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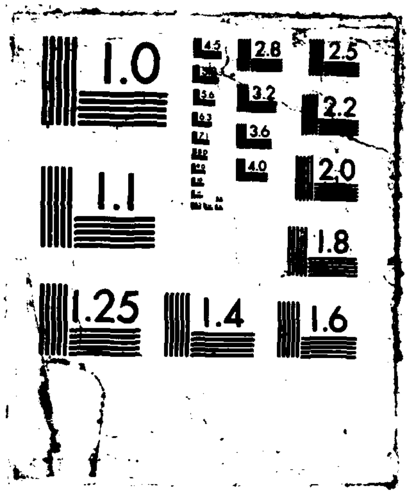
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DEVELOPMENT OF SACCADE LENGTH INDEX OF TASKLOAD
FOR BIOCYBERNETIC APPLICATION

James G. May, Ph.D., Robert S. Kennedy, Ph.D.
and Jennifer E. Fowlkes

ANNUAL TECHNICAL REPORT



Prepared by

Essex Corporation
1040 Woodcock Road, Suite 227
Orlando, Florida 32803
(305) 894-5090

November 1987

The Contractor, Essex Corporation, hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. F49620-87-C-0002 is complete, accurate, and complies with all requirements of the contract.

30 November 1987

Date

Robert S. Kennedy, P.I.
Vice President
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This report reviews progress made during the first year of a two year Phase II SBIR program to develop the Saccade Length Index of Mental Workload or SLIT. The ultimate goal of this effort is to develop a fully portable system to measure workload using the SLIT metric. Phase I work showed that workload and saccade length were related when workload was manipulated using an auditory tone counting task. Research conducted thus far in Phase II has replicated the Phase I results and has also shown 1) that the saccade length index is not affected by extended practice on a difficult tone counting task, and 2) that practice on a difficult tone counting task does not invalidate the saccade length measure when subjects perform less difficult levels of the same task. Preliminary results suggest that saccade length reflects workload on visual counting tasks in addition to auditory counting tasks, thus extending the possible application of SLIT to visual tasks which do not require precise visual fixation or tracking. Hardware has been purchased for the SLIT system and progress has been made on software development so that SLIT system may be automated for data collection and analyses.

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**22b TELEPHONE (Include Area Code):** (202) 767-5021

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## INTRODUCTION

The capabilities and complexity of aircraft have steadily increased over the years and demands on aircrew have increased concomitantly. Historically, it has been possible for crewmembers to operate and to realize the full potential of aircraft systems. In recent years, despite an increase in automated functions, the information richness of the tactical environment and the burgeoning number of sub-systems (e.g., electronic warfare sub-systems) routinely threaten to exceed the capabilities of operators.

To develop aircraft which can be safely and effectively operated, decisions must be made concerning the relative roles of man and machine. Considerable controversy exists concerning both the number of required operators and the delegation of duties traditionally fulfilled by humans to machines. To determine the optimal separation of duties between man and machine requires (a) the identification of tasks which must be performed by the man-machine system to attain mission goals and (b) the delineation of the tasks which can be performed by humans without loss of system effectiveness.

In effect, the "difference" between the tasks that must be performed and the tasks which humans are capable of performing must either be performed by machines or neglected when task demands exceed machine capabilities. There is relatively little problem in identifying the tasks necessary for mission success (e.g., task analysis). However, despite considerable efforts, the capability to objectively measure the ability of humans to perform tasks simply does not exist. For example, the "optimal combination" of man and machine is often achieved by first producing aircraft and, then, in response to tragic accidents resulting from task demands which exceed human capabilities, deployed aircraft are "fixed" -- The development of optimal man-machine systems on such an iterative basis is expensive in terms of human safety, cost, and time. Since critical tasks can be identified, but the capability of humans to perform these tasks cannot be predicted, the need to predict human workload capabilities is exceedingly important.

While it is essential to deal with both mental and physical workloads to develop optimal man-machine systems, only physical workload has been successfully addressed. For example, the adverse effects of g-loading are relatively easily measured and have been minimized by such steps as g-suits, personnel selection, and training. In contrast, mental workload has neither been convincingly defined nor measured and, thus, remains a significant problem. Despite the lack of agreement concerning a single definition of mental workload, there is, oddly enough, widespread agreement that mental workload is a significant problem aggravated by technological advances in aircraft. This agreement is evidenced by the diverse attempts at measuring workload.

## MEASUREMENT OF MENTAL WORKLOAD

The measurement of mental workload (i.e., the development of mental workload indices) can be divided into roughly three categories - Subjective Indices, Task Descriptions, and Response Measurements (Aunon, Kantowitz, McGillem, and Plonski, 1987; Gopher & Braune, 1984; Wickens, 1984).

1. Subjective Index: Subjective measures of mental workload (Gopher & Braune, 1984; Moray, 1979) are operator ratings of task difficulty and task attention demands obtained via debriefing interviews and questionnaires. Subjective measures include the Cooper-Harper Scale (Cooper & Harper, 1969; Sheridan & Simpson, 1979), Subjective Workload Assessment Technique (SWAT - Reid, Shingledecker, & Nygren, 1981; Reid, Shingledecker, & Eggemeier, 1981), and the Multi-descriptor Scale (Casali, 1982). For example, the Multi-descriptor Scale used by Casali (1982) requires that operators rate task demands according to each of six descriptors (i.e., attentional demand, error level, difficulty, task complexity, mental workload, and stress). The average of these six ratings is used as a measure of mental workload. Advantages of subjective techniques include ease of administration, low costs, and minimal instrumentation requirements. Disadvantages include interruption of task to obtain ratings, operator bias, and low correlation with measures of performance (Gopher & Braune, 1984).

2. Task Description: Task descriptions are based upon the assumption that workload increases with increased task demand upon the human. Measures of task parameters include time between presentation of stimuli, information bits, and number of information sources. The primary advantage of this approach is the quantitative precision offered (e.g., bits of information per second). Disadvantages include task dependency of the index (e.g., new index must be developed for each task) and the uncertain relationship between task parameters and demands upon the human.

3. Response Measurements: Response indices consist of either (a) task performance or (b) physiological measures.

(a) Task performance indices are based upon the assumption that decreasing performance results from increasing workload. Thus, workload is measured by performance. Examples of performance measures include number of errors, percent correct, response time, and deviation from an optimal flight path. A common performance measure technique is to measure operator performance on a secondary task (Wickens, 1984). For example, Wierwille and Connor (1983) assigned a primary task to subjects (i.e., straight and level simulated flight) simultaneously with secondary tasks (e.g., mental arithmetic). Given a constant level of workload on the primary task, the performance on the secondary task is thought to represent "residual resources" or "spare mental capacity" (Kantowitz & Sorkin, 1983). Performance variations on the secondary task are thus presumed to measure workload imposed by the primary task which are not reflected by performance on the primary task. Disadvantages of performance measures include the uncertain relationship between performance and workload. Moreover, when secondary tasks are employed, it is essential that the primary task remains primary, a problem not always handled satisfactorily (Damos, Bittner, Kennedy, & Harbeson, 1981; Kantowitz & Weldon, 1985).

