THE TASK-EVOKED PUPILLARY RESPONSE 
AND COGNITIVE OVERLOADING 
DURING A DICHOTIC SHADOWING TASK

An Honors Thesis (ID 499)

by

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INTRODUCTION

It has been proposed that pupillary dialation may serve as a physiological measure of the employment of resources during cognitive activity. Kahneman (1973) theorized that the Task-Evoked Pupillary Response (TEPR) was a primary measure of processing load in his Effort Theory of Attention. He supported the use of such a measure by indicating the empirical relation between task demands and pupillary dialation. He also gave criteria for any physiological indicator of processing load: 1) It should be sensitive to within-task variations in task demands that are produced by changes in task parameters; 2) it should reflect between-task differences in processing load brought about by qualitatively different cognitive activities; 3) it should capture between-individual differences in processing load as individuals with different abilities perform a fixed set of cognitive activities.

Beatty (1982) reviewed the results of several studies and found that TEPR appears to respond in such a way that indicates an orderly relation between the amount processing demand placed on the subject and the size of the TEPR. Those tasks which were less demanding produced smaller TEPRs while tasks more demanding produced larger TEPRs. Beatty reported on a study by Peavler (1974) that demonstrated that as long as some information-processing capacity remained, increasing memory load is reflected by increasing pupillary dialation. Once this capacity has been reached, further increases in task demands do not increase pupil diameter. In the study, the TEPR was measured for five, nine, and 13 digit strings which were randomly mixed in presentation. During the presentation of the digits, dialation increased as an increasing function of memory load for digits one through seven. At the seventh or eighth digit, an assymptote was reached and no further dialation was observed.
Ambler, Fisicaro, and Proctor (1976) completed the first study of TEPR and dichotic shadowing. Their results showed a large response during shadowing with the largest pupillary response occurring at the beginning of a trial, followed by a gradual, negatively accelerated decrease in response. Ambler, et al could not accurately conclude what the shape of the TEPR curve is during a dichotic shadowing task since they used a limited number of samples during each trial.

In another study Clark, Barr, and Dunham (1985) found that the TEPR curve resembles an inverted-U shape function, rapidly increasing at the beginning of the task, leveling off and then gradually decreasing toward the end, unlike Ambler's results. Also, evidence in support of the sensitivity of TEPR to different levels of difficulty was shown. The TEPR produced by a 100 word per minute rate was much larger than the TEPR produced by a 60 word per minute rate. There was also an unexpected finding of a lower TEPR during the first block of three trials for the group that shadowed at 100 words per minute on the left ear indicating that processing load in this group was reduced by the omission of words to be shadowed. The TEPR therefore appears to reflect the actual amount of information processing accomplished rather than the amount required. Similar results were found in a study completed by Dunham (1986). The TEPR curve during the dichotic shadowing task varied significantly at different times during the trial as the information-processing task proceeded and the difficulty levels progressed from a slow rate to a fast rate of word presentation. An inverted-U shaped function was also evident in this study.
STATEMENT OF THE PROBLEM

Theoretically, if there is no limit to information processing capacity. As a subject is required to process a progressively more information (for example, as the number of words per second increases in dichotic shadowing) the TEPR curve, subjective ratings of perceived effort, subjective ratings of perceived difficulty, and proportion of words correctly produced should increase in a positively sloped linear function. On the other hand, a lot of cognitive research has demonstrated that people are limited capacity processors. Thus, Peaveler's study demonstrated there should be some limit above which the TEPR levels off or decreases.

