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Age and vigilance: The effects of event rate and task pacing

Jack D. Mohney

"AGE AND VIGILANCE: THE EFFECTS OF EVENT RATE AND TASK PACING"

A Thesis

Presented to the

Faculty of

California State

University, San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

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In

Psychology

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ABSTRACT

The effects of age, background event rate, and pacing (self versus yoked) on vigilance performance were examined in this study. Thirty-six male and twelve female volunteers ages 18 to 76 responded during the one hour time on task (TOT) to infrequent critical stimuli presented on a three-block, lighted bar display. Background events consisted of two blocks flashing on and off while the critical signals were all three lights flashing on. Subjects responded to the critical signals by pressing a telegraph key with the index finger of their preferred hand. Two subjects participated during each session. The background event rate (BER) for both subjects was controlled by one subject, a condition unknown to either subject. Reaction times (RTs), false alarms (FAs), and missed critical signals were manually recorded by the experimenter while event rate data were recorded by computer. ANOVAs were performed on both RT and BER data in addition to trend analysis and signal detection theory analysis. Results indicated that RTs increased with age and TOT, self-pacing dramatically improved miss and FA performance, older subjects reduced BER, and younger subjects' performance benefited more from self pacing during TOT. These can be

interpreted as criteria for human factors engineers when designing systems that incorporate older people to perform sustained attention.

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INTRODUCTION

American corporate and governmental organizations are faced with a phenomenon of major significance. The population in the United States is growing older and is projected to continue to age dramatically past the turn of the century. Older people seem destined to become a larger and more influential segment of American working society. For example, in 1900, approximately 6 percent of the U.S. population was over age 60 with 4 percent over age 65. In 1981, 15 percent of the U.S. population was over age 60, with 10 percent over age 65. By the year 2020, it is projected that 22 percent will be over age 60 with 15 percent over age 65 (Botwinick, 1981). This also coincides with the projection that the total number of younger workers entering the labor force will decrease sharply during the next two decades (Copperman and Keast, 1983). These demographic trends will directly affect the composition of the labor force. Although the percentage of women working may continue to rise, most women who are interested and available to work are in all likelihood already working. The bulk, (though not all) of the younger male labor force population is also employed. In addition, there are ever-increasing numbers of handicapped also joining the working ranks. Thus, the most readily available worker pool will soon consist of persons in the older age groups.

Human Factors Implications of Aging

Aging is a natural process that manifests itself in changing environmental interactions. Kochnar (1979) states that aging is a multidimensional process in which people age at differing rates. For example, a person may be functionally younger or older than the chronological age typically exhibited by his or her contemporaries (cohorts). In addition, using chronological age as a determining factor for employment has recently come under increasing scrutiny and criticism, especially in the highly visible area of forced retirement of airline pilots. The United States Supreme Court recently upheld a lower court ruling which found Trans World Airlines guilty of age discrimination by not allowing pilots to become flight engineers and forcing them to retire at age 60. A new employer viewpoint in job assessment may thus be in order.

With these factors in mind, it would seem that the human factors engineer in the year 2000 and beyond will be dealing with problems quite different from those of today. In the past decade, there has been a rapid increase in the exploration of applications of human factors knowledge and technology to aging and the aged. The scope of human factors has broadened and the concept "engineering for human use" has become more differentiated. With the aging of the population, it seems that it may behoove human factors specialists to take a progressive attitude when designing environments and machinery rather than designing for a fixed-age range population (as many present corporate and military acquisition philosophies now practice). Work designs that enhance the capabilities of older people and assist in maintaining satisfactory performance could be developed and implemented. Industrial applications have also become increasingly apparent, especially in the fields of inspection, vehicular and workstation operation, and civilian air-traffic control. In addition to the widespread potential military and civilian application of this research philosophy, space applications are also obvious. With the increase in space experimentation and industrialization brought on by the convenient space shuttle, there have already been older, experienced engineers as crew members. Satisfactory performance by all personnel, regardless of age, is mandatory in the hostile environment of space.

Along with the military and civilian human factors engineer, the perceptive employer, government or otherwise, would be interested in how this changing demographic composition will affect performance of the corporation or agency; i.e., how does the older work force affect product quality, quantity, or reliability? How can the older work force respond to compressed time schedules or changing workloads? How can the older work force adapt to the evolving role of computers? These and many more management issues must be answered correctly if personnel policy is to be congruent with corporate or agency goals. An important and logical prerequisite for designing valid management philosophies and policy is to have a general understanding of the psychological characteristics of the older worker. It is assumed that most interested agencies place strong emphasis on the psychological aspects of the worker as well as pay, physical health, additional benefits, and other issues. It is also assumed that a major corporate concern associated with the projected aging of the work force is sustained work performance.

