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THE RELATIONSHIP OF EYE BEHAVIOR, CARDIAC ACTIVITY AND ELECTROMYOGRAPHIC RESPONSES SUBJECTIVE REPORTS OF MENTAL FATIGUE AND PERFORMANCE ON A DOPPLER IDENTIFICATION TASK

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THESIS

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by

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September 1973

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by

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ABSTRACT

This research investigated relationships between subjective fatigue, performance, and four physiological parameters: sinus arrhythmia, pupil behavior, blink rate, and tension of the neck muscles. Fatigue was induced by a doppler recognition task and rigid body posture. Performance was measured as the proportion of correct doppler identifications. There was no detection of a performance change during the two and one-half hour experimental sessions. Sinus arrythmia and eyelid blink rate were also found to remain unchanged. An alteration was found in the measures of neck muscle tension levels, subjective fatigue, and the average pupil diameter.

Subjective ratings of fatigue were found to be highly correlated with time-on-task and the electromyographic response of certain neck muscles. Polynomial regression indicated a significant linear relationship between the subjective ratings and the tension measured.

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I. INTRODUCTION

Performance and fatigue are often critical issues in the use of human resources. Mental performance and fatigue may be thought of as differing from physical performance and fatigue (Bartley and Chute, 1948). An example is the fatigue resulting from work such as adding digits as contrasted to the results of weight-lifting. Under modern conditions of rapid technological innovations, the problems of mental fatigue have attained increasing significance. Few people deny acquaintance with it. Mental fatigue is a very important factor in limiting a workman's output in various information-processing jobs, or in vigilance tasks such as monitoring, or even tasks requiring relatively low levels of skill. As a consequence, work performance is detrimentally affected. Unfortunately attempts at reducing or predicting the onset of mental fatigue have not enjoyed any great degree of success (Kalsbeek, 1971).

The present study consisted of an investigation of mental fatigue in a task requiring low levels of energy expenditure. The following three aspects of mental fatigue were considered: a) physiological response, b) performance decrement, and c) subjective fatigue response. An assumption was made that the experimental task performed by each subject would produce mental fatigue. The cause of the fatigue was assumed to be the result of the mental load produced by an informa-

tion-processing task and the stationary posture required of the subject. (Bonsper, 1970; Hess, 1965; Holland and Tarlow, 1972; Innes, 1973)

Four physiological measures which have been suggested as being related to fatigue or mental load were examined in the present experiment. Those areas concerned sinus arrhythmia, pupil behavior, blink rate, and tension of the neck muscles.

The heart rate of an average healthy human being is often irregular. These irregularities can occur as variations in rate of up to ten or fifteen beats per minute. This is generally referred to as sinus arrythmia. Recent experimental evidence suggests that an increase in mental load results in a decrease in sinus arrythmia (Kalsbeek, 1971; Bonsper, 1970; Douglas 1972; Innes, 1973). Though there are numerous methods of its measurement, one technique appears to be superior when comparing sinus arrythmia to mental load (Mulder and Muelen, 1972). This measure, SABS/N, is the sum of absolute differences in beat to beat heart rates divided by the number of waves occuring during the interval of measurement. If the rate of information processing is held constant during a task, it can be postulated that performance changes are the result of differing mental states or physiological changes. If the changing mental states are a result of changing mental loads then sinus arrythmia may be considered an indicator of this change (Bonsper, 1970).

The behavior of the eye is a source of information on mental activity. The diameter of the pupil varies with

mental load; that is, the pupil dilates as the load increases (Hess and Polt, 1964; Hess, 1965; Hope, 1971; Kahneman, et al, 1969; Kahneman and Peavler, 1969). After having dilated, the pupil will constrict from its dilated state if either the task is ended or the task becomes so difficult that the subject cannot accomplish it (McFeely, 1972; Edwards, 1972). Because changing mental activity may be observed in altering patterns of pupil behavior, the detection of this may be a significant tool in understanding the nature of man's response to various types and durations of work.

A second facet of eye behavior considered in the present experiment was blink rate. It has been observed that the rate of blinking varies with certain mental activities. Holland and Tarlow (1972) observed that blink rate was related to the difficulty or amount of mental activity associated with a given task; blinking decreases as mental load increases. Blinking is an easily detected variable; therefore it becomes a tool with which to readily measure change in mental activity.

The neck muscle tension level was the fourth physiological measurement taken in this study. Although this measure has not been related to mental load, it has been studied in conjunction with mental fatigue. Innes (1973) measured mental fatigue by means of subjective fatigue responses and observed a correlation of neck muscle tension to subjective fatigue.

As reflected in electromyographic responses, the amount of tension in the neck muscles increased as subjective fatigue increases.

In the present investigation fatigue was measured subjectively by using descriptive statements developed for this purpose (Pearson and Byars, 1956; Innes, 1973). A fatigue check list of terms commonly used to describe a subject's appraisal of his feelings was employed in the assessment of fatigue.

Finally, the actual accuracy of each subject's processing of information was measured. A task was selected which resembled realistic mental work. The chosen task was doppler identification in sonar echoes. The signal intensity was low and detection of target echoes among reverberation noise was difficult. Standard Navy doppler drill tapes were used to present the desired sonar echoes. Signal frequency ranged from one to three target echoes per minute.

Each sonar echo was composed of reverberation noises and a single target echo; thus, the signals appeared infrequently throughout the vigilance task. The number of correct doppler identifications among the total number of responses was used as a measure of performance.

II. METHOD

The general goal of the experiment was to induce fatigue by means of a task which involved total concentration. In order to achieve this, subjects (S's) were required to identify the doppler characteristics of a target in sonar echoes. A set of three similar sonar echoes with the same target doppler were presented to the S then the S indicated the nature of the doppler by a hand-gestured response to oral questioning by the experimentor (E).

A. TEST SITE AND SUBJECTS

The experiment was performed in the Man-Machine Systems Design Laboratory at the United States Naval Postgraduate School in Monterey, California. Eight male associates of the E served as S's. Their ages ranged from 20 to 35 with an average age of 28. The S's had never participated in an experiment of this kind and had no previous sonar experience.

B. APPARATUS

The equipment used in the experiment ranged in four general divisions; that used to measure neck muscle tension, sinus arrhythmia, and eye behavior, as well as that concerning the recording of the sonar tapes.