(b) Physiological measures have been extensively utilized to measure capability to perform physical workloads. As a logical extension, and in view of the working assumption that cognitive functions have an underlying physiological basis, measures of physiological responses have been extensively employed as an indices of mental workload. Examples include measures of cardiovascular, brain, respiratory, and visual functions. While physiological measures have potential in providing a handle to mental workload (Donchin & Kramer, 1986; Donchin, Wickens, & Cole, 1983; Frazier, 1966; Kennedy, 1978; Lewis, 1983 a,b; McCloskey, 1987; O'Donnell, 1981; O'Donnell & Shingledecker, 1986; O'Hanlon, 1971; Wilson, O'Donnell, & Wilson, 1982; Wilson, Purvis, Skelly, Fullenkamp, & Davis, 1987; Yolton, Wilson, Davis, & McCloskey, 1987), they may reflect stress rather than cognitive load (Shingledecker, 1982), and rarely account for a large proportion of the variance in the criterion.

It is clear that no single subjective, task, or response measure has allowed mental workload to be reliably and objectively quantified. Persistent barriers to satisfactory measure of mental workload include: 1) inadequate conceptualization of mental workload (e.g., Aunon et al., 1987; Kantowitz & Sorkin, 1983), 2) task dependent nature of many workload techniques (e.g., McCloskey, 1987; Wierwille, Rahimi, & Casali, 1985), 3) and lack of methodologies to handle human differences in task demands such as extent of practice on task, previous workload, ability or skill level (e.g., Matthews, 1986).

EYE MOVEMENT INDICANTS OF MENTAL WORKLOAD

Of particular interest to this report is the potential of monitoring activity of the visual system to quantify mental workload. In view of the central role of eye movements in visual, cognitive, and refined motor activities, it is not surprising that numerous studies have related various quantitative aspects of eye movements to attention, cognitive performance, mental effort, fatigue, drug state, and the integrity of the underlying neural mechanisms (Ditchburn, 1973; Hall, 1976; Kim, Zangemeister, & Stark, 1984; Krivohlavy, Kodat, & Cizek, 1969; Monty, Hall, & Rosenberger, 1975). Visual activities which have been monitored for these purposes include visual evoked brain potentials, eye blink frequency, pupil diameter, visual nystagmus, pursuit eye movements, percent time that eyes are closed, and saccadic eye movement (e.g., velocity, amplitude, and duration).

RATIONALE

Impetus for the present effort began with the finding that habituation of the fast phase component of vestibular-ocular response was attenuated in subjects who performed a vigilance task (Kennedy, 1972). This might be expected, it was argued, since the fast phase component of nystagmus is dependent on the integrity of the reticular formation which is also related to arousal and alertness (Cohen, Feldman, & Diamond, 1969; Darhoff & Hoyt, 1971; Yules, Krebs, & Gault, 1966). Given that other research related nystagmus to arousal (Collins, Crampton, & Posner, 1961; Collins & Posner, 1963), the idea was pursued to relate velocity and latency of saccades to performance on a task which could be varied in terms of the demands it placed on the operator.

Thus, in the initial experiment of Phase I (May, Kennedy, Williams, Dunlap, & Brannan, 1985), subjects performed an auditory tone counting task at three levels of difficulty while the velocity and latency of saccades in the horizontal plane were recorded. The results showed that there was little evidence for a relationship between workload and eye movements since (a) saccade velocities obtained during the baseline condition of free-viewing did not differ significantly from velocities obtained under tone counting conditions, and (b) latency varied with workload but practice effects masked the relationship between saccade latency and workload.

The second Phase I experiment examined the relationship of another eye movement measure--saccade length--to workload since experimental evidence existed which suggested that extent of eye movements might be reduced under conditions which induced high levels of arousal. For example, Malmstrom and colleagues (Malmstrom & Reed, 1983; Malmstrom, Reed, & Randle, 1983) reported a restriction of pursuit eye movement range during a concurrent auditory task. In addition, restriction in saccade length was measured in cats under conditions of high arousal induced by amphetamines (Crommelinck & Roucoux, 1976).

To test the relationship between saccade length and arousal, subjects in the second Phase I experiment performed an auditory tone counting task at three levels of difficulty while saccadic eye movements were recorded. The mean range of eye movements in the horizontal plane for each of the three workload conditions are presented in Table 1 along with mean performance on the tone counting task. As seen in the table, performance varied inversely with difficulty level of the tone counting task suggesting that the different task conditions induced different levels of mental workload. This relationship was substantiated by a significant linear trend ($F(1,4) = 9.10$, $p = .0393$). Average extent of saccadic eye movements was also related to task difficulty; saccade length was restricted with increased task difficulty level ($F(1,4) = 16.65$, $p = .02$). To further substantiate the relation of saccade length to workload, correlation coefficients between saccade length and performance were computed for each subject. The correlations ranged from $r = .37$ to $r = .99$ with a mean of $r = .64$. Thus, the results from this research suggests that saccade length is a promising measure of mental workload.

TABLE 1. NORMALIZED SPONTANEOUS SACCADIC LENGTH AND TONE COUNTING PERFORMANCE (PERCENT CORRECT) AS A FUNCTION TASK DIFFICULTY

| | | Task Difficulty | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Saccade Length | Mean | 3.25 | 3.01 | 2.44 |
| | (SD) | (2.30) | (3.08) | (2.32) |
| Performance | Mean | 0.96 | 0.82 | 0.64 |
| (Percent Correct) | (SD) | (0.09) | (0.19) | (0.23) |

DESCRIPTION OF PROJECT GOALS

The purpose of Phase II is to expand on the results of the second experiment in Phase 1 and to develop the Saccade Length Index of Workload or SLIT. The total Phase II undertaking is keyed toward a single objective--the development of a transportable system to assess mental workload via the SLIT metric. This effort entails three aspects which are outlined below and expanded upon in Sections II through V: Research, Development, and Field Testing.

**RESEARCH EFFORT.** The research performed in Phase II is designed to: 1) extend Phase I results, 2) refine recording techniques, and 3) compare SLIT to other physiological indices of workload. A brief description of each experiment occurs in Table 2. More detailed descriptions may be found in Sections II and III.

TABLE 2. PROPOSED RESEARCH FOR PHASE II SLIT PROGRAM

| Experiment | Description |
|---|---|
| 1 | Establish the relationship between the saccade length index of taskload and task performance. |
| 2 | Determine the validity of SLIT procedures when visual tasks are employed. |
| 3 | Examine the effects of practice on SLIT. |
| 4 | Extend SLIT to include vertical as well as horizontal eye movements. |
| 5 | Modify SLIT to reject eye blink artifacts using binocular recording. |
| 6 | Compare SLIT to other physiological indices of workload. |

**DEVELOPMENT EFFORT.** The development effort (which is detailed in section IV) is aimed at developing a portable, ruggedized, and versatile computer based SLIT system. The explicit goals are to:

- o Develop a portable, head mounted interface for eye movement inputs for the SLIT system.
- o Select a low cost microprocessor for the SLIT system.
- o Develop software for the SLIT system to permit automated data collection and analyses.