Evolving Human-Machine Interface

The aging work force must cope with the changing phenomenon of expanding machine complexity. As devices and equipment have become more complicated and more automated, the human operator's active controller role has changed to a manager, monitor, and director. Sheridan (1970) describes this as representing a shift from active to "supervisory" control. In today's highly automated systems, critical events or conditions may be discovered by instruments, and the necessary actions and processes may be executed by machines with speed and accuracy far beyond human capabilities. Nevertheless, countless deteriorating human performance and substandard monitoring operations still occur during tasks of prolonged duration when these automated systems fail or some out-of-tolerance but rare condition happens. The incident at the Three Mile Island nuclear power plant and the recent fatal mishap of the Air Force B1-A test aircraft (whose pilot was 55 years old) are two extremely visible American examples of this occurrence. Notwithstanding the public inquiry and outcry, the possible outcome of these incongruent human-machine interfaces could have resulted in the loss of many lives, (not to mention the millions of dollars in law suits). The Soviet Chernobyl nuclear accident is a vivid example of a rare occurrence happening, critical signals being ignored, and actions being untimely or incorrect. The results were disasterous; lives were lost, the environment dangerously polluted, and neighboring nations psychologically and politically shaken. Moreover, the exploration of space will only compound the problem. Highly automated spacecraft must be monitored over extended periods of time. With increased exploration, these periods will certainly expand, and so will the increased need for sustained human attention.

The Vigilance Decrement

To understand why performance levels decrease over prolonged time, an understanding of the processes involved is needed. As defined by Mackworth (1957), the pioneer in vigilance research after World War II, vigilance (synonymous with sustained attention) is "a state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment. . ." over a sustained period of time (pp. 389-390). The ability of a person to attend and respond to infrequent critical stimuli over this sustained period of time typically declines over a tasking session. This phenomenon is known as the vigilance decrement. Past research on this decrement has centered on understanding why this decrement occurs. There have been doubts cast as to the validity of this research (Nachreiner, 1977). These doubts coalesce around the premise that contemporary vigilance research fails to replicate operational and industrial scenarios properly. This poor modeling is responsible for decrements that are due to laboratory-specific factors and not vigilance-specific factors. However, there is substantial evidence that the vigilance decrement is present during operational scenarios such as industrial inspection and that past laboratory research has broadened the present understanding of vigilance phenomena. In Chapman and Sinclair's (1975) study, detection rates by inspectors of substandard chicken carcasses were low (60%) and their rates decreased over time. Harris and Chaney (1969) found 50% inspection rates for experienced electronic inspectors. Finally, Drury and Sinclair (1983) found similar results with metal tube inspectors. Their correct response rate dropped over the task duration, resulting in an overall correct response rate of 60% with a 20% false alarm rate. The findings of these operational scenarios hardly support the position that decrements occur only in the laboratory. It would thus seem that further research is warranted, for without it, the human factors engineer cannot manipulate or design improved work environments for an enhanced systems performance level during extended and tedious tasks.

Signal Detection Theory

Fortunately for current human factors specialists, about thirty years ago, psychologists and electrical engineers pooled their talents to systematize theories and techniques to combine the mathematical and human capabilities to detect signals into an integrated theory. Signal detection theory, or TSD, as it came to be known, has since had a major impact on human factors engineering and has been utilized on computers, quality control, athletics, crime analysis, and many other human-machine (system) interactions (Hutchinson, 1981). TSD allows theorists to understand mechanisms of the senses and the complex processes of signal detection, discrimination, and recognition.

Signal detection theory also facilitates measurement and analysis of a variety of human performance attributes. Its fundamental premise is quite basic. A variable is input into the detection system (such as a target on an air traffic controller's radar screen) and undergoes various computations (in this case, in the operator's brain) based on data already stored in the system's memory. This computed figure is then compared with the criterion figure in memory and a response based on that comparison is initiated. If the computed figure exceeds the stored criterion figure, a particular response is made; if the computed figure is less than the stored criterion figure, another response is made. These responses are easily measurable and quantifiable, allowing comprehensive statistical analyses.