A Hewlett-Packard series 3960 instrumentation tape recorder was used to record processed physiological data and synchronizing pulses. Recordings were made at 15/16 inches per second on Ampex 641 Professional magnetic recording tape.

Data so recorded was in turn played back into a Digital Equipment Corporation lab 8/e digital computer via an analog-to-digital multiplex converter.

The neck muscle tension was measured by the myoelectrical potential across the semispinalis capitis and splenius capitis muscles. Electromyographic responses were input into a Beckman 9852A GMG intergrator coupler. Two electrodes were placed on the neck with an indifferent third electrode located above the right shoulder (Lippold, 1967).

Electrical responses from the cardiovascular system were processed by a Beckman type 9857 cardiotachometer coupler. The sensing electrodes were located at the top of the sternum and below the left breast at the sixth intercostal space. An indifferent electrode was attached above the left shoulder (Innes, 1973).

Beckman electrodes filled with Beckman Electrode Paste were held in place with Beckman Adhesive Collars. Alcohol was used to cleanse the electrode placement sites.

Behavior of S's eye was processed by a Space Sciences Incorporated Model 830 TV Pupillometer. The pupillometer was designed to measure the diameter of a S's pupil. A S's head was held against the forehead restraint and chin rest of the pupillometer integrated base by elastic bands. The bands extended from the upright posts between the head rest and chin rest to both sides of a neck brace. The neck brace itself was an integral part of a sterno occipital mandibular immobolizer (SOMI) brace (Figure 1). This arrangement

permitted S's to endure the lengthy experiment with restricted head movements.

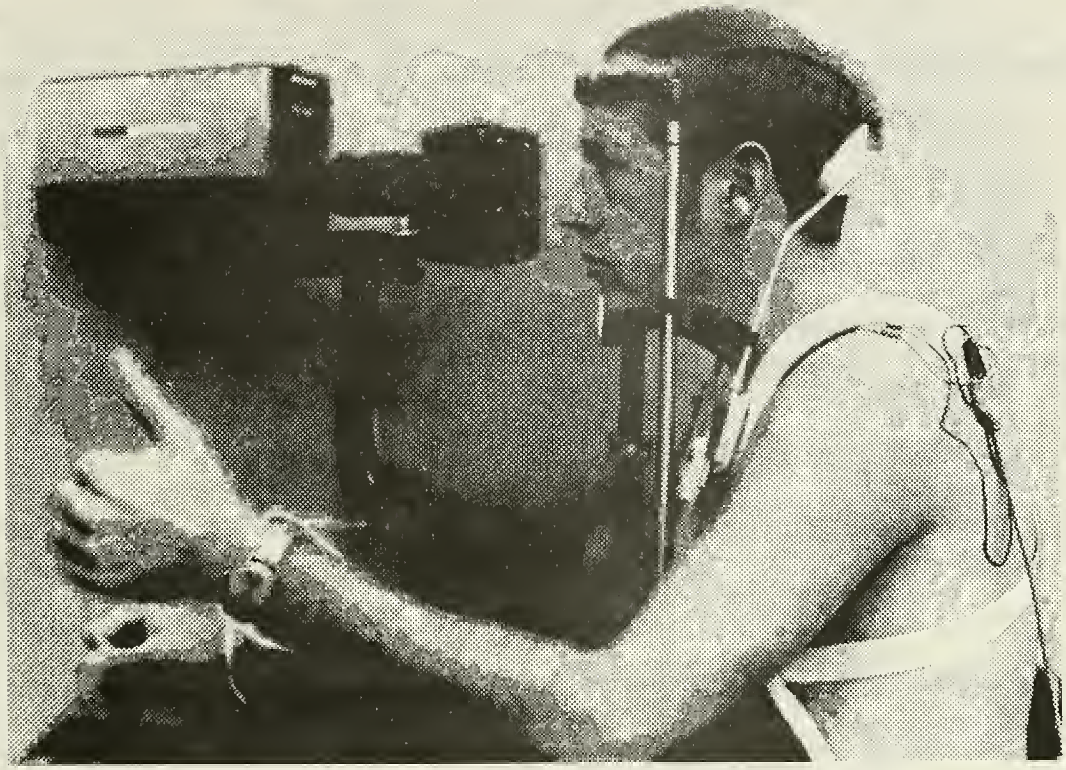

Figure 1. Subject in Position

The sonar echoes that were presented to S were recorded and played back on an additional Hewlett-Packard series 3960 instrumentation tape recorder. The sonar echoes consisted of the Active Sonar Training Tape, SQS-23 Doppler Drill.

Recorded simultaneously with the echoes were synchronizing signals. At the beginning of each set of echoes a momentary pulse of one and one-half volts was recorded on the data tape. Thus during the experiment, as the S responded to the doppler stimuli, synchronizing signals were being produced.

Isolation for the length of the test was achieved by an Industrial Acoustics Company acoustical chamber. The S sat with his eye fifty inches from a four inch by four inch visual target. The target consisted of three strips of paper each four inches by one inch in size. The strips were placed one-half inches apart. This simple target had a three-fold purpose: a) it restricted the movement of the eye, b) it maintained a constant focal distance, and c) it was of low contrast and thus pupil behavior was not affected by variations in brightness. The E sat to the rear and left of the S. A dividing curtain separated S from E and the recording equipment.

C. PROCEDURES

The entire test was preceded by a preliminary session in which each S was requested to train himself until he could satisfactorily recognize doppler. This was done by listening to Active Sonar Training Tape, Introduction to Doppler. Once the S felt he had mastered doppler recognition he filled out a brief questionaire (See Appendix A). He was given an instruction sheet describing the subjective rating checklist (See Appendix B) He then listened as E read a description of the experiment procedures (See Appendix C).

The S was next requested to remove all his clothing above the waist and his wrist watch. The SOMI brace was put on and adjusted. As the electrodes were placed on the S a brief explanation of their operation and safety precautions

was given. The E checked to insure proper electrode operation and interface with the Beckman couplers. The S then entered the acoustical chamber and was positioned in the pupillometer head restraint and the pupillometer and earphones were adjusted. At that time the E and S practiced response procedures. The S was allowed to spend approximately ten minutes becoming adapted to the experimental environment and the body position before the onset of data collection. During that adaptation period the E calibrated instrumentation and verified recording levels for each data recording channel of the instrumentation tape recorder.