FIELD TESTING. The field testing of the SLIT system (detailed in section V) will involve examining its generality. Specifically, we proposed to:

- Perform a meta-analysis of the literature concerning predictive validity of physiological indicants of workload.
- Survey potential application areas for the SLIT technique
- Field test the SLIT system in some candidate areas of application.

Table 2 contains the projects goals along with the work schedule proposed in the Phase II proposal.

TABLE 3. PROPOSED PHASE II PROGRAM SCHEDULE

| | Month 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Research Effort** | | | | | | | | | | | | |
| Experiment 1 | ---- | ---- | ---- | | | | | | | | | |
| Experiment 2 | | | | ---- | ---- | ---- | | | | | | |
| Experiment 3 | | | ---- | ---- | ---- | ---- | | | | | | |
| Experiment 4 | | | | ---- | ---- | ---- | ---- | | | | | |
| Experiment 5 | | | | | | ---- | ---- | ---- | | | | |
| Experiment 6 | | | | | | | | ---- | ---- | ---- | | |
| **Development Effort** | | | | | | | | | | | | |
| Computer | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | | |
| Interface | | | | ---- | ---- | ---- | ---- | ---- | ---- | ---- | | |
| Software | | | | ---- | ---- | ---- | ---- | ---- | | | | |
| **Field Testing** | | | | | | | | | | | | |
| Lit Search | ---- | ---- | ---- | ---- | ---- | ---- | | | | | | |
| Meta-Ana. | | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | | |
| Field Study | | | | | | | | | | ---- | ---- | ---- |

## SECTION II

## RESEARCH EFFORT: YEAR 1

In an effort to address issues concerning the reliability and validity of the SLIT technique, we proposed experiments to be conducted over the two year period of this contract. Except for experiment 6, all experiments employ the complex counting task of Jerison (1956) which has been implemented on a portable computer (Kennedy & Bittner, 1980). The counting task has been adapted to use auditory (experiments 1, 3, 4, and 5) and visual (experiment 2) stimuli.

### EXPERIMENT 1: THE RELATIONSHIP BETWEEN SACCADE LENGTH AND TONE COUNTING PERFORMANCE

RATIONALE. The purpose of this experiment was to employ a difficult level of the counting task in order to precisely relate saccade length to performance measures. However, as we began the experiment with the first ten subjects, we found that 1) subjects were not able to perform the task, and 2) there was virtually no correlation between saccade length and performance. When these subjects were brought back for a second session of testing, it was found that tone counting performance improved for many of them. Thus, the importance of practice seemed evident and we opted to perform experiment 3 (listed below as 3A) as the initial research. The outcome of experiment 3 persuaded us that our originally proposed experiment 1 was illadvised and we herein propose a more promising alternative (experiment 7).

### EXPERIMENT 3A: THE EFFECTS OF PRACTICE ON SACCADE LENGTH

RATIONALE. Practice of a difficult task results in more efficient performance and, possibly, the reduction of mental workload associated with that task. Our previous demonstration (Phase I, second experiment) that increased task complexity results in decreased saccade length was obtained with low levels of pretest practice. In the present experiment, we examined the effects of different levels of practice on saccade length. Our hypothesis was that saccade length would increase with increasing practice, reflecting the decrease in task load that derives from increasing automaticity. Such a result would provide evidence that SLIT is sensitive to an important factor (i.e., practice) in human performance.

METHOD. Ten volunteer subjects were employed in 10 eye movement recording sessions occurring over a period of 10 successive days. Each subject was paid $100.00 at the completion of the experiment.

APPARATUS. An infrared eyetracking instrument was used to record eye movements from the left eye. These signals were applied to the modulation input of a voltage-controlled frequency generator (Wavetek, Model <u>148</u>), the output of which was fed into a signal processor (Nicolet, Model <u>1072</u>) which was programmed to accumulate a time-interval histogram. In this fashion, eye movement extent was coded in terms of frequency modulation.

The auditory version of the tone counting task was administered with a microprocessor (NEC, Model 8201A) which was programmed to present a random series of 36 low pitch tones, 28 medium pitch tones and 24 high pitch tones.

Tone durations were .5 seconds and the same temporal distribution was repeated every 60 seconds, but the subjects did not recognize that a pattern was present. The task required that subjects hit one of three keys after each fourth low, medium, and high pitch tones. Three separate keys were used to indicate the three different tone counts. Scoring was always reset in the event of a miss or an incorrect response.

PROCEDURE. Subjects participated in 10 sessions. In the first session, each subject performed the auditory tone counting task once prior to recording eye movements. The following control conditions were then performed for five minutes each while eye movements were recorded: 1) a fixation condition in which subjects fixated a small cross (subtending 10 min of visual angle), 2) an alternating fixation condition which required 20 degree saccades at an aperiodic rate (.2 Hz), and 3) a free-viewing condition in which subjects were permitted to freely move their eyes. Following the control conditions, eye movements were recorded while subjects performed the tone counting task for five minutes. The procedure was repeated in the subsequent nine sessions except that subjects were not given the pretest practice.

RESULTS. Data reduction involved normalizing the range of saccades for fixation, free-viewing and task related saccades by dividing these measures by the range for alternate fixation. These three measures and the performance scores (mean percent correct) for each session were submitted to an analysis of variance. For eye movement data, a condition by sessions design was employed. For the tone counting performance measure, a simple repeated measured design was employed.

Mean normalized saccade lengths across testing sessions are depicted in Figure 1 for each condition. The mean ranges for the fixation condition are consistently lowest across sessions, while those for free-viewing are highest. The ranges obtained in the task condition fell between those obtained for the free-viewing and fixation conditions. The analysis of variance revealed that none of the saccade length measures changed systematically with practice on the tone counting task. These conclusions are supported by the results of the analysis of variance which revealed a significant main effect for conditions ($F=10.1$; df = 18; $p < .01$ but no other significant main effects. Newman-Keuls tests revealed significant differences between the fixation and free-viewing conditions ($p < .001$), task and free-viewing conditions ($p < .05$), but not between fixation and task conditions.

In Figure 2, mean normalized saccades lengths obtained during the task condition have been replotted along with mean tone counting performance as a function of practice sessions. It is apparent in the figure that performance increased considerably with practice. This is supported by the results of the analysis of variance which revealed a significant main effect for sessions ($F = 9.13$; df = 9, 18; $p < .01$).

Finally, an intercorrelation matrix between performance and saccade length, collapsed across trials, did not reveal any significant correlations.