In fact, these system performance analyses can be plotted on a figure called the Receiver Operating Characteristic, (ROC). In a ROC, the operator's perceptual sensitivity (d') is calculated and plotted to summarize the behavior of the observer. It shows the hit and false alarm rates for the calculated d' and the possible internal response bias, (β), that may influence the observer's willingness to act upon a detected critical signal; considerations extremely important to the human factors engineer.

Signal detection theory lends itself to analysis of vigilance phenomena due to the response characteristics inherent in such occurrences, and can be used to predict performance for a task situation. Applied properly, it can go far in assisting the human factors engineer in making key system design decisions. However, this theory does have its critics. Vickers and Leary (1983) progressively lowered the critical signal rate during a vigilance task, thus decreasing the signal/noise ratio. Over time, the observers became less conservative in their response bias, rather than more conservative as contemporary TSD suggests. In addition, the use of TSD measures for all vigilance scenarios has been criticized (Warm and Berch, 1985) because of nonindependent d' and measures (Long and Wang, 1981). Nevertheless, while TSD theory must be cautiously applied to vigilance research, it does provide a valuable tool in its assessment of vigilance phenomena (Davies and Parasuraman, 1982).

Research Designs

Research on vigilance of the aged, as other-age related research, has traditionally employed one of two research designs, the cross-sectional or the longitudinal. The former provides information about present age differences while the latter, also known as a follow-up design, yields data on within-subject age changes. Most of the age and vigilance studies that have investigated performance differences of younger and older adults have been cross-sectional in nature. However, according to Palmore, (1978), this cross-sectional research cannot identify causal factors associated with age-related differences. Palmore also states that it is inappropriate in many cases to draw age-based conclusions because these studies do not permit the isolation of age or period (cohort) effects. Nevertheless, cross-sectional studies do have advantages beyond the obvious ones of time and economy. Describing cross-sectional age differences in terms of the systems (human-machine) approach familiar to all human factors engineers provides a novel and "real-time" process to describe these data because it focuses attention on what present measures must be taken in a standard situation involving people of currently different ages to achieve a desired outcome. In addition, cross-sectional studies allow age-related differences in performance to be described by isoperformance functions (Fozard, 1981). An isoperformance function first specifies the levels of performance desired. The result would then be a specified performance curve at differing levels of task difficulty, and, theoretically, age. Specifying the conditions in which persons of present differing ages perform at the same level constitutes an isoperformance age function, ideal for vigilance studies in which many independent variables can be manipulated under many differing conditions.

Past Research Findings

Regardless of the method controversy, reliable age differences in vigilance performance have been reported, with older individuals consistently performing less well than younger individuals. Davies and Davies (1975) found that correct detections declined with age while the actual experimenter-controlled false alarm rate remainded about the same, suggesting a reduction in stimulus sensitivity (d') with increasing age. Research done by Czaja and Drury (1981) on age and pre-inspection training observed that increasing age reduces performance. However, while pretraining had a significant positive impact on total performance, it did not reduce individual age differences. In Harkin's (1974) study, older people had fewer correct detections, more false alarms, longer reaction time latencies, and a larger performance decline during an odd-even vigilance task. This evidence suggests that older individuals should exhibit lower d' and less cautious β and that performance differences between older and younger age groups are more likely to be found in tasks in which the event rate is high. However, there are no studies which have systematically examined the effects of event rate or pacing on age differences in vigilance (Parasuraman, 1984).

Background Event Rate

One of the most cogent factors influencing vigilance performance is the event or information presentation rate of the task. A study by Saito and Tanaka (1977) of industrial inspectors working in a bottling plant found inspection efficiency was markedly improved by reducing the inspection rate of bottles (event rate) from 300 to less than 200 bottles per minute. Significant performance decrements were also observed after only a short time at work when the event rate was higher. Parasuraman (1979), in a review of the effects on event rate on a number of laboratory vigilance tasks, found that decrements in perceptual sensitivity (d') were unlikely if the event rate was less than 24 events per minute. During a monitoring task, Weiner (1977) found that a stimulus presentation rate of 12 per minute had a significantly lower performance decline as compared to a stimulus rate of 60 per minute. Monty (1973) concluded that performance tends to decline if input rates were higher than 60 events per minute. All studies found decreased event rate produced lower overall vigilance decrements. These results have also been buttressed by a number of studies (Krulewitz et al., 1975; Parasuraman and Davies, 1976; Warm et al., 1976). However, allowing industrial inspectors more time to inspect individual items may increase labor and operating costs significantly (Chapman and Sinclair, 1975;

Drury, 1978), and corporate management must balance these costs against improved inspector accuracy.