The two and one-half hour experiment was divided into ten segments each fifteen minutes long. Each segment began with instructions on the implementation of the subjective rating check list. This was followed by S's responses to the thirteen descriptive statements of fatigue. The order of the statements was varied for each segment. Following completion of the rating, a reminder was given to the S as to the nature of his task (See Apprendix D). The recorded sets of sonar echoes were then presented for the remainder of the fifteen minute segment. During the first segment the recorded task had a brief period of instruction (See Appendix F). Following the final segment the subjective rating check list was given as if a new segment were beginning. This completed the data collection.

D. MEASURES

1. Performance Measures

The first measure concerned the percentages of correct doppler identifications by a S. In each segment, these were recorded as his SCORE.

2. Fatigue Measure

Next, the responses to each statement on the subjective fatigue check list were weighted. A "better than" response yielded a weight of three; "same as" was assigned a weight of two; and "worse than" responses were given a weight of one (Person and Byars, 1956). The totals of the thirteen weights for each time to which the list was responded gave eleven data points. Two groupings were made of subjective ratings of fatigue. The ratings before each doppler drill assumed the treatment grouping SF 0-9. Those ratings made after each drill composed the treatment grouping SF 1-10.

3. Physiological Measures

The neck muscle tension level (NMTL) was computed by averaging all samples of the amplified potential between active electrodes on the neck during each segment of doppler drills. A similar calculation was made by averaging all pupillometer output voltage samplings during each drill segment (APV).

Heart rate variability, or sinus arrhythmia, was computed from the output of the cardiotachometer. The raw rate data was in the form of a DC voltage, the amplitude of

which represented the heart rate from beat to beat. Two parameters were involved in calculating sinus arrhythmia. First the voltage was converted to a rate. The sum of absolute values of the difference in rates from one data sample to the next was computed for each doppler segment. Following that, a count was made during the entire doppler drill segment of each slow down and speed up in rate. For example, when beat to beat rates stopped decreasing and started increasing, a speed up in rate would be counted. Finally, the sum of absolute values of differences in rates was divided by the number of changes in rate trends to give a measure of sinus arrhythmia (SABS/N) (Mulder and Meulen, 1972).

A final measure was calculated. Blink rate (BR) was computed from the recorded pupillometer voltages. A blink was defined as a decreasing voltage output for 8/100 of a second. The rate of sampling data was at least fifty samples a second. This criterion effectively counted blinks only. The number of blinks was divided by the time period over which data sampling occurred but omitted computational time.

E. REDUCTION OF DATA

The two and one-half hour experiment was divided into ten segments each lasting fifteen minutes. Eleven subjective ratings of fatigue were made by each S. Because subjective rating of fatigue was to be analyzed for each segment, two values were considered; those immediately before (SR 0-9) and immediately after (SR 1-10).

The variables for analysis were SABS/N, NMTL, APV, BR, SCORE, SR 0-9, and SR 1-10. Each S underwent ten treatments for each variable; that is, ten segments in which each variable was measured once. The segments were ordered naturally by time, from the first segment period (PERIOD) to segment ten at the termination.

Eight S's started the experiment; however, only seven completed it. NMTL data was usable for four subjects. The subjective fatigue rating questionaire was expanded from ten to thirteen descriptive statements after two S's had completed the experiment. Therefore, only the fatigue ratings of five S's were analyzed.

The statistical analysis included two-way analysis of variance, correlation matrix, stepwise least-square regression, and polynomial regression. Actual analysis was completed by standard programs at the W. R. Church Computer Center, Naval Postgraduate School. SNAP/IEDA computing package carried out each two-way analysis of variance, produced the correlation matrix, and each stepwise regression. Polynomial regression was produced by Biomedical Computer Program BMD05R.

III. DISCUSSION AND SUMMARY

Several statistical tests were performed on the data collected. A level of 0.05 was chosen as significant in testing a hypothesis. Three of the variables showed no difference in their values from segment to segment. Because SCORE was a ratio of correct doppler identifications divided by the number of doppler sets during each test segment, an arcsin transformation was made on each SCORE data point before an analysis of variance was performed. Tables I, II, and III indicated that sinus arrhythmia, blink rate, and SCORE were similar among segments. Significant difference was measured when these variables were compared subject to subject. Figure 2 was drawn for these same three variables. The mean value among subjects for each variable was plotted at each doppler test segment.

During the course of this experiment SCORE, SABS/N, and BR varied in a manner which could be explained as random samples from one population. Thus no statement supporting a hypothesis that these variables changed systematically throughout the experiment can be made. The lack of changes in SCORE indicated that no learning occurred and that fatigue had no effect on performance at a level of significance of 0.05. The experimental conditions did not affect sinus arrhythmia from segment to segment when using the same statistical criterion. Furtheremore, the rate of blinking was statistically constant throughout.

TABLE I. Analysis of Variance on SABS/N

Source	df	SS	MS	F
Subjects	6	208736.66	34789.44	17.81*
Time Segments	9	22306.54	2478.50	1.27**
Error	54	105474.93	1953.24	
Total	69	336518.12		

*p .0001

**p = .275

TABLE II. Analysis of Variance on Blink Rate (BR)

Source	df	SS	MS	F
Subjects	6	0.2537	0.0423	10.9675*
Time Segments	9	0.0112	0.0012	0.3227**
Error	54	0.2082	0.0039	
Total	69	0.4731		

*p .0001

**p = .9639

TABLE III. Analysis of Variance on Arcsin (SCORE)

Source	df	SS	MS	F
Subjects	6	0.568	0.0947	5.0862*
Time Segments	9	0.307	0.0341	1.8328**
Error	54	1.005	0.0186	
Total	69	1.88		