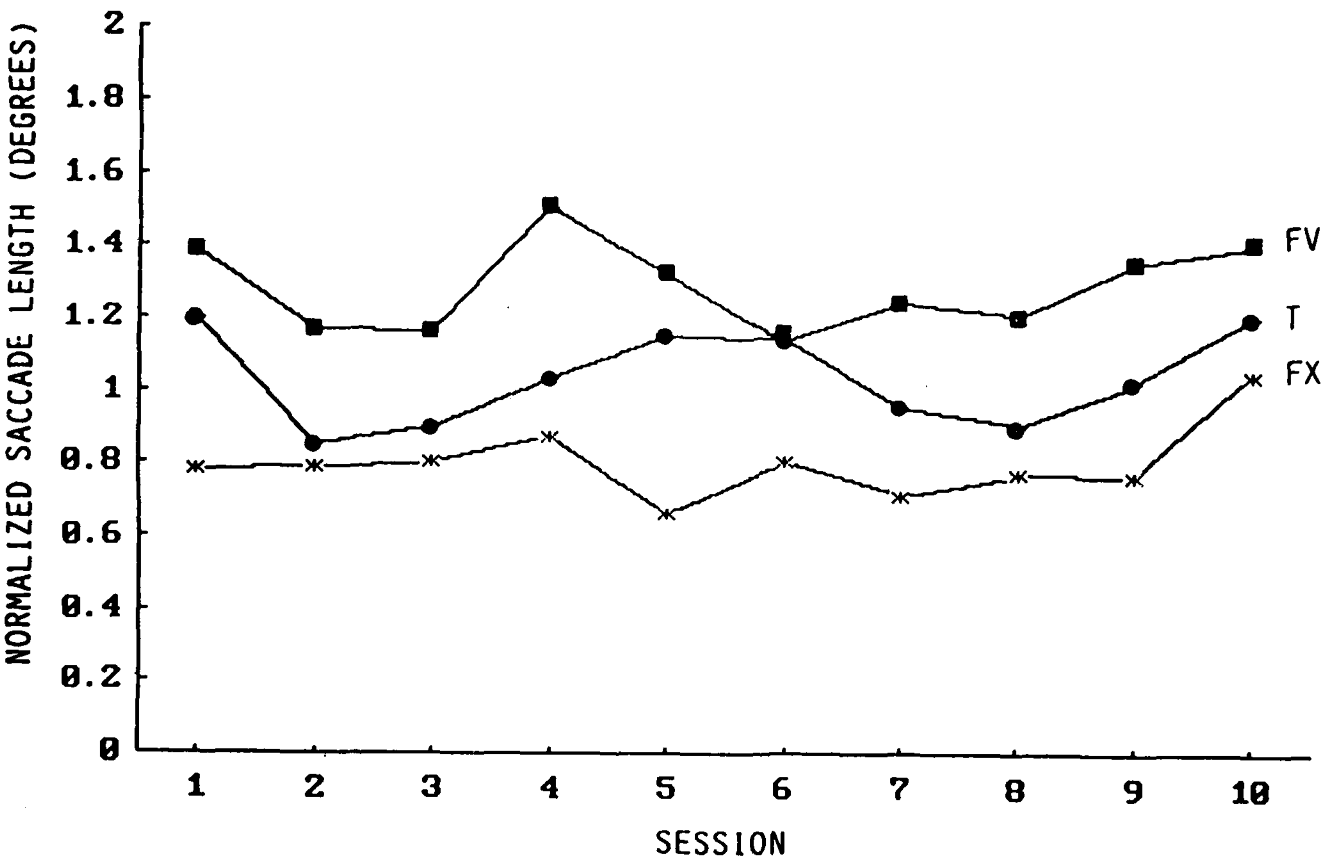


Figure 1. Mean normalized saccade ranges for the free-viewing (FV), fixation (FX), and task (T) conditions across ten testing sessions.

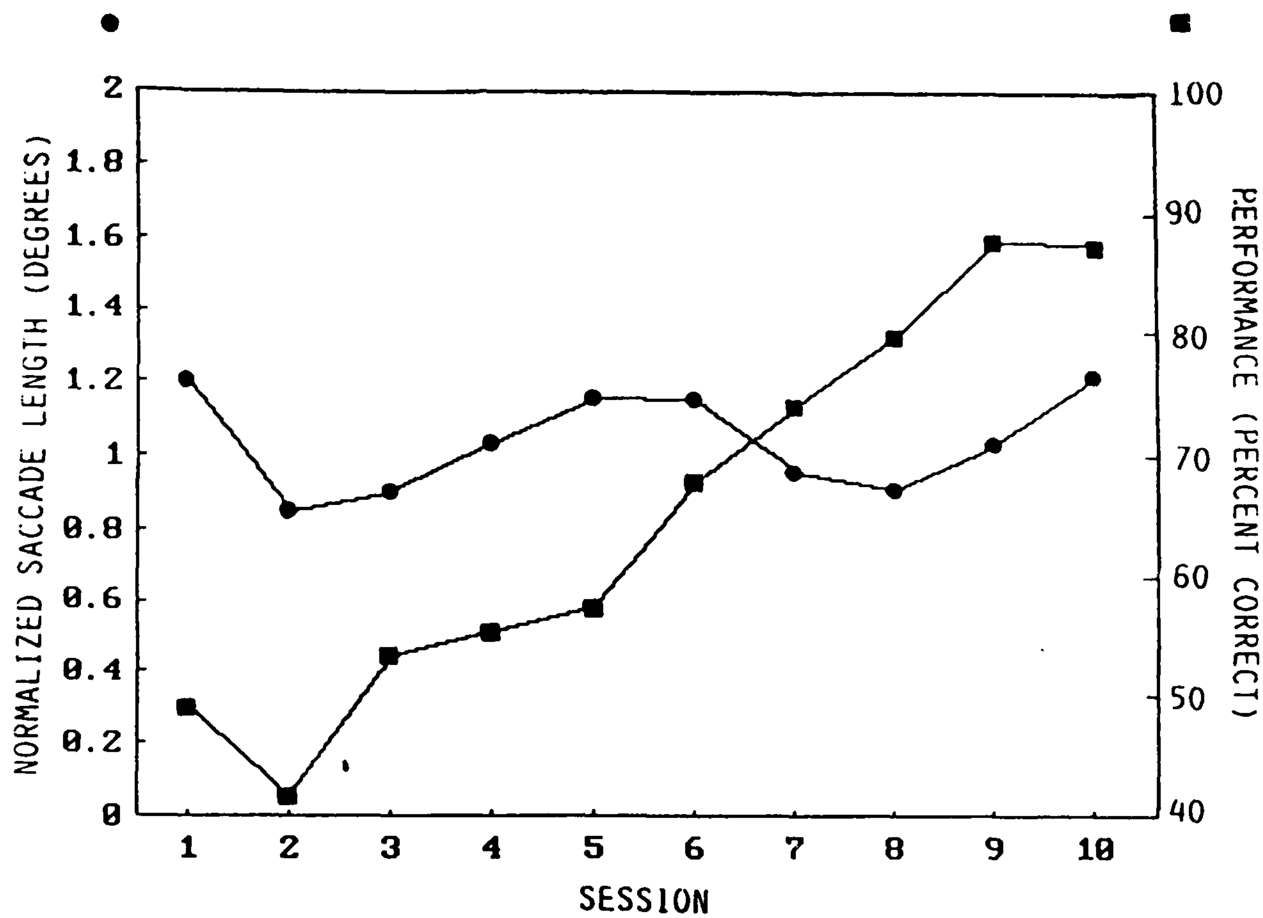


Figure 2. Mean normalized saccade length obtained under task conditions and tone counting performance (percent correct) across testing sessions.