On the other hand, if a person has too little to do while performing a task over extended time, boredom may set in and detract from task attention, lowering the performance level. In Weiner's (1984) study, it was found that increasing task load during a monitoring/tracking vigilance task facilitated total vigilance performance. This would suggest an inverted-U function (which human-machine engineers are fond of) for performance versus arousal level. An optimal level of arousal may therefore be present for sustained attention with a possible relation to age.

Pacing and Yoking

It is generally believed that a self-paced operator will be more efficient and will be less likely to show a performance decrement. Wilkinson (1961) observed the number of correct detections for two experimenter-paced tasks (one regular interval, the other irregular) to be lower than that of a subject-paced task. However, the total decrement for the subject-paced task was higher than that of either experimenter-paced tasks. Colquhoun (1962) found equivalent decrements in both experimenter-paced (essentially yoked) and subject-paced tasks during a panel inspection task. Eskew and Riche (1984) investigated whether personality variables and pacing were significant to vigilance performance. They found that response bias (β) may be a prime factor in performance decrements rather than d', with an interaction of locus of control and pacing. They also concluded that merely slowing a task did not necessarily affect performance, but pacing (or lack of) did. In addition, Drury, Morawski, and Tsao (1979) found that subjects chose their own optimal search times when inspecting computer printouts; whereas, experimenter-paced (yoked) inspection times yielded larger performance decrements. However, the systematic effects of yoking the task speed of one experimental subject to another subject are not clear in the vigilance literature.

In a review of past literature on aging, Welford (1981) hypothesized that lower performance for older people may be due to attention being concentrated on the responding aspect of the task. This compares to the widely-held notion that overly-rapid pacing is to blame. In the absence of evidence to provide insight that self-pacing produces <u>increased</u> vigilance decrements, allowing self-paced work may be beneficial as it tends to reduce worker fatigue and boredom (Grandjean, 1979; McFarling and Heimstra, 1975).

<u>Spatial Complexity and Uncertainty</u>

Most of the evidence for the vigilance decrement has been obtained in relatively simple tasks with single sources of signals. The tasks used in most studies vary so widely that it is not possible to classify individual tasks along a dimension of task complexity. Nevertheless, the weight of the evidence suggests that task complexity does not affect the "pure" vigilance decrement per se. However, Parasuraman (1984) concludes that d' and β are significantly influenced by task complexity. In addition, age-related effects are not addressed in a majority of these vigilance studies. Also, the temporal uncertainty associated with the appearance of a signal is a major attribute of "pure" vigilance tasks. This is not true of search tasks, in which spatial uncertainty is the major factor of interest. Nonetheless, Thackray and Touchstone (1980) found that reaction time to critical signals increased over a two-hour period of complex monitoring.

Search can also harm vigilance performance, which may suffer for two reasons. First, although vigilance performance may not decline, the level of performance with a display requiring extensive search may be unacceptably low. Second, although the overall performance may be acceptable, the detection of particular items in the display, particularly those on the periphery of vision, or those carrying low-value information, may deteriorate if the search requirement is increased. Schoonard, Gould, and Miller (1973) found that inspectors tended not to fixate on the edges of slides of integrated circuits and thus tended to miss faults that occurred at these locations. These studies show that targets presented at peripheral parts of displays are less well detected than more centrally presented targets in prolonged search tasks.

Study Limitations, Assumptions, and Threats to Internal and External Validity

This study attempted to tie the abilities of older people to vigilance-type tasks that are becoming more prevalent in the ever evolving human-machine interaction. However, as with all experiments of this type, this study was characterized by various limitations and assumptions. Together, these can influence its capability to be both internally and externally valid.

First, the generalizability of this study may be degraded by the extensive use of both younger and older subjects with military experience. Due to physiological screening and structured training of this particular cohort, the applicability of this study's findings to the general population may be questioned. This cohort effect would also tend to minimize any group differences during a vigilance task. Second, even though the time of day each trial was conducted was tightly controlled, the varying periods of maximum alertness for each individual quite possibly affected their performances by varying d'. Random assignment to control groups would minimize this effect.

Finally, the effects of the practice session may adversely affect validity by creating a pretesting subject bias. However, it can be argued that most operational scenarios experience the same influence.

Numerous assumptions were also necessary to accomplish this study. First, it was assumed that any physical limitations inherent in any particular population would not affect performance. For example, the effects of visual limitations on motor dexterity were controlled by the large and simple displays with a high luminance contrast ratio and the simple, non strenuous response of key pressing. Second, it was assumed that all experimental effects were due to psychophysical phenomena, not to any gender or cohort effects. Any of these effects that may be present would be minimized by the experimental paradigm itself and the specific experimental design employed in this particular study.