*p = .0003

**p = .0832

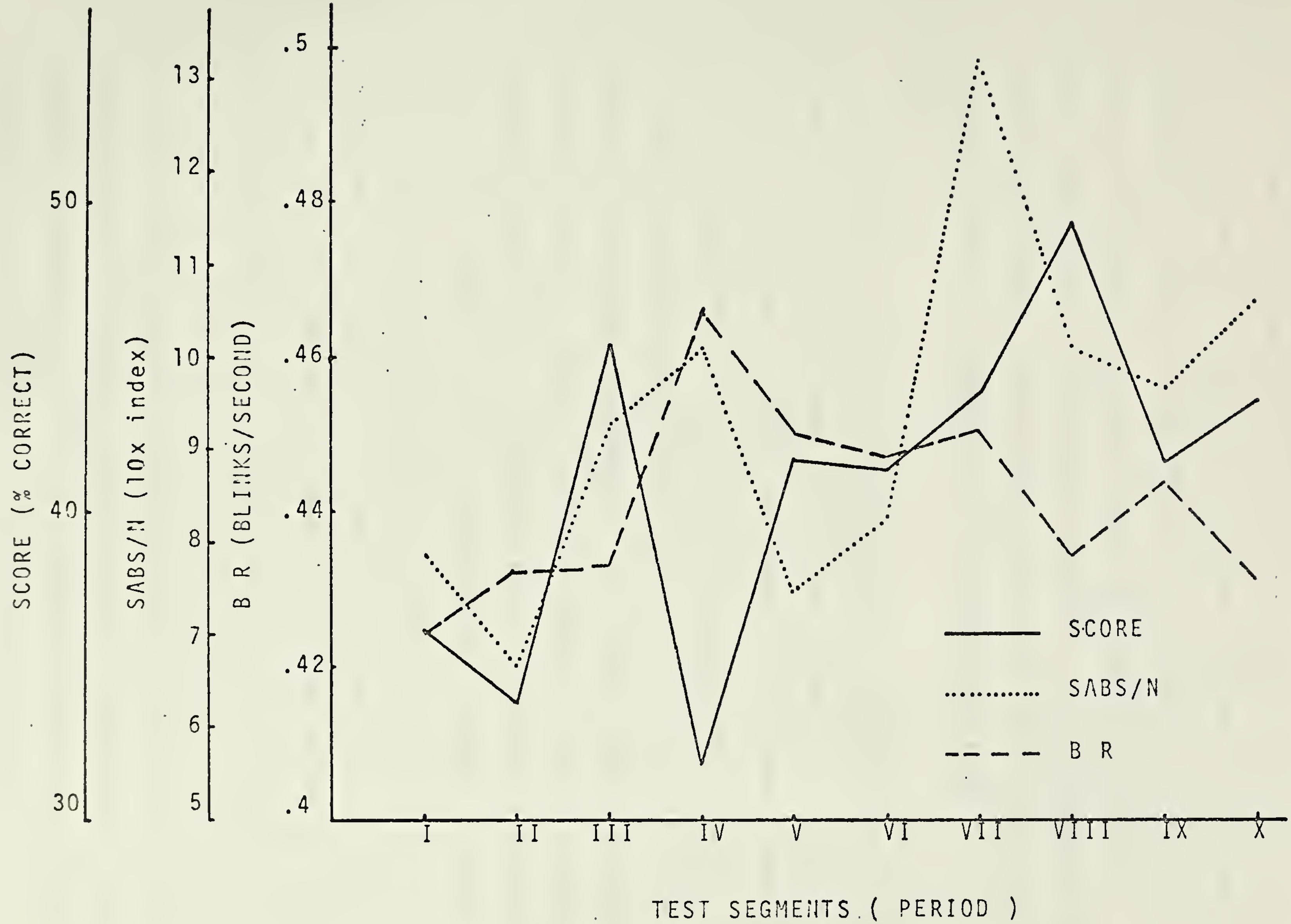

Figure 2. SCORE, SABS/N, BR -vs-PERIOD

In contrast to the variables previously discussed were the average pupillometer voltage, neck muscle tension level, and the subjective ratings of fatigue. Tables IV, V, and VI indicate the results of an analysis of variance on each of these new variables. In each case the subjects differed among themselves on the variable measured. An illustration of the relationship between NMTL, APV, and SRF on one axis and the segments of doppler drill is characterized in Figure 3.

Having found that the average voltage output of the pupillometer was not the same for all the segments, a Duncan multiple-range test was made in order to find those segments in which a difference was significant at a level of 0.05. This test indicated that the APV during the first fifteen minutes of the experiment was not the same as that during the last hour, and that APV's for the sixth and ninth test segments were different. The combination of factors resulting in a voltage output from the pupillometer is hard to identify. When a S's eyelid was not covering the pupil, the voltage was representative of the pupil diameter. However, no S was able to prevent his eyelid from occluding his pupil during the course of the entire experiment. In this case, the eyelid was covering a portion of the pupil, or all of it. When that happened a voltage output of the pupillometer represented the distance from the bottom of the pupil to the bottom of the eyelid, and if the eye was closed there was no voltage. As time passed for each S, the E noticed a

TABLE IV. Analysis of Variance on APV

Source	df	SS	MS	F
Subjects	6	0.0110	0.0018	12.85*
Time Segments	9	0.0032	0.0004	2.52**
Error	54	0.0077	0.0001	
Total	69	0.0219		

*p $<$ .0001

**p = .0172

TABLE V. Analysis of Variance on NMTL

Source	df	SS	MS	F
Subjects	3	0.0152	0.0051	17.12*
Time Segments	9	0.0263	0.0029	9.87**
Error	27	0.008	0.0009	
Total	39	0.0494		

*p = .0028

**p = .0032

TABLE VI. Analysis of Variance on SR 0-10

Source	df	SS	MS	F
Subjects	4	384.8362	96.2091	20.05*
Time Segments	10	1300.581	130.058	27.10*
Error	40	191.9644	4.7991	
Total	54	1877.382		