The purpose of this experiment was to incorporate the methods used by Clark, et. al and Dunham to observe what happens during an information processing task as the subjects approach their maximum processing capacity. Given that Clark, et. al indicated that the TEPR appears to reflect processing actually done rather than the imposed difficulty of the task, it is hypothesized that as the difficulty of an information-processing task increases the TEPR will at first be small then rapidly increase until it levels off or decreases in size reflecting the amount of information-processing actually done. The function of the number of words per second (words/s) correctly shadowed or produced should resemble this function. In other words, as the presented number of words/s is increases, the number of words/s correctly produced should increase until task difficulty approaches and eventually surpasses the subject's maximum processing capabilities. The TEPR at should at that time be at a maximum level in response to work load. As this maximum
level nears, the number of words/s correctly produced should also level off or decrease, mirroring the TEPR. Subjectively perceived effort should continue to increase, as the performance levels off, if the subject feels he/she could work harder in the more difficult conditions. In contrast, if the subject feels as if he/she is working his/her hardest, subjectively perceived effort may level off while the subjectively perceived task difficulty should continue to increase, reflecting the subject's perception of the task difficulty (Dornic, 1980).

The major difference between this study and the study of Dunham was to reverse the order of conditions. In the Dunham study all subjects progressed from a slow rate of word presentation to the fastest rate. This confounds practice effects with increasing difficulty of the shadowing task and possibly making the fast shadowing condition less difficult. The present study reverses the order of the presentation rates from slow to fast to fast to slow. The result of this reversal should be to enhance the difficulty level of the faster rates of presentation as compared against the slower rates.
METHODS

SUBJECTS

The subjects were 32 undergraduate students enrolled in Introductory Psychology classes at Ball State University, participating in research to obtain credit for a course requirement. Each subject was informed before participation that his/her pupil was to be measured while he/she completed a cognitive task of various difficulty levels.

Prior to participation each subject was given a Snellen Visual Acuity Test. The basis for exclusion from the study was as follows: 1) If the subject’s vision was poorer than 20/40; 2) if hard contact lens were worn; 3) if the subject was currently on medication which would affect pupil response, and 4) if the subject had previously participated in a dichotic shadowing study.

The subjects were alternately assigned to one of two groups. Half of the subjects were asked to shadow on their right ear and the other half on their left. At the end of the study both groups consisted of 16 subjects.

APPARATUS

All stimuli were presented from a Sherwood S-450 CP Full Auto Cassette Deck through Realistic Nova Pro Hi-Fi Stereophonic Headphones at approximately 70db (SPL). The stimulus material was disconnected prose consisting of one or two syllable words.

Each subject was secured in the pupillometer headrest using velcro strips attached behind the head to reduce movement artifacts. The chin rest was lowered after the head was secure to allow the subject to speak while keeping the head in a stationary position. Subjects were asked to fix their gaze on a small red dot in the center of a 53 cm X 53 cm screen.
approximately 1.43 m away from their eyes. The screen luminance was 1.798 cd/m$^2$ as measured from the subject's eye. It was emphasized that the gaze of the subjects remain fixed on the dot during each trial. Pupil diameter was measured by an Applied Science Laboratory, Model 1000, infrared TV pupillometer connected to a Narco Biosystems chart recorder. The data was obtained by an Apple-ISSAC 91A laboratory computer system at four samples per second beginning 5 seconds before stimulus presentation and ending 5 seconds after the end of stimulus presentation for a total trial duration of 26 seconds.

**PROCEDURE**

Subsequent to the pre-experiment screening, instructions were given, and questions answered. Subjects were familiarized with the stimulus material by completing monaural shadowing practice trials at the medium rate (1.25 words per second). Each subject was asked to repeat each word as it was heard—as if they were echoing the word. Subjects were required to make two or fewer errors on a practice trial before being asked to place their head into the headrest to begin the experimental dichotic trials.

All subjects heard the dichotic disconnected prose at five different rates—fast (1.75 words/s), medium fast (1.5 words/s), medium (1.25 words/s), medium slow (1.0 words/s), and slow (.75 words/s). The slow condition was a rate at which most every subject was able to accurately shadow. The fast condition was at a speed which few were able to accurately shadow. At the beginning of the experiment, each subject was
presented with the fast condition and proceeded through each condition to the slowest following four trials at each condition. The task-evoked pupillary response (TEPR) was recorded during the experimental trials.