Performance Measures

It is critical to take adequate and valid experimental data when conducting research on sustained attention. Therefore, multiple measures reinforce any conclusions that are obtained during the research. This study used five performance measures to analyze the complex behavior of vigilance to facilitate confident conclusions of this phenomenon.

Sensitivity and Response Bias. The dependent variables of the vigilance decrement can be measured using critical signal detection rates, false alarm rates, reaction times, and other measures. These measures shed light on the effects of sensitivity, d', and response bias, β . A decrement in d' would indicate the lessening with which the subject can distinguish critical signals from background signal noise. A decrement in β would indicate the lessening of the operator's propensity towards responding when a critical signal is observed.

Response Latency. Reaction time can be measured from the onset of the critical signal to the moment the subject physically responds if the signal is detected. If this latency extends to the next presentation of a non-critical signal, the critical signal is classified as a complete miss. For purposes of analyses, the total task time is blocked in equal time periods. If response latencies expand or become more variable for each succeeding block, a vigilance decrement can be inferred.

Correct Detection/Miss Rate. Correct detection/miss rates can also be used to measure the vigilance decrement. As with response latency, the task is broken down into equal periods. If the number of correct detections decrease, a decrement can be said to exist.

False Alarm Rate. False alarms can be measured and used in conjunction with correct detections using the same time-blocking technique. While none of the above measures alone can identify decrements in d' or β, together they can provide strong evidence for such findings.

Background Event Rate (BER). Finally, the background event rate the subject chooses can be measured to indicate the level of attention in which the subject is comfortable. The same time-blocking technique can be used to find where the subject changes the event rate during the course of the vigilance task. This measure would also lend support to the concept of subjects attempting to compensate for d' sensitivity decrements by decreasing total background event rate.

Hypotheses

The present study was designed to investigate the influence of pacing, age, and stimulus background event rate on performance during a vigilance task. Based on past research, it was postulated that these factors will have varying effects on the performance of individuals during an extended task. Specifically, the following hypotheses were tested:

Main Effects

I. Age

a) Older Ss will have longer response latencies than younger Ss.

b) Older Ss will miss fewer critical signals and have more false alarms than younger Ss.

II. Pacing

a) Yoked Ss will have longer response latencies than self-paced Ss.

b) Yoked Ss will miss more critical signals and have more false alarms than younger Ss.

III. Time on Task

a) All Ss will have longer response latencies as time on task increases.

b) All Ss will miss more critical signals and have more false alarms as time on task increases.

Interactions

IV. Age x Pacing

a) The response latency difference of older Ss (older self-paced versus older yoked) will be greater than the response latency difference of younger Ss (younger self-paced versus younger yoked). In other words, older Ss' response latencies benefit more from self-pacing.

b) Older Ss' missed critical signals and false alarms benefit more from self-pacing.

V. Age x Time

a) The effect of time on task will increase response latencies for older Ss more than for younger Ss.

b) The effect of time on task will increase missed critical signals and false alarms for older Ss more than for younger Ss.

VI. Age x Background Event Rate (BER)

Older Ss will choose a slower BER than younger Ss.

VII. Time x BER

As time on task increases, BER will decrease for all Ss.

VIII. Age x Pacing x Time

a) As time on task increases, older

self-paced Ss' response latencies benefit more than self-paced younger Ss'.

b) As time on task increases, older self-paced Ss' missed critical signals and false alarms benefit more than self-paced younger Ss".

XII. Age x Pacing x BER

a) Low BERs and self-pacing will produce the largest benefit for older Ss' response latencies.

b) Low BERs and self-pacing will produce the largest benefit for older Ss' missed critical signals and false alarms.

METHOD

Subjects

The Ss for this study were 36 volunteer men and 12 volunteer women ages 18 to 76, divided a priori into two age categories, 18-38 and 53-76. They were a mixture of government service, active duty military, civilian, and civilian retirees. Each subject had at least correctable 20/40 vision and no experience with a prolonged vigilance task situation.

Experimental Design

A four-group, 2 X 2 factorial experimental design was counterbalanced with respect to age and sex. Subjects were randomly assigned to one of 4 groups: younger self-paced with younger yoked (y-y), younger self-paced with older yoked (y-o), older self-paced with younger yoked (o-y), and older self-paced with older yoked (o-o). The independent variables were Ss' age, sex, time on task, and pacing (self versus yoked). The dependent variables were each S's reaction times, false alarms, misses, and background event rates. The second type of data taken from the subject consent forms was demographic information which served to describe the sample for purposes of generalizability and any post-hoc analyses.