*p $<$ .0001

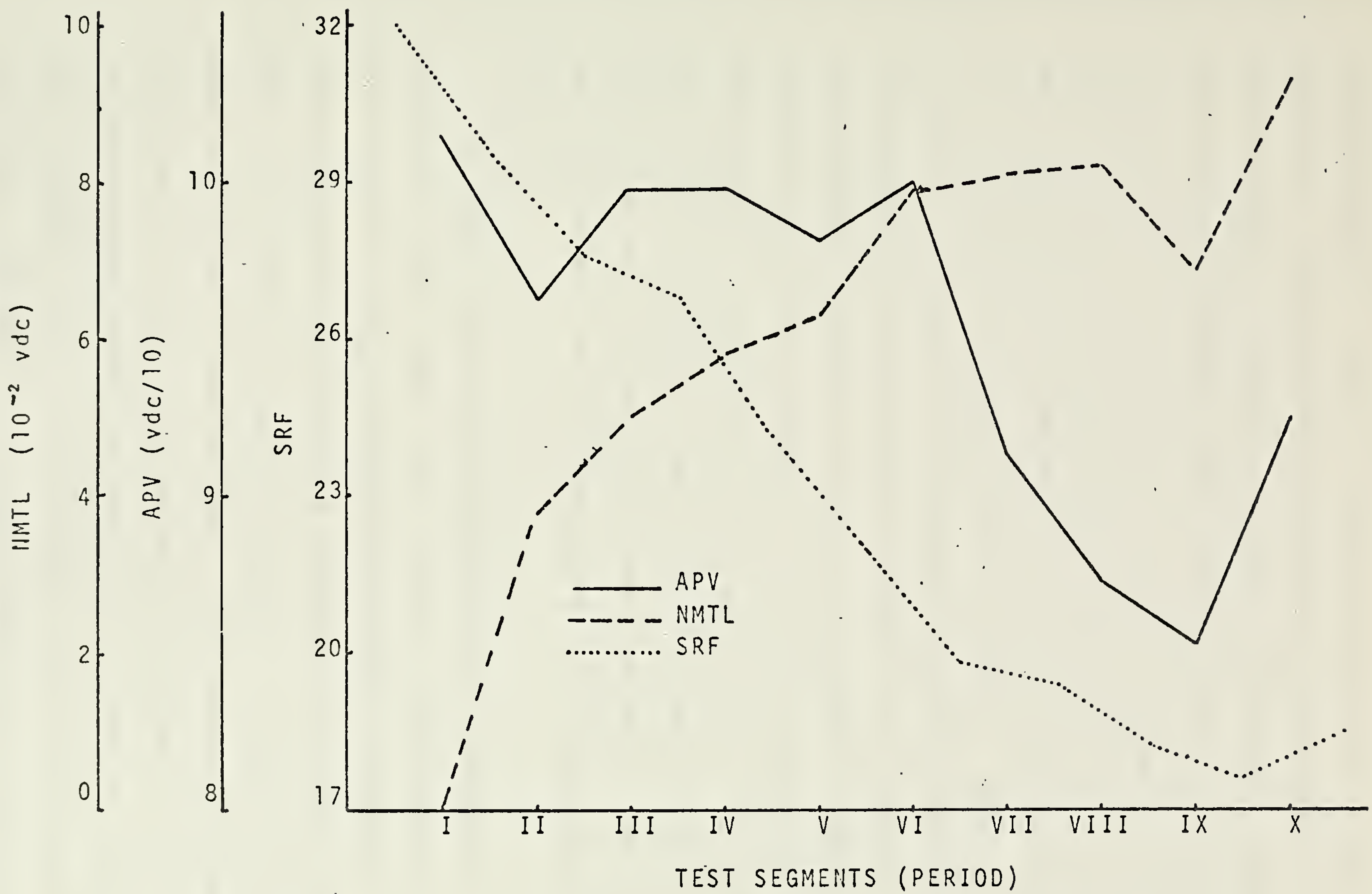

Figure 3. NMTL, APV, SRF -vs- PERIOD

tendency for S's eyelid to cover portions of the pupil. The results of the experiment confirmed this observation. The data indicates an increased drooping of the eyelid during the course of the experiment. As the S's endured the experiment, they kept their eyes closed for longer time periods during blinks and/or did not open their eyelids as wide. This tendency prevented the interpretation of the data as resulting from a significant change in pupil diameter. Table VII indicates an insignificant correlation between blink rate and APV when using a critical-ratio z-test for the Pearson product-moment correlation at the 0.05 level, assuming linear relations and normality. This low correlation indicates success in measuring blink rate because a blink is only a quick covering of the pupil; also the APV changed but blink rates were similar during the experiment. Had this not occurred both variables may have been measuring the same mechanism.

There were eleven administrations of the subjective rating of fatigue check list. One was given before the first doppler drill, and before every drill thereafter. A final rating was made by the S following the tenth doppler drill. The E gave no indication before the final rating was made that indeed it was the last. For planning purposes each S was told that the experiment would last a little over two and one-half hours, but each did not know how long the drill segments would be nor how many there were during the experiment. The S's did not wear watches and thus had no

	SCORE	SR 0-9	SR 1-10	SABS/N	NMTL	APV	BR
PERIOD	.27*	-.84*	-.76*	.15	.64*	-.31*	.02
SCORE		-.11	-.07	.28*	.13	.02	.07
SR 0-9			.94*	-.14	-.74*	.25*	.18
SR 1-10				-.17	-.72*	.33*	.15
SABS/N					-.07	-.38*	.45*
NMTL						.06	-.33*
APV							-.18

* Significant at 0.05 Level

TABLE VII. Correlation Matrix

mechanical way of measuring time. After each experimental session the S was asked if he knew when the last check list was being given, and none did. They all said that it felt as though they had been in the experiment for a long time but that they thought the difficulty of the task was causing a misconception of time. They generally estimated the experimental length at one and one-half hours when asked their feeling of time at the conclusion. It is assumed that no "end-of-the-experiment" anticipation influenced the measurement of any variables.

Figure 3 shows the eleven mean values for SRF. The values were plotted between test segments in order to permit before and after comparisons of variables. The ten before-drill measures of SRF were grouped into variable SR 0-9; the after-drill measures were grouped as SR 1-10. Indications of the correlation existing between these two variables and the other experimental variables are displayed in Table VII. The variables PERIOD, NMTL, and APV are not uncorrelated with both SR 0-9 and SR 1-10 at a level of 0.05. Duncan's multiple-range test was used in order to discover which treatments among the ratings of fatigue were actually different at the 0.05 level. An interesting pattern was discovered. Each treatment was silimar to the one immediately following. Also the seventh through the eleventh ratings were similar. The second and sixth were similar to the two following them, but were again different from the remaining ones. These relations generally indicate that the check

list discriminated over greater periods than fifteen minutes except near the termination of the experiment. Either the S felt much the same during the last hour or the subjective rating of fatigue check list could not discriminate the change in S's feelings.