After each condition, subjects were asked 1) to subjectively rate the amount of effort they felt they had put into the task for those trials (0-100, with 100 meaning they felt they could work no harder); 2) if they felt they omitted any words in order to keep up with the word list and if so, how many; 3) to determine the number of words they felt they had accurately shadowed; 4) if they felt themselves repeating words from the other list (from the unattended ear); and 5) to rate how difficult they felt the task was (0-25, with 0 meaning the task was not difficult and 25 meaning the task was as difficult as it could be). The rating scale for effort and task difficulty were different in order to force the subjects to rate effort and difficulty independently.

DATA SCORING

The TEPR was computed on each trial as the deviation values from the mean diameter during a baseline period for the samples. This was taken from a 5 second period prior to stimulus presentation of each trial. Four deviation values for each 1 second interval were also averaged to yield 26 time samples. The averaged time samples were then averaged (26 values for each rate) over the four trials in each condition. Any value that was not between 2.8 and 8.9 was automatically thrown out by the computer. If more than 50% of the baseline samples were rejected by the computer, the trial was thrown out. If any subject had more than two missing trials in any condition, the subject's data was rejected.
Subjective rating scores were recorded by the experimenter and averaged for each rate condition. The subjective difficulty ratings were converted to a 0-100 scale by multiplying by four for later comparisons.

ANALYSIS

The design used was a mixed between-subjects and with-in subjects design. This involved one between-subjects variable, ear of shadowing, with two levels, left vs. right, and either one or two within-subjects variables. TEPR was analyzed using two within-subject variables involving rate, with five levels, and time samples, with 21 levels. The baseline data were not included in the analysis. The other analyses were performed using only rate as the within-subjects variable. These include TEPR, proportion of words produced (including commission errors), proportion of words correctly shadowed, subjective estimates of perceived effort, and subjective estimates of perceived difficulty.
RESULTS

The following analyses were composed of an analysis of variance (ANOVA) with orthogonal decomposition for proportion of words correctly shadowed, proportion of total words produced, subjectively perceived difficulty ratings, and subjectively perceived effort ratings.

Analysis of TEPR over time

The size of the TEPR during a dichotic shadowing task was hypothesized to significantly vary at different times during a trial as the shadowing task proceeded. An ANOVA for repeated measures was performed which revealed a significant rate by time sample interaction, $F(80, 2400)=2.04, p<.0001$, in support of the preceding hypothesis. The TEPR deviations from baseline increased as the information-processing task proceeded with a maximum TEPR appearing later in the trial as the task became more difficult. These results can be seen in Figure 1.

It is apparent that there was a difference in the TEPR depending on the rate of presentation. With this evidence established, individual analyses of other dependent variables was performed.

Proportion of words correctly shadowed

The proportion of words correctly shadowed was computed as a measure of shadowing proficiency. Proportion of words correctly shadowed was computed by subtracting the number of omissions and commission errors from the total possible words and dividing by the number possible. This proportion should have decreased or leveled off as the information-processing task became more difficult. As can be seen in Figure 2, there was a significant difference in proportion of words
Figure 1—The Task-Evoked Pupillary Response Averaged over Four Trial of Dichotic Shadowing for each Rate Condition.
Figure 2- Proportion of Words Correctly Shadowed
correctly shadowed as the rate of presentation increased, \( F(4, 120) = 233.38, p < .0001 \). There were proportionally fewer words produced correctly in each rate. The orthogonal decomposition of this function was quartic, \( E(1, 30) = 147.5, p < .0001 \). There was an indication of a borderline interaction rate by ear effect since the right and left ear curves are separate and begin to converge. An ear main effect \( E(1, 30) = 9.51, p < .0044 \), can also be seen as the lines for left and right ear shadowing are different.