Apparatus

The vigilance task environment consisted of two air-conditioned, flourescent-lighted test rooms measuring 3.0 meters high, 3.0 meters wide, and 4.8 meters long, each with a table and armless chair situated at the wall opposite the door. The ambient lighting at the subject's station is diagrammed in Figure 1. All light measurements were taken using a portable Tektronix J-16 Digital Photometer with a Tektronix J-6503 Illuminance Probe.

Each vigilance task display consisted of a 15.2 cm x 7.6 cm x 10.2 cm box with three 4 cm square translucent lighted blocks. The display was located approximately ½ meter from the Ss' eyes, 30° below horizontal line of sight. This corresponds to the recommended limits set forth in Military Standard 1472C for visual display viewing angles. Figure 2 depicts the display and the light analysis. This analysis corresponds to both McCormick's (1982) and Woodson's (1981) recommendations of between 10% and 200% contrast ratio between display and ambient light levels. The lighting consisted of 23%, 47%, and 55% additive contrast ratios for each light, respectively. Both Ss also had a telegraph key situated on each table to register their individual responses to the critical stimuli. Room #1 also contained a control box that allowed S #1 to manipulate the stimulus rate (See Figure 2). Room #2 had no

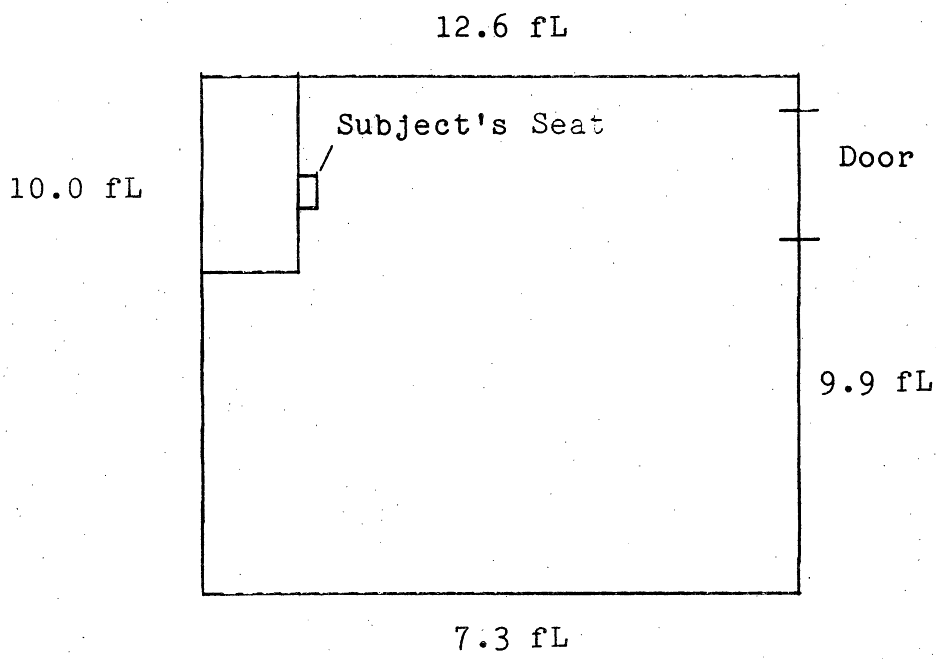
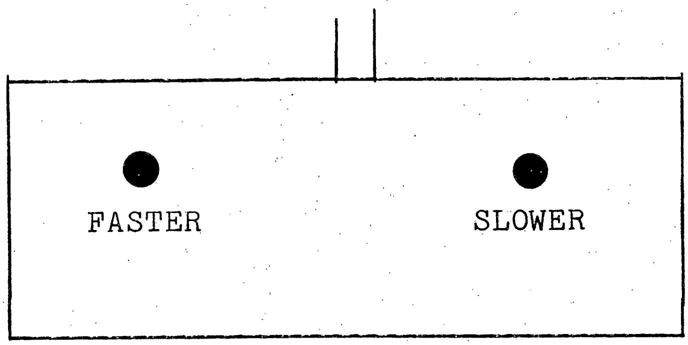
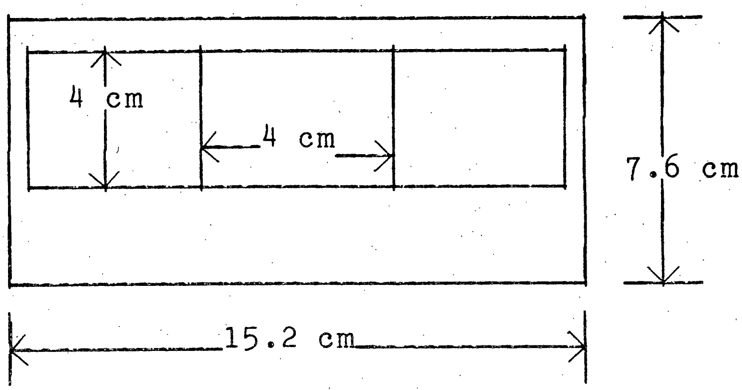