The various treatments within the measurement of NMTL were not the same (see Table VI). Duncan's multiple-range test was again used to find where treatments were significantly different at the 0.05 level. The NMTL during the first doppler drill segment was similar to the second, but was different from all other treatments. The second measure of NMTL was similar to numbers 3, 4, and 5, but was different from number 6 through the last treatment. The third was similar to numbers 4, 5, 6, and 9; and it differed significantly from numbers 7, 8, and 10. When comparing all treatments after the third, only two pairs were significantly different; they were the fourth compared with the tenth, and the fifth with the tenth. Once again discrimination among the later treatments in the experimental series was poorer than among the earlier ones. Table VII indicates a significant correlation between NMTL and SR 0-9 SR 1-10, PERIOD, APV, and BR. The greatest correlation occurs between the subjective rating of fatigue before each segment and the NMTL during that segment.

Table VIII was produced in order to compare the results of regressing variables on one another. Four S's were accurately measured for NMTL, five S's answered similar

TABLE VIII. Multiple Regression

Dependent Variable	Independent Variable Entered	Independent Variable Not Used	R^2	F	P <
SR 0-9*	NMTL	SABS/N, APV SCORE, BR	.553	46.9	.001
SR 0-9*	NMTL, APV	SABS/N, BR SCORE	.634	8.2	.005
SR 0-9**	APV	SABS/N, BR SCORE	.065	3.3	.1
SR 0-9**	APV, BR	SABS/N, SCORE	.131	3.6	.05
SR 1-10*	NMTL	SABS/N, APV BR, SCORE	.518	40.8	.001
SR 1-10*	NMTL, APV	SABS/N, BR SCORE	.625	10.6	.001
SR 1-10**	APV	SABS/N, BR SCORE	.08	3.3	.1
SR 1-10**	APV, BR	SABS/N, SCORE	.16	3.5	.05
Period*	NMTL	SABS/N, APV BR	.404	25.8	.001
Period*	NMTL, APV	SABS/N, BR	.512	8.1	.005
Period	APV	SABS/N, BR SCORE	.097	7.3	.01
Period	APV, SCORE	SABS/N, BR	.175	6.3	.005
Score*	NMTL	SABS/N, APV BR	.405	25.9	.001
Score*	NMTL, APV	SABS/N, BR	.515	8.4	.005
Score	Period	-	.074	5.4	.025

* Measures only on four subjects.

** Measures only on five subjects.

subjective rating of fatigue check lists, and seven yielded measurements of SABS/N, APV, and BR. These factors made it desirable to perform multiple regressions on differing sets of S's. An F-ratio of 3.0 was required for the inclusion of an independent variable at each step in the multiple regression procedure. Those independent variables listed as not used contributed a reduction in residuals which was insignificant. Each step of the regressions was listed in order to highlight the improvements gained as more independent variables were added.

Further attention was given to the relationship between SR 0-9 and SR 1-10 with NMTL. Figure 3, Table VII and Table VIII point to the importance of exploring these relationships. An analysis of variance on polynomial regressions for both these pairs was calculated in Tables IX and X.

Linearity of these relationships is strongly indicated. NMTL was a better predictor of SR 0-9 than SR 1-10 in this experiment. Table XI presents the simple linear regression equations. Figure 4 illustrates the relationship between the line generated by the equation for SR 0-9 as a function of NMTL and the line segments joining the plotted points for each pair of mean NMTL and SR 0-9 observed during a treatment.

Because performance as measured by SCORE was statistically constant throughout the experiment, no predictors of this important variable were found. Sinus arrythmia appeared to be correlated with SCORE and therefore more

TABLE IX. Polynomial Regression, Analysis of Variance SR 1-10 (Dependent) -vs- NMTL (Independent)

Source	df	SS	MS	F	P <
Linear Term	1	634.24	634.24	44.17	.001
Quadratic Term	1	41.72	41.72	2.91	.1
Cubic Term	1	13.36	13.36	0.93	.5
Quartic Term	1	32.53	32.53	2.27	.2
Deviation about Regression	35	502.55	14.36		
Total	39	1224.40			

TABLE X. Polynomial Regression, Analysis of Variance SR 0-9 (Dependent) -vs- NMTL (Independent)

Source	df	SS	MS	F	P <
Linear Term	1	822.46	822.46	48.12	.001
Quadratic Term	1	28.75	28.75	1.68	.25
Cubic Term	1	10.96	10.96	0.64	.5
Quartic Term	1	33.41	33.41	1.95	.2
Deviation about Regression	35	598.23	17.09		
Total	39	1493.77			

TABLE XI. Simple Linear Regression

Variable		Constant	Regression Coefficient	Independent Variable
(SR 1-10)	=	28.78728	-113.30782	(NMTL)
(SR 0-9)	=	31.33271	-128.43331	(NMTL)