DISCUSSION. The results show 1) that the average saccade length obtained while subjects perform a difficult tone counting task is restricted compared to free-viewing conditions, and 2) that percent correct performance on the tone counting task continued to improve across ten testing sessions while saccade length was not modified as a function of practice. The first finding reinforces the contention that saccade length may be used to measure mental workload. The second finding runs contrary to the original expectation that the task would become automated with practice and that saccade length would increase. It may be hypothesized that, although subjects were getting better at the tone counting task, it remained a "high" workload task which was reflected in saccade length which remained constant across sessions. If this hypothesis were true, then it could be expected that if these subjects were administered low and medium difficulty levels of the tone counting task, saccade length should reflect the decrease in workload but performance should remain high. This expectation was tested in an additional unplanned experiment (experiment 3B).

EXPERIMENT 3B: THE EFFECTS OF EXTENDED PRACTICE AT HIGH WORKLOAD ON SACCADE LENGTH OBTAINED UNDER LOW AND MEDIUM WORKLOADS

RATIONALE. Following the rationale outlined above, we replicated our Phase I experiment 2 with the three subjects from experiment 3A who had the best performance on the tone counting task.

METHOD. Three subjects from experiment 3A were used. Subjects were required to participate in the control conditions as in experiment 3A. Next, they were required to perform a one-tone counting task (depressing a key after every fourth low tone), a two-tone counting task (depressing a key after every fourth low tone and another key after every fourth medium tone), and then a three tone-counting task (depressing separate keys after every fourth low, medium, and high pitch tones). Each of the tone counting tasks were performed for five minutes under free-viewing conditions while eye movements were recorded.

RESULTS. The data were reduced and analyzed as in experiment 3A. The mean performance scores (percent correct) and the mean normalized saccade lengths are presented in Figure 3 for each tone counting condition. As is apparent in the figure, tone counting performance did not vary significantly with task load, as expected. In contrast, saccade length decreased with increased task difficulty, also as expected. Finally, the correlation between saccade length and tone counting performance scores was not statistically significant.

DISCUSSION. Saccade length measured in subjects who performed tasks of low, medium, and high difficulty reflected changes in mental workload after they had extensive practice on the high difficulty level of the task. This finding supports the hypothesis that workload remained constant across testing sessions in experiment 3A. The combined results of experiments 3A and 3B suggest two important findings. First, the saccade length measure is not affected by extended practice under difficult task conditions. Thus, under extended practice on a task that induces high workload, saccade length reflected workload while performance did not. This finding is important given the use of performance indices to measure workload. Moreover, it is a partial answer to the question posed for experiment 1; namely, the relationship between SLIT and performance. Second, these results suggest that saccade length remains a valid measure of the mental effort required under low and medium task difficulty levels even after extended performance at high task difficulty level. This finding is important given the increasing concern with temporal factors involved in workload (e.g., Matthews, 1986) and the possible effects of practice on workload indices reported in other research (May et al., 1985; Wilson, McCloskey, & Davis, 1986).

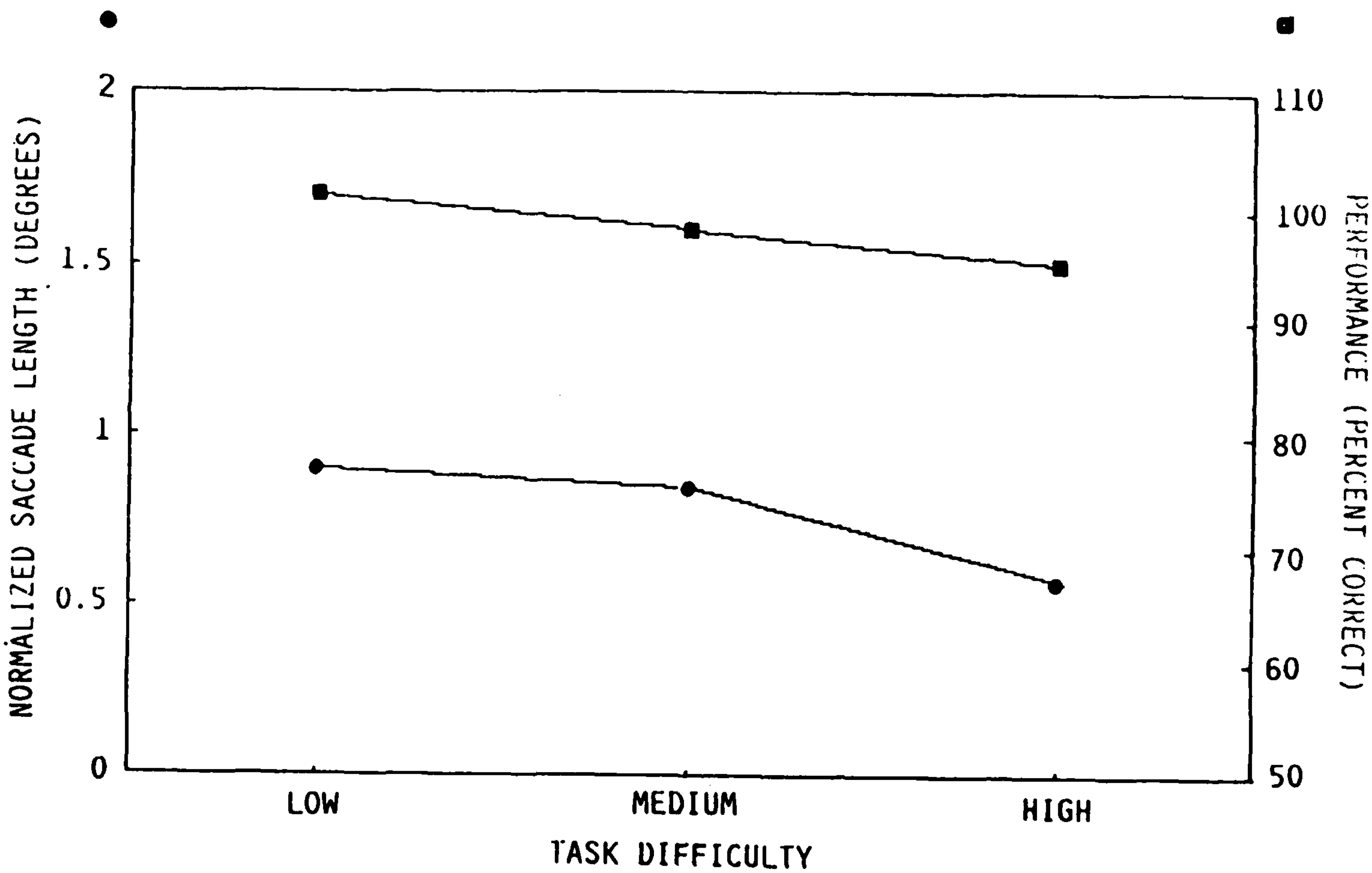


**Figure 3. Mean normalized saccade length and tone counting performance (percent correct) under low, medium, and high task difficulty levels.**

EXPERIMENT 2: THE EFFECTS OF VISUAL TASKLOAD ON THE EXTENT OF SACCADIC EYE MOVEMENT.