Figure 1. Ambient lighting analysis for both experimental rooms.



Event Rate Control Box



Experimental Display

ILLUMINATION LEVELS AT DISPLAY LIGHT SOURCE

Light # / Location	1	2	3
Source (ftC)	43	54	48
2 Feet (ftC)	13	19	22

Figure 2. Control box configuration, display dimensions, and lighting analysis.

control box and its display was yoked directly to the display in Room #1. By pressing and holding either the Faster or Slower button, S #1 could speed up or slow down the stimulus rate exactly 5% for each presentation.

The controls and displays were timed by a Coulbourn logic network which also visually and auditorily presented the response latencies, misses, and false alarms to only the experimenter. These data were recorded by the experimenter on a standardized data sheet. The logic network process involved a Lablinc output port (Coulbourn Instruments, L62-08) receiving event signals that were boosted to 28 volts by a power driver (Coulbourn Instruments, S61-05) and delivered to both subject displays. The vigilance display consisted of a flashing bar of light. Critical signals were defined as an extension of the lighted bar. When the signal for the third light (the critical signal) was received by the output port, three other occurrences were simultaneously triggered. First, a 100 Hz tone of ½ second duration was gated from the precision timer base (Coulbourn Instruments, S51-11) to a pair of ear phones (David Clark, 8 ohm) worn by the experimenter. This auditory signal alerted only the experimenter that one or both subjects responded to a critical signal on their individual displays. Second, the signal passed through a flip-flop switch (Coulbourn Instruments, S41-12), routed through an and-gate to the msec pulse source (Coulbourn Instruments, S51-11) and the electronic counter and display (Coulbourn Instruments, R11-45) which presented the response latencies for the experimenter to record on the data sheets (See Appendix A). The counter was reset when the switch input (Coulbourn Instruments, S22-02) increased the voltage and modified the phase of the signal back to the flip-flop. Lastly, the counter was reset to zero when it received the critical signal from the output port. To control the signal event rate, the computer scanned the Lablinc input port (Coulbourn Instruments, L22-08) during each presentation. This was connected to the control box in Room #1. If the "Faster" button was being pressed by the subject during a presentation, the computer would speed up the event rate by 5%. If the "Slower" button was pressed, it slowed down the event rate by 5%. At the start of each session, the computer began with a baseline background event rate of 60 signals per minute. There was an upper limit of 130.972 signals per minute and a lower limit of 46.427 signals per minute built into the computer software. The total apparatus was controlled by an Apple 2e computer which also recorded event rate data. Due to software and hardware limitations, BER data was the only data recorded by the computer. See Figure 3 for a schematic of the complete apparatus.