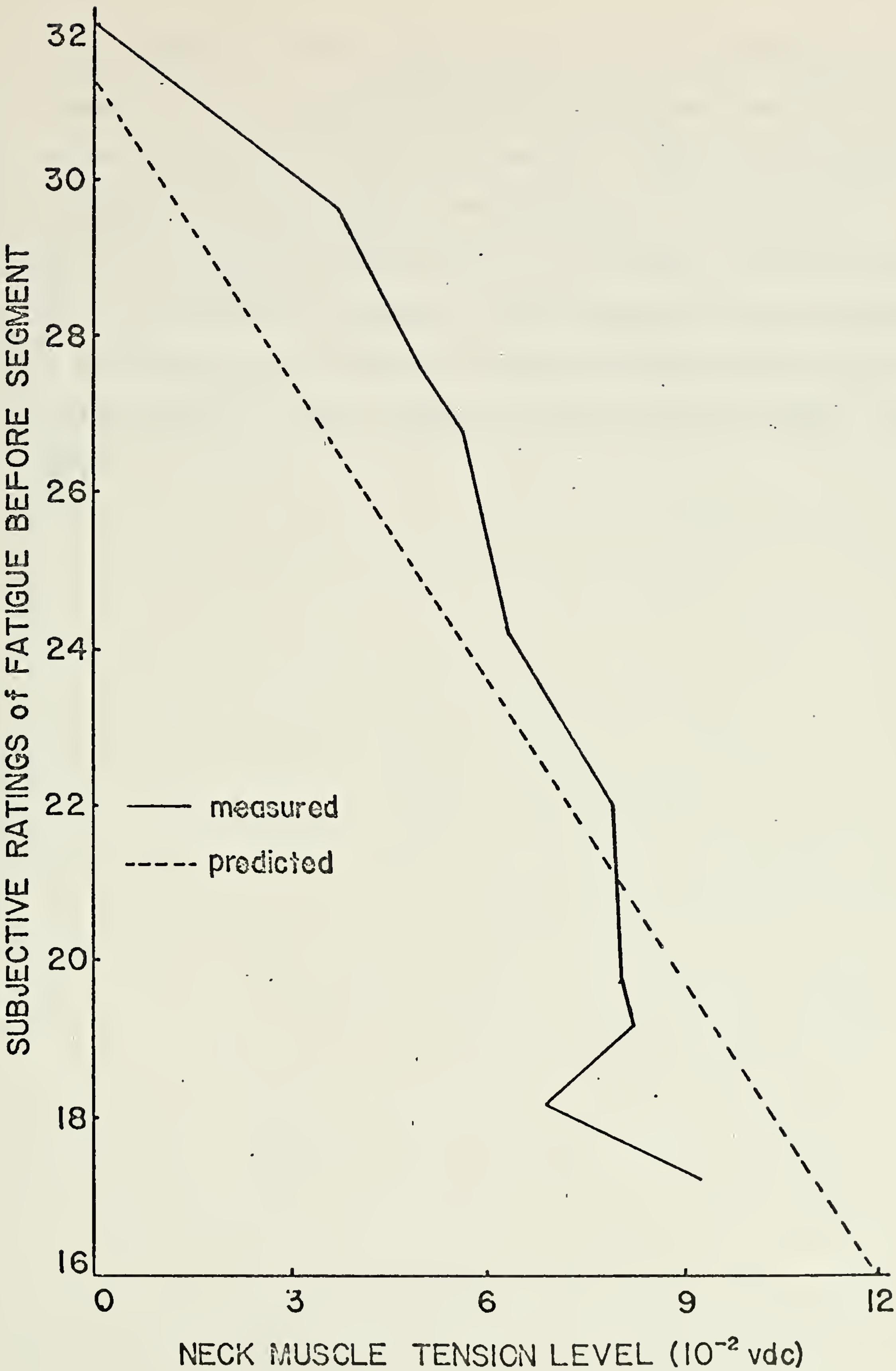

Figure 4. SR 0-9 -vs- NMTL

investigation of this relationship may be appropriate. The behavior of the pupil during this experiment was lost in the noise generated by eyelid movements. There were significant correlations among pairs of variables as indicated in Table VII although these were not as highly correlated as SR 0-9 and NMTL. Therefore, this experiment has supported a hypothesis that fatigue, measured subjectively, may be predicted by a linear equation involving neck muscle tension level.

APPENDIX A

Subject Questionaire

Name ______________________________________

Age ______________________________________

Do you have any unusual	(circle one)	
Heart Behaviors	No	Yes
Muscle Troubles	No	Yes
Hearing Impediments	No	Yes
Eye Impairments	No	Yes

(If answer is Yes, please explain)

How do you feel today?________________Do you feel a little sick or have any distracting condition that may periodically give you discomfort?____________________

APPENDIX B

Explanation of Subjective Check List

People feel differently at various times for various reasons. Some arise after a night's rest feeling QUITE RESTED, while others may feel A LITTLE TIRED. A hard day's work or a vigorous workout at the gymnasium may make you feel FAIRLY WELL POOPED, yet a shower, a cup of coffee, or merely a few minutes relaxing in a comfortable chair may make you feel VERY REFRESHED.

I would like to find out how you feel at various times. During the experiment you will hear statements which describe different degrees of FRESHNESS or POOPEDNESS or TIREDNESS. For each statement you will have to determine in your own mind whether you feel at that instant (1) better than, (2) same as, (3) worse than the feeling described by that particular statement. Having done this you will then give a thumb up sign for a feeling "better than" the statement; a horizontal thumb sign for a feeling "same as" the statement; and a thumb down sign for a feeling "worse than" the statement. Consider the following example:

Statement: SOMEWHAT TIRED

Better Than	Same As	Worse Than
thumb up	horizontal thumb	thumb down

If right now you feel SOMEWHAT TIRED you would give a thumb horizontal response for the "same as" feeling. If, however, you feel fresh or full of pep you would give a thumb

up "better than" sign because you felt better than "somewhat tired". On the other hand, if you felt exhausted, you would answer with a thumb down.

Take each statement as it is presented. Listen carefully so that you understand what it means. It may help you to understand some statements more fully if you insert the words "I feel," or "I am," preceeding the statement.

This is not a test. You will have all the time you need. Do not try to be consistent in your answers each time. You may experience no change during the experiment; or you may feel up and down during it. The important thing is to answer your feeling at that exact moment!!!

APPENDIX C

Explanation of Experiment

The mechanism and progression of mental fatigue and the manner in which it affects performance are at present poorly defined. This experiment in which you are participating has been designed in order to add information to the study of fatigue.

This is a test to measure mental fatigue. You will not go away feeling rested and energetic. The whole purpose is to measure your fatigue through electrical responses from the cardiovascular system, the muscles at the back of the neck, eye behavior, and subjective fatigue reports. So you may surmise that it is an extensive and rather long test; hence, you'll just have to "set your mind to it."

It demands somewhat rigid body posture and there will be times that you may want to move around or you may have an urge to droop your eyelids. Please do not. You must keep alert and working hard at all times.

This test is mental as well as physical. You will listen to some sonar tapes and be asked to identify the character of the echo doppler. Your answers will be scored and their correctness will be a part of the overall results. I must stress that you put your best efforts into this task! EVERY minute is important.

Listen to the training tape until you feel confident you can distinguish doppler. During the experiment you will

respond with a thumb up for up doppler, thumb down for down doppler, and a horizontal thumb sign for no doppler.

Do not answer until questioned. The length of the test is set. I am not looking for an answer which will mean the termination of the test. There must be honesty in each response. You must try to keep from closing your eyes in order to hear better, or during answering the questionaire.

APPENDIX D

Introduction to Each Subjective Check List

Data is still being recorded during these questions. The statements to follow are to help you decide how you feel at this time -- not an hour ago, not five minutes ago, not even one minute ago -- but right now. For each statement you must determine whether you feel (1) better than, (2) same as, (3) worse than, the feeling described by that statement.