RATIONALE. In Phase I and in Phase II, we demonstrated that the extent of visual saccades was decreased as task complexity was increased using a three channel auditory tone counting task. In this experiment, we attempt to replicate these findings while using an analogous visual task that does not require precise visual fixation or tracking but does require the same type of cognitive effort (i.e., counting). The issue addressed here is generalization which is an important concern in the SLIT program. Although the study has not been completed, the results to date are presented.

METHOD. Four subjects were asked to perform low, medium, and high difficulty levels of a visual counting task while eye movements were recorded using the same methodology reported previously in experiment 3A. In addition, the same microcomputer was used to administer the task, but the microprocessor was reprogrammed to present a series of three dark rectangles (1 cm X 2 cm) on the face of a LCD screen. The rectangles were arrayed horizontally in three channels (left, center, and right) with the left and right rectangles located ten degrees to each side of the central one. The screen was located 18 inches in front of the subject's bite bar. Each rectangle was presented for one second and their order of occurrence was aperiodic with the average rate of occurrence being .2 Hz. Under the three counting conditions the subjects 1) counted each occurrence of the left rectangle and depressed a key after each fourth occurrence, 2) counted the occurrence of each left and middle rectangle and depressed different keys after the fourth occurrence of each one, and 3) counted the occurrence of each left, middle, and right rectangle and depressed different keys after the fourth occurrence of each. Fixation, alternating fixation, and free-viewing control conditions were run as described previously in experiment 3A.

RESULTS. Measures of rectangle counting performance and normalized saccade length were computed for each condition. The mean saccade length and counting performance scores have been presented in Figure 4 for each counting condition. Although these data have not yet been submitted to analyses of variance, it appears in the figure that decreasing saccade length was associated with increases in task difficulty.

DISCUSSION. Although the results are preliminary, these data indicate that the saccade length index of taskload is valid under conditions of visual channel monitoring. Thus, it appears as though the SLIT technique may be generalized to many visual performance tasks which do not require precise fixation or tracking.

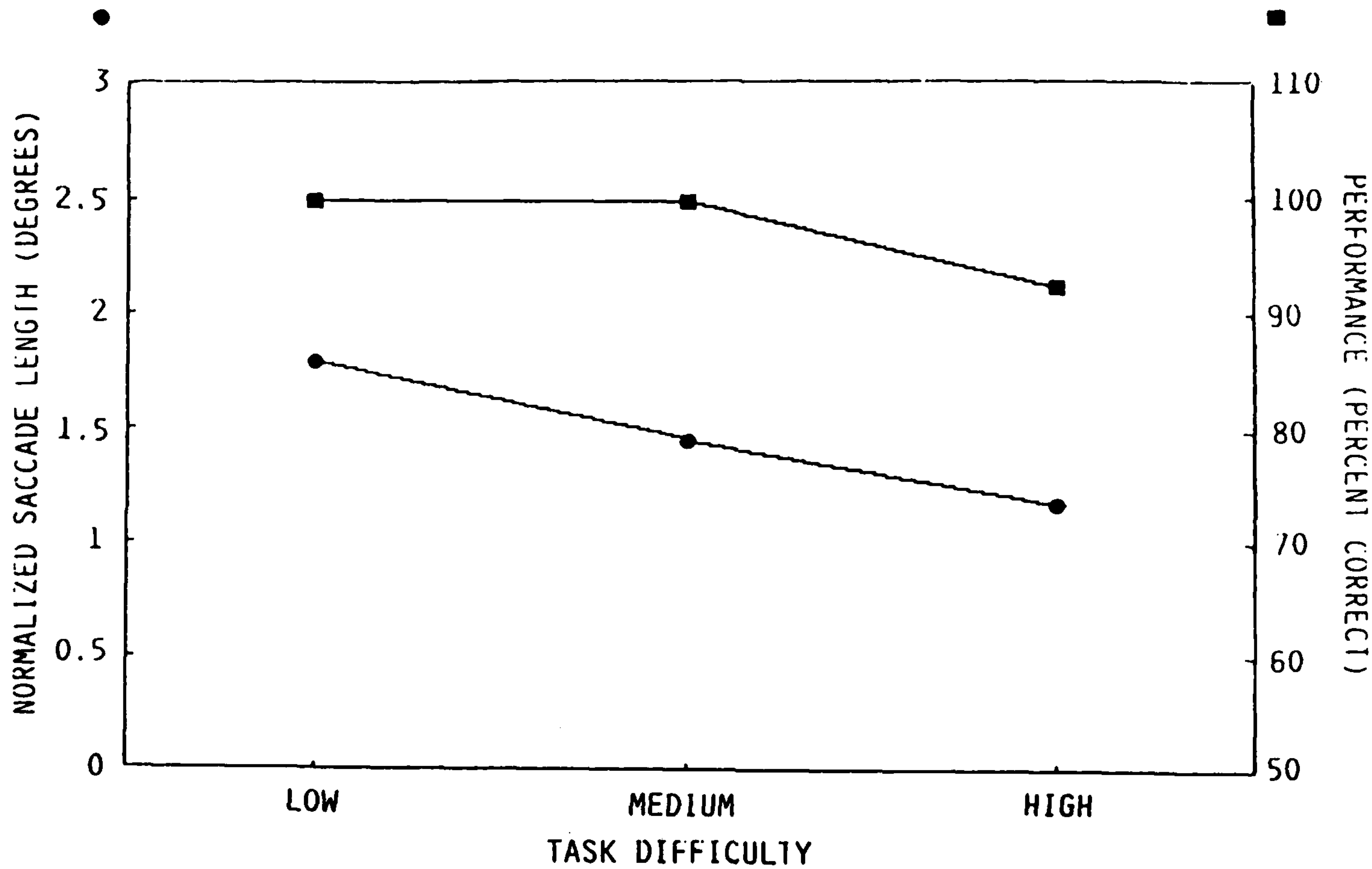


**Figure 4. Mean normalized saccade length and visual counting performance scores (percent correct) under low, medium, and high task difficulty levels.**

## SECTION III

## RESEARCH EFFORT: YEAR 2

Research performed in year 2 will consist of the proposed experiments (experiments 4 to 6) and an additional unplanned experiment (experiment 7). These are described below.

### EXPERIMENT 4: TWO-DIMENSIONAL EYE MOVEMENT RECORDING

RATIONALE. Since the majority of eye movements occur in the horizontal plane during free-viewing, we measured eye movements in that plane only in our work to date. However, we recognize that there are physiologic, anatomic, and behavioral differences between the oculomotor control movements responsible for vertical and horizontal eye movements (Guedry & Benson, 1971; Benson & Guedry, 1970). It is possible that the inclusion of vertical as well as horizontal eye movements could result in a more sensitive SLIT technique. Thus in this experiment we will examine saccade length scores under three different workloads using vertical, horizontal, and combined eye movement inputs.

