be accompanied by increased arousal due to the anxiety associated with an incorrect performance, or additional rehearsal or review designed to confirm the erroneous performance, or both.

The general conclusion drawn from this investigation is that the pupillary response is indeed a reliable and sensitive index of momentary cognitive processing.

The implications of the pupil responses following errors are highly interesting, and further investigations designed to separate the hypothesized anxiety component from the information processing component should prove to be very worthwhile.

A SELECTED BIBLIOGRAPHY

Adler, F. H. Physiology of the Eye. St. Louis: Mosby, 1965.

Beatty, Jackson & Daniel Kahneman. Pupillary changes in two memory tasks. Psychonomic Science, 1966, 5, 371-372.

Beck, Benjamin B. The effect of the rate and intensity of auditory click stimulation on pupil size. Paper presented at the American Psychological Association Convention, 1967.

Bernick, N. & M. Oberlander. Effect of verbalization and two different modes of experiencing on pupil size. Perception & Psychophysics, 1968, 3, 327-330.

Bjork, Robert A. The effect of instructions to selectively forget during short-term memory, Memorandum Rep. No. 3, Human Performance Center, University of Michigan, 1967.

_______, David LaBerge, and Ross Legrand. The modification of short-term memory through instructions to forget. Psychonomic Science, 1968, 10, 55-56.

Bradshaw, J. L. Pupil size and problem solving. Quarterly Journal of Experimental Psychology, 1968, 21, 116-122.

_______. Pupil size as a measure of arousal during information processing. Nature, 216, 1967, 515-516.

Hess, E. H. Pupillometric assessment. In John M. Shiler (ed.), Research in Psychotherapy, Vol. 3. New York: A.P.A., 1968.

_______. Attitude and pupil size. Scientific American, 1965, 212, 46-54.

_______ & J. M. Polt. Pupil size as related to interest value of visual stimuli. Science, 1960, 132, 349-350.

Hess, E. H. & J. M. Polt. Pupil size in relation to mental activity during simple problem-solving. Science, 1964, 143, 1190-1192.

Hess, E. H., A. L. Seltzer, & J. M. Shlien. Pupil response of hetero- and homosexual males to pictures of men and women: A pilot study. Journal of Abnormal Psychology, 1965, 70, 165-168.

Kahneman, D. & J. Beatty. Pupil diameter and load on memory. Science, 1966, 154, 1583-1585.

______. Pupillary responses in a pitch-discrimination task. Perception and Psychophysics, 1967, 2, 101-105.

Kahneman, D., L. Onuska, & R. Wolman. Effects of grouping on the pupillary response in a short-term memory task. Quarterly Journal of Experimental Psychology, 1968, 20, 309-311.

Kahneman, D. & W. Peavler. Incentive effects and pupillary changes in association learning. Journal of Experimental Psychology, 1969, 79, 312-318.

Kahneman, D., B. Tursky, D. Shapiro, & A. Crider. Pupillary, heart rate, and skin resistance changes during a mental task. Journal of Experimental Psychology, 1969, 79, 164-167.

Lowenfeld, I. E. Mechanisms of reflex dilation of the pupil. Historical review and experimental analysis. Documenta Ophthalmol., 1958, 12, 185-448.

Lowenstein, O. & I. E. Lowenfeld, I. E. The pupil. In H. Davson (ed.), The Eye. Vol. 3. New York: Academic Press, 1962. pp. 231-267.

Nunnally, J. C., P. D. Knott, A. Duchnowski, & R. Parker. Pupillary response as a general measure of activation. Perception and Psychophysics, 1967, 2, 149-155.

Paivio, A. & H. Simpson. The effect of word abstractness and pleasantness on pupil size during an imagery task. Psychonomic Science, 1966, 5, 55-56.

Parker, Ronald K. & Robert S. Mogyorosy. Pupillary response to induced muscular tension. Paper presented at the American Psychological Association Convention, 1967.

Payne, Donald T., Mary E. Parry, & Stefan J. Harasymiw. Percentage of pupillary dilation as a measure of item difficulty. Perception and Psychophysics, 1968, 4, 139-143.

Simms, T. S. Pupillary responses of male and female subjects to pupillary difference in male and female picture stimuli. Perception and Psychophysics, 1967, 2, 553-555.

Simpson, Herb M. & Allan Paivio. Changes in pupil size during an imagery task without motor response involvement. Psychonomic Science, 1966, 5, 405-406.

______. Effects on pupil size of manual and verbal indicators of cognitive task fulfillment. Perception and Psychophysics, 1968, 3, 185-190.

Sokolov, E. N. Perception and the conditioned reflex. New York: Macmillan, 1963.

Thorndike, Edward L. & Irving Lorge. The Teachers' Word Book of 30,000 Words. New York: Bureau of Publications, Teachers College, Columbia University, 1944.

Turvey, M. & R. Wittlinger. Attenuation of proactive interference in short-term memory as a function of cueing to forget. Journal of Experimental Psychology, 1969, 80, 295-298.

West, Michael. A General Service List of English Words. London: Longmans, 1953.

Woodmansee, John J., Jr. An evaluation of pupil response as measure of attitude toward Negroes. Dissertation Abstracts, 1966, 26, 6896-6897.