Now answer each of the following statements. A thumb up sign will indicate a "better than" feeling. A horizontal thumb means that you feel the "same as" the statement. And finally, a thumb down signifies a "worse than" the statement feeling. Please pause after each statement in order to assess your feeling at that very moment. Take your time in responding, for there is no time limit.

Check List

Quite Fresh	Extremely Peppy
Tuckered Out	Somewhat Fresh
Slightly Tired	Very Refreshed
Fairly Well Pooped	Petered Out
Ready to Drop	Very Lively
Extremely Tired	Slightly Pooped
Very Tired	

Instruction Following Check List

Try very hard on each sonar echo. Do not let your mind wander. Do not answer until called upon.

APPENDIX E

Introduction to Doppler Task

A set of three sonar echoes will be presented to you. Each of the echoes in the set has the same doppler. After you have heard the three similar echoes, you will be asked whether the doppler was UP, DOWN, or NO DOPPLER. For example, before each set of three echoes you will hear the verbal guidelines, "next set". Then you will hear three echoes in a row. Finally you will hear a question, "your answer is?". At that time make your UP, DOWN, or NO DOPPLER response.

The test begins now.

BIBLIOGRAPHY

1. Bartley, S. H. and Chute, E., Fatigue and Impairment in Man, p. 302-323, McGraw-Hill, 1947.

2. Bell, R. R., "Experimenter Expectancy in Pupillometric Research", Perceptual and Motor Skills, v.33, p. 174 October, 1971.

3. Bonsper, D. E., The Effect of Increased Information Processing on Sinus Arrhythmia, Masters Thesis, U.S. Naval Postgraduate School, September, 1970.

4. Burns, T. V., Pupil Diameter Variation in a Visual Interpretation Task, Masters Thesis, U.S. Naval Postgraduate School, March, 1972

5. Dixon, W. J., Biomedical Computer Programs, University of California Press, 1968.

6. Douglas, R. E., Information Processing, Sinus Arrhythmia, and Academic Achievement, Masters Thesis, U.S. Naval Postgraduate School, March 1972.

7. Edwards, B. R., Pupillary Size Changes During Information Processing Overload, Masters Thesis, U.S. Naval Postgraduate School, March, 1972.

8. Ehema, J. H. and Zielhuis, R. L., "Physiological Parameters of Mental Load", Methodology in Human Fatigue Assessment, (Eds.) Hashimoto, K., Kogi, K., and Grandjean, E., Taylor and Francis, 1971.

9. Hess, E. H., "Attitude and Pupil Size", Scientific American, v. 212, p. 46-54, October, 1965.

10. Hess, E. H. and Polt, J. M., "Pupil Size in Relation to Mental Activity During Simple Problem-Solving", Science, v. 140, p. 1190-1192, November, 1964.

11. Holland, M. K. and Tarlow, G., "Blinking and Mental Load", Psychological Reports, v. 31, p. 119-127, August, 1972.

12. Hope, R. E., Pupillary Size Change as Correlated with Mental Activity, Masters Thesis, U.S. Naval Postgraduate School, March, 1973.

13. Innes, H. E., Subjective and Physiological Indicators of Fatigue in a Vigilance Task, Masters Thesis, U.S. Naval Postgraduate School, March, 1973.

14. Kahneman, D. and Peavler, W. S., "Incentive Effects and Pupillary Changes in Association Learning", Journal of Experimental Psychology, v. 79, p. 312-318, February, 1969.

15. Kahneman, D., and others, "Pupillary, Heart Rate, and Skin Resistance Changes During a Mental Task", Journal of Experimental Psychology, v. 79, p. 164-167, January, 1969.

16. Kalsbeek, J. W. H., "Sinus Arrhythmia and the Dual Task Method in measuring Mental Load", Measurement of Man at Work: An Appraisal of Physiological and Psychological Criteria in Man-Machine Systems, (Eds.) Singleton, W. T., Fox, J. G., and Whitfield, D., Taylor and Francis, 1971.

17. Lippold, O. C., A Manual of Psychophysiological methods, (Eds.) Venables, P. H. and Martin, I., p. 287-288, North Holland, 1967.

18. McFeely, T. E., Pupil Diameter and the Cross Adaptive Critical Tracking Task; a Method of Workload Measure, Masters Thesis, U.S. Naval Postgraduate School, June, 1972.

19. Mulder, G. and Mulder-Hajonides von der Meulen, W. R. E. H., "Heart Rate Variability in a Binary Reaction Task: An Evaluation of Some Scoring Methods", Acta Psychologica, v. 36, p. 239-251, July, 1972.

20. Air University School of Aviation Medicine, USAF, Report 56-115, The Development and Validation of a Check List for Measuring Subjective Fatigue, by Pearson, R. G. and Byars, G. E., December, 1956.

21. Sayers, B. M., "Analysis of Heart Rate Variability", Ergonomics, v. 16, p. 17-32, January, 1973.

22. Stanners, R. F., and Headley, D. B., "Pupil Size and Instructional Set in Recognition and Recall", Psychophysiology, v. 9, p. 505-511, September, 1972.

23. U.S. Fleet Anti-Submarine Warfare School, Active Sonar Training Tape; Introduction to Doppler, program number 12-3522.6 TR-5, 1962.

24. U.S. Fleet Anti-Submarine Warfare School, Active Sonar Training Tape; SQS-23 Doppler Drill, program numbers 12-3522.6TR-7, 12-3522.6TR-10, and 12-3522.6TR-13, 1962.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This research investigated relationships between subjective fatigue, performance, and four physiological parameters: sinus arrhythmia, pupil behavior, blink rate, and tension of

20. ABSTRACT

the neck muscles. Fatigue was induced by a doppler recognition task and rigid body posture. Performance was measured as the proportion of correct doppler identifications. There was no detection of a performance change during the two and one half-hour experimental sessions. Sinus arrythmia and eyelid blink rate were also found to remain unchanged. An alteration was found in the measures of neck muscle tension levels, subjective fatigue, and the average pupil diameter.

Subjective ratings of fatigue were found to be highly correlated with time-on-task and the electromyographic response of certain neck muscles. Polynomial regression indicated a significant linear relationship between the subjective ratings and the tension measured.

The relationship of eye behavior, cardiac activity and electromyographic responses to subjective reports of mental fatigue and performance on a doppler identification task.

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