METHOD. Twenty subjects will be paid $10.00 to perform three pretest practice runs (low, medium, and high difficulty task conditions), three control conditions (fixation, alternating fixation, and free-viewing) and three experimental conditions (low, medium, and high difficulty tone counting) while eye movement (vertical, horizontal, and vertical plus horizontal) measurements are made. These data will allow us to determine whether two dimensional eye movement recording offers significant improvement in saccade length sensitivity to workload.

PROGRESS. As originally planned, software was written in year one to permit the horizontal and vertical eye movement recordings proposed above. Preliminary testing has been conducted to test the calibration procedures and software. Experiments 4 will begin immediately into the second year of the contract, as scheduled.

### EXPERIMENT 5. THE EFFECTS OF EXCLUDING EYE BLINKS FROM SLIT MEASUREMENTS.

RATIONALE. The procedures employed in Phase I and thus far in Phase II do not permit the exclusion of eye blink artifacts. In this experiment, we will use horizontal EOG recordings from both eyes so that eye blinks are easily detected and we will employ artifact rejection programs to exclude these signals from the eye movement recordings. This approach will allow us to assess the degree to which our original results were influenced by eye blinks, and to ascertain the degree to which SLIT sensitivity may be improved by such exclusions.

METHOD. Twenty subjects will be paid $10.00 for a single session in which they will perform all of the conditions outlined in experiment 4. Only horizontal EOG channels will be used. Surface electrodes placed at the outer canthi (reference) and the nasion (active) will allow eye movement recordings (of opposite polarity) for each eye. With this arrangement, eye blinks will give rise to signals with the same polarity. Computer programs will digitize 500 msec epochs of EOG and store that information in a buffer. The buffered signals will be analyzed for eye blinks and rejected if present. Eye blink free epochs will be passed on to the subsequent stages of the SLIT apparatus. Comparisons with and without eye blinks will be made.

PROGRESS. The software to reject eye blink artifacts is currently being written. We expect that experiment 5 will begin, as originally proposed, in about the third month of the second year.

EXPERIMENT 6: A COMPARISON OF SLIT TO OTHER PHYSIOLOGICAL MEASURES OF AROUSAL AND WORKLOAD.

RATIONALE. The review in the introduction showed that many studies in the scientific literature have found positive relationships between physiological indicants and performance. It was also pointed out that these measures have limitations; that is, they rarely account for a large proportion of the variance in the criterion, and invariably require sampling over large periods of time and even over subjects, and may require triggering through an input pathway in order to elicit the responses. In order to compare SLIT to other physiological indices, we proposed a "bake-off" of several measures where the tests and measures are reported in terms of unique and common variance-accounted-for.

METHOD. As originally stated in the proposal, the exact conditions of this experiment will be specified after consultation with the COTR. The task can be one in which we have familiarity (tone counting) or, it may be possible to use one with more obvious relevance to the military. Additionally, we would advocate the incorporation of an existing biopack system already known to be under development by USAF and USA laboratories. Moreover, it may make practical sense to undertake this experiment in a situation where SLIT is added "piggyback" to an ongoing USAF study

EXPERIMENT 7 (UNPLANNED). MEASUREMENT OF SLIT WITH A VISUAL FORCING FUNCTION

RATIONALE. The experiments carried out to date indicate that the eyes movements are restricted in range when subjects are performing tasks involving high degrees of mental workload. So far, none of the tasks employed have required eye movements. In the present study will examine the relationship between saccade length and workload while subjects view a field of drifting stripes. This stimulus normally causes optokinetic nystagmus (OKN). One of two outcomes is hypothesized for this situation: 1) OKN will be unaffected during the task and saccade length will no longer be related to the level of task complexity, or 2) OKN will be inhibited and the degree of inhibition will increase with workload. If the first hypothesis is confirmed it will imply that the SLIT technique is not useful in situations which require reflexive eye movements. If the second hypothesis is confirmed, it will imply that the cognitive load results in a reduction of saccade length even in the presence of provocative stimulation.

METHOD. Twenty subjects will be paid $10.00 to perform 1) three pretest practice runs on the tone counting task at the low, medium, and high difficulty levels, 2) the free-viewing, fixation, and alternate fixation control conditions, and 3) three experimental conditions in which subjects perform the tone counting task at the three levels of difficulty while eye movements are recorded. During the experimental conditions, subjects will view a field of vertical stripes which appear to drift either left or right during the three levels of tone counting. The results of this research will allow us to determine whether saccade length is a sensitive measure of workload during optokinetic stimulation.

## SECTION IV

## DEVELOPMENT EFFORT

We proposed to develop a portable, ruggedized, and versatile SLIT system in our Orlando facility. Development will take cognizance of the experimental results and, where practical, incorporate features found beneficial (e.g., two-dimensional eye movement recording, eye blink rejection). Development issues concern: computer selection, interfaces, and software.

### COMPUTER SELECTION

We purchased a PC's LIMITED 12 Mhz 286 microcomputer as the main processor of the SLIT system. The computer has 2.5 megabyte memory, 72 megabyte hard disk, 1.2 megabyte and 360 kilobyte floppy disk drives and thus has sufficient computational power for the SLIT system. In year two, we will purchase a portable microcomputer which will enable SLIT to be transportable. There are many off-the-shelf portable computers currently available which possess sufficient computational power and we will evaluate them for their processor speed, memory capacities, display resolution, and bus expansion. This will permit the SLIT system to achieve its portable status and to be tested in operational environments for the field testing part of the Phase II effort.

### INTERFACES

Interface issues concern the development of a head mounted recording system, easily applied surface electrodes, reliable amplification, and a analog-to-digital converter.

- We have experimented with both silver/silver chloride and gold surface electrodes and with different methods of attaching them. Although we are obtaining suitable recordings with these, we are still testing best methods of attachment and placement in order to reduce noise in the system. Currently, we favor 4 mm silver/silver chloride electrodes for EOG recordings. Once optimal electrode type and placements have been selected, an apparatus to permit easy mounting of electrodes will be developed in our Orlando Facility.

- We are using a reliable amplifier featuring characteristics suitable for EOG recording

- We purchased a Metrobyte Dash 16-F 8 channel (bipolar) analog-to-digital converter capable of sampling up to 100,000 samples per second to serve as the SLIT interface to the microprocessor.

### SOFTWARE

We have written software for the SLIT system to permit storage of analog-to-digital conversions of eye movement signals (including two-dimensional recording), data archiving, and immediate play-back. In addition, software has been written to take a novice SLIT system user through calibration techniques and actual use of the system. Software is currently being developed for automatic scoring of saccade length.

## SECTION V

## FIELD TESTING

The purpose of this effort is to synthesize the scientific findings on eye movement based indicants of attention, arousal, and workload into a meta-analysis (Green and Hall, 1984). This effort will accomplish two purposes. First, it will serve to delineate fundamental issues in the workload literature. Second, it will prepare for the last six months of Phase II where it will be necessary to validate the SLIT system against operational systems performance. A meta-analysis of the literature on indicants of workload in operational settings will be used to formalize field research to validate the SLIT metric.