**Proportion of total words produced**

This measure of shadowing proficiency was a proportion of the total number of words produced subtracting only omission errors. Similar results were found in comparison to the proportion of words correctly shadowed. There was a significant difference in the proportion of total words produced across rates of presentation, \( F(4, 120) = 196.15, p < .0001 \). This rate effect also demonstrated an ear main effect, \( E(1, 30) = 10.19, p < .0033 \), and a borderline rate by ear interaction. An orthogonal decomposition indicated that this function was also quartic, \( E(1, 30) = 135.21, p < .0001 \) (See Figure 3).

**Subjectively perceived difficulty ratings**

It was hypothesized that the ratings of subjectively perceived difficulty would increase despite the leveling of the subjectively perceived ratings of effort. There was a difference in ratings of difficulty as the rate of presentation increased, \( F(4, 120) = 40.54, p < .0001 \), as seen in Figure 4. The difference indicated by the rate by ear interaction was also significant, \( F(4, 120) = 5.84, p < .0002 \). As was indicated, ratings of
Figure 4—Subjectively Perceived Difficulty Ratings
subjectively perceived difficulty continued to increase as the information-processing task became increasingly difficult.

**Subjectively perceived effort ratings**

Subjective measures of perceived effort were analyzed in order to examine how hard the subjects perceived they were working. These ratings of effort were hypothesized to begin to level off at the same time the TEPR and number of words correctly shadowed began to level off. An ANOVA of subjectively perceived effort ratings did not reveal significantly perceived differences in effort ratings as rate of presentation increased. Results indicated a weak significance in laterality effect for effort interaction with right ear superiority, $F(4, 120) = 3.58, p<.0086$, as seen in Figure 5.
Figure 5 - Subjectively Perceived Effort Ratings
DISCUSSION

The TEPR reflects information processed rather than the imposed difficulty of the task as was indicated by this study. There have been conflicting results in previous studies that have attempted to cognitively overload subjects, but the present study supports the findings of Dunham (1986) and Clark, Barr, and Dunham (1985). As a subject is required to process a progressively more difficult task, the TEPR, subjective ratings of perceived difficulty, proportion of correctly shadowed words, and the proportion of the total number of words produced would increase. As a cognitive task's difficulty increases, the number of correct responses should also increase until the difficulty of the task approaches and surpasses the maximum processing capabilities of the subject. As this level approaches, the number of correct responses should level off or decrease similar to the TEPR. Subjectively perceived task difficulty should continue to increase in reflection of the subject's rating of the difficulty of the task.

As the subjects were presented with the fastest rate, they began to process the information until they could process no more and were in effect "overloaded." Once the subject had reached his/her capacity, performance leveled or decreased during the rest of the trial. The TEPR therefore seems to reflect the amount of information being processed rather than the proportioned difficulty. Subjects also showed some laterality effect as would be expected with this type of study due to the neurological functioning differences between right and left hemispheres of the brain.

The results demonstrated that reversing the rates of presentation enhanced the difficulty level of the faster rates as compared to the slower rates. A greater decline in the TEPR was seen in the fastest rate of
presentation that in Dunham's results. The TEPR decreases fastest in the fast condition, surpassing the decline of both the medium and medium fast conditions. This rapid decline in the curve is an indicator of a greater task difficulty and overloading. Similarly, the proportion of words correctly shadowed demonstrates a larger decline in the curve than was found in the Dunham study. The curve indicates a greater number of omitted words in the fastest rate of presentation than in the other conditions. This also is an indicator of enhanced task difficulty and subject overload.

Subjectively perceived effort should reflect the amount of cognitive loading the subject is experiencing as was reported in the Dunham study. This study did not find such results as have previous studies. In fact, a left/right ear difference of ratings was found (only slight significance). This could be explained by the neurological differences between hemispheres, or it is possible that those subjects shadowing on the left ear actually were better practiced at the task before beginning and did not perceive that as much effort was needed for the task as did the right ear group of subjects.
REFERENCES