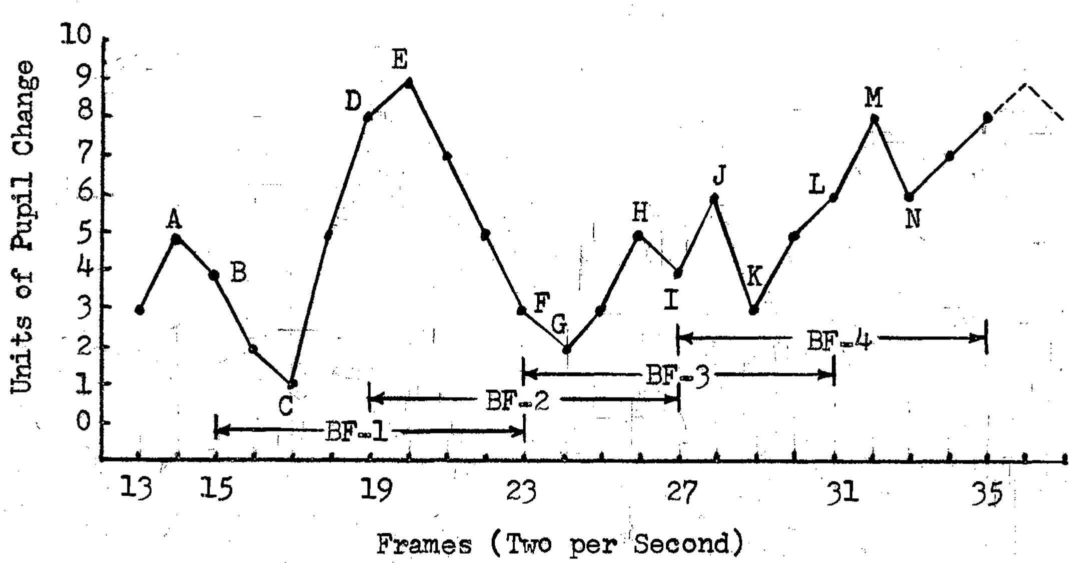
_______. Methodological problems in pupillographic experiments. Proceedings of the 74th Annual Convention of the American Psychological Association, 1966, 1, 133-134.

APPENDIX

SCORING PROCEDURES

A constriction score was obtained for each of the four BFs for each trial. The greatest monotonic decrease in pupil size which occurred within each BF was scored for a particular BF if: (1) the peak of dilation preceding the constriction also occurred in that BF, and (2) the peak preceding the constriction had not been associated with a constriction score in the preceding BF. Also, if two or more decreases of equal size occurred within a particular BF, the first one satisfying the two conditions above was scored for that BF.

The figure below represents a hypothetical response curve of the input phase of a trial. Following the figure is an explanation of how the constriction scores for each BF were obtained.



BF-1 (6) The 6 unit drop from E to F was scored. Had B to C been the longest drop, it would not have been scored, since the peak, A, lies outside BF-1.

BF-2 (1) The 1 unit drop from H to I was scored. F to G was not scored, since the peak, E, had been associated with a constriction score in BF-1.

BF-3 (3) The 3 unit drop from J to K was scored.

BF-4 (4) The 2 unit drop from M to N was scored.

Dilation scores for each BF of each trial were obtained by finding the net increase in pupil size from the initial frame of a particular BF to the highest peak of dilation occurring within that BF, provided the peak had not been considered the peak of the preceding BF.

The dilation for each BF of the hypothetical response curve above was scored as followed:

BF-1 (5) The net increase of 5 units from B to E was scored.

BF-2 (-3) The net increase of minus 3 units from D to H was scored.

BF-3 (3) The net increase of 3 units from F to J was scored.

BF-4 (4) The net increase of 4 units from I to M was scored.

VITA

David Alan Johnson

Candidate for the Degree of

Doctor of Philosophy

Thesis: PUPILLARY RESPONSES DURING A SHORT-TERM MEMORY TASK WITH INSTRUCTIONS TO FORGET

Major Field: Psychology

Biographical:

Personal Data: Born in Joplin, Missouri, September 12, 1933, the son of Bethel W. and Catherine Johnson.

Education: Graduated from Joplin High School, Joplin, Missouri, in May, 1951; received a Bachelor of Arts degree from the University of Tulsa, with a major in Industrial Psychology, in 1955; received a Master of Science degree from Kansas State College of Pittsburg, with a major in Psychology in 1964; completed requirements for the Doctor of Philosophy degree, with a major in Psychology, at the Oklahoma State University in August, 1969.

Professional Experience: Served as Instructor of Psychology at Kansas State College of Pittsburg during the academic year, 1964-65; served as Instructor of Psychology at Southeast Missouri State College, Cape Girardeau, Missouri, during the academic year, 1965-66; served as a graduate teaching assistant in the area of psychology at the Oklahoma State University from June 1966 through July, 1968; served as Instructor of Psychology at the Oklahoma State University during the academic year, 1968-69; am employed as Assistant Professor of Psychology at Sweet Briar College, Sweet Briar, Virginia.