### LITERATURE REVIEW/ META-ANALYSIS

A central question for any indicant of workload is its dependence on task characteristics. In other words, to what extent is validity task specific or specific to levels of a task? For example, eye blinks have been found to covary with task difficulty for perceptual tasks (Kim et al, 1984) but not for verbal tasks (Wilson, McCloskey, & Davis, 1986). This question is parallel to the question Schmidt and Hunter (Schmidt & Hunter, 1977; Schmidt, Hunter, Pearlman, & Shane, 1979) posed about validity generalization of tests used in personnel selection and can be answered in the same "meta-analytic" approach. Schmidt and colleagues found that when validity coefficients are corrected for artifactual variances (e.g., criterion reliabilities, test reliabilities, range restrictions), selection tests have more generality than previously held. The same meta-analytic (Green & Hall, 1984) approach will be used to evaluate the validity of eye movement based indicants of workload.

In the Phase II proposal we stated that we intended to enlist the services of two consultants early in the first year in order to prepare us for the field evaluation work. One of the consultants, Dr. Bruno Breitmeyer, was to cull studies where physiological indicants had been used in the assessment of operationally related performance and where reliability estimates were available for the indicants and for the criterion studied. The second consultant, Dr. Marshall B. Jones, was to conduct the meta-analysis and together with Dr. Kennedy and other Essex scientists he was to synthesize the literature into a report.

At Dr. Breitmeyer's suggestion stemming from the size of the literature (which is larger than we thought), we have substituted Ph.D. level readers to go into the literature and more thoroughly integrate the material before we hand it over to Dr. Jones for the meta-analysis. The original plan was to conduct the literature cull through the first year and begin the meta-analysis in the latter part of year 1 and continue it through year 2. In view of the changes that have been made, the meta-analysis will begin in the second month of the second year of the contract and continue through to the end of the contract period. As originally proposed, the meta-analysis will guide the field testing and will culminate in a report.

FIELD STUDY

During the final six months of Phase II, we will conduct field testing of the SLIT system in three areas of application. We consider that the availability of information from the meta-analysis will permit us to transition our laboratory techniques successfully into the operational environment. Field testing will permit us to determine the validity of the technique and the generality of its application. It will also form the basis for our later attempts to obtain venture capital for the production and marketing of the final product. In the field testing, we expect that one application will be laboratory based -- perhaps a flight simulator, and at least one would be in an operational system-- we hope an aircraft. The third application is likely to be a large communication (or C cubed) system.

## SECTION VI

## SUMMARY OF PROGRESS/APPLICATIONS

### SUMMARY OF PROGRESS

We proposed to conduct experiments 1, 2, and 3 by the end of the first year and to complete the remainder of the experiments during the second year. Although experiment 1 was not performed, experiments 2 and 3 have been conducted. In addition, to help clarify the results of experiment 3, an additional study was performed (experiment 3B). Moreover, a more promising alternative to experiment 1 was proposed (experiment 7) which will be conducted during the second year. Thus, the research effort is largely on schedule.

The development effort is also on schedule; as planned, software development began during the second six months of year one and will continue through the first six months of year two. Software has been written to permit immediate start up of experiment 4 (two-dimensional eye movement recording), data archiving, and data play back. In addition, progress has been made on software for exclusion of eye blink artifacts (experiment 5) and for automated data collection and analyses. Hardware for the SLIT system has also been purchased as planned.

The last effort, field testing, has been delayed somewhat. The literature cull was to continue through the first year with the meta-analysis beginning in year one and continuing until the planning stage of the field testing. In view of the changes described earlier, the literature review will continue through the second month of year two with the meta-analysis continuing through to the end of year two. As proposed, the meta-analysis will serve to guide the field testing which is still planned for the last six months of the contract.

### APPLICATIONS

A nonintrusive indicant of attention during monitoring and control tasks has obvious biocybernetic relevance, particularly in dynamic environments. Further, an index which provides objective assessment of task difficulty will permit test and evaluation of systems for human use as well as improve the basis on which they are designed. These uses apply equally for DoD and the private sector. Such a technique can also be employed to measure pilot performance and, through feedback, permit improved weapon systems operations. These metrics may be used to determine individual differences in capability and thereby aid in personnel selection and classification. The possible commercial applications of SLIT for the private sector have been expanded below:

- SLIT may be used as an independent assessment of an individual's attention which may wane with time on task or due to other factors. Such a relationship might be of interest during quality control on assembly lines, or on long truck routes where impending sleepiness may signal disaster, or in remote emplacements where security displays are monitored.

- Since SLIT size appears to be proportional to workload, displays and workstations could be evaluated objectively and compared for difficulty level. Different display options could be compared. The task demands of systems could then be related to design criteria and human engineering standards.

- Preliminary evidence suggests that individual differences in saccade length may be sufficiently reliable so that they should be studied for stability over time and then examined for relations to equipment and operator aptitude tradeoffs in systems designs.

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## APPENDIX A

### LIST OF PROFESSIONAL PERSONNEL ASSOCIATED WITH THE RESEARCH EFFORT
(in alphabetical order)

#### BRUNO BREITMEYER

| | |
|---|---|
| Ph.D. | Psychology, Stanford University, Palo Alto, CA, 1971 |
| B.A. | Mathematics, University of Illinois, Urbana, IL, 1968 |

#### JENNIFER E. FOWLKES

| | |
|---|---|
| Ph.D. | Experimental Psychology, University of Georgia, Athens, GA Expected May 1988 |
| M.S. | By-Passed, University of Georgia, 1985 |
| B.A. | Psychology, Appalachian State University, Boone, NC |

#### MARSHALL B. JONES

| | |
|---|---|
| Ph.D. | Psychology, University of California at Los Angeles, 1953 |
| B.A. | Philosophy, Yale University, 1949 |

#### ROBERT S. KENNEDY

| | |
|---|---|
| Ph.D. | Experimental Psychology, University of Rochester, Rochester, New York, 1972. |
| M.A. | Experimental Psychology, Fordham University, New York, New York, 1959. |
| B.A. | English & Philosophy, Iona College, New Rochelle, New York, 1957. |

#### JAMES E. MAY

| | |
|---|---|
| Ph.D. | Psychology, University of Houston, Texas, 1969 |
| M.S. | Psychology, University of Southern Mississippi, 1966 |
| B.A. | Psychology, Louisiana State University, 1965 |

#### KEVIN SCHNITZIUS

| | |
|---|---|
| B.S. | Computer Science, University of Central Florida, Expected May 1988. |

#### MARTIN G. SMITH

| | |
|---|---|
| B.A. | Psychology, University of Central Florida, 1975 |

## APPENDIX B

### MANUSCRIPTS PLANNED FOR LATER SUBMISSIOM

Kennedy, R. S., May, J. G, Jones, M. B., & Fowlkes, J. E. (1988). Review of eye movement indicants of mental workload. Manuscript to be prepared and submitted to Human Factors.

Kennedy, R. S., May, J. G., Smith, M. G., Schnitzius, K., & Fowlkes, J. E. (1988). Saccade length as an index of mental workload. Manuscript to be prepared and submitted to Human Factors.

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