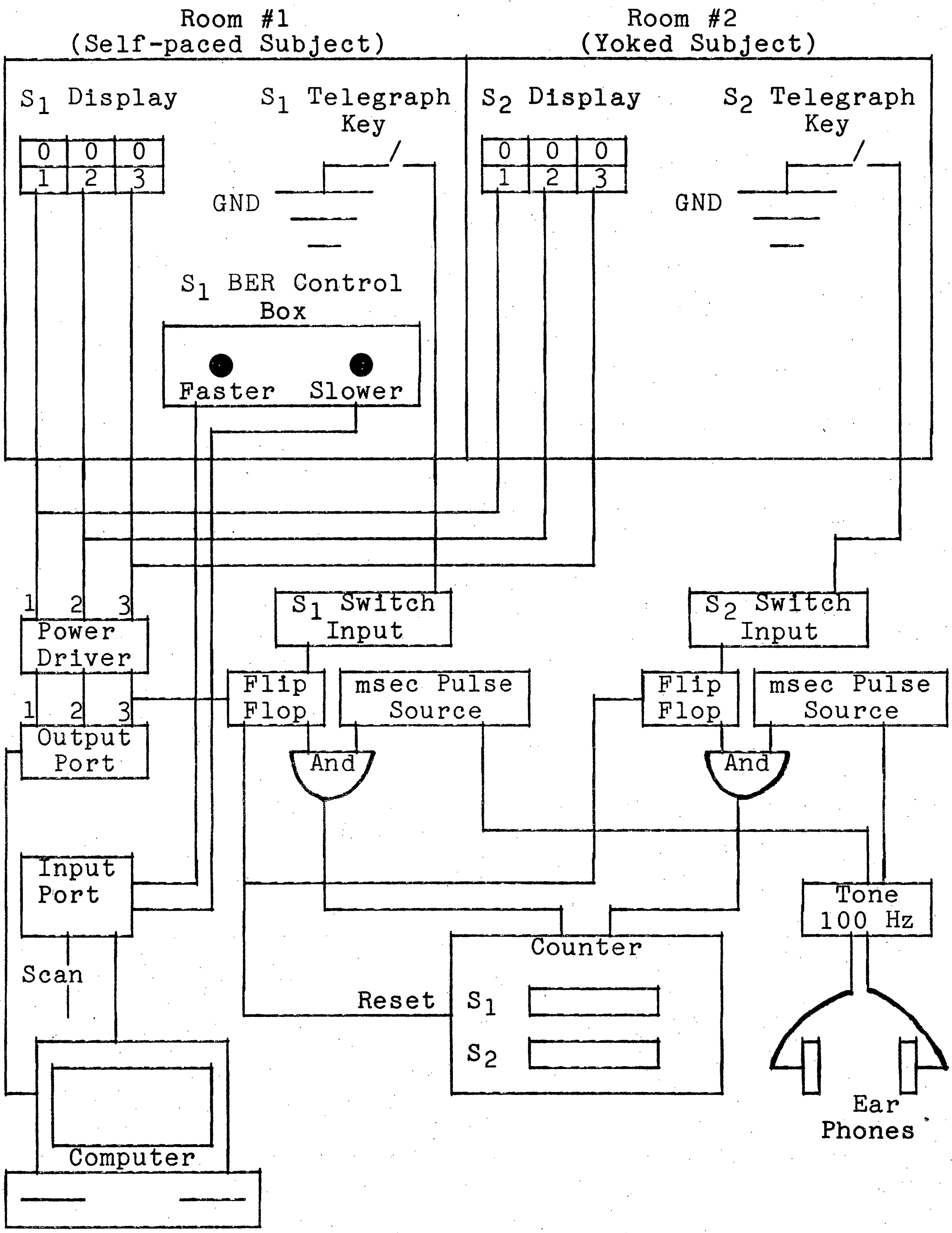


Figure 3. Schematic diagram of experimental apparatus and logic network.

Critical signals were input into the computer software using a random number generator. The signal to noise ratio (S/N) of .008 was computed using the value of 30 critical signals randomly imbedded into 3600 total signals. This 3600 value was computed by using a constant baseline BER of 60 events per minute maintained throughout the 1 hour session. It must be noted that this S/N ratio was only an estimation due to the variable BER. See Appendices B, C, and D for the computer command listings used in this study.

Procedure

The subjects each received an individual briefing on the purpose of this research study and instructions for the task (See Appendices E and F). The only deception of the experiment was that neither subject was aware of the yoked event rate. The subjects were instructed to hold the index finger of their preferred hand on a dot located 2.240 cm in front of the telegraph key and respond to the display by pressing the key when all three lights flashed on. In addition to the instructions given to the subject in Room #2 (the yoked subject), the subject in Room #1 (the self-paced subject) was instructed on how to manipulate the event rate using the additional control box. Both subjects then performed a one minute practice session to become familiar with the apparatus and task. The experimental session immediately followed the practice session.

During the one hour continuous task session, the subjects received no feedback regarding their performance. At the end of the session, the subjects were debriefed on the detailed purpose of the study and the need for confidentiality so that subsequent subjects would not be influenced. All questions were answered and it was stressed that all individual performances were coded to ensure their confidentiality. Due to the coded nature of the data, no immediate performance feedback to the individuals was possible.

All experimental trials were run a priori between the hours of 10:00 A.M. and 4:30 P.M. to control for the usual period of maximum alertness for humans.

Pilot Study

After numerous trial runs in which the experimental apparatus and procedures were refined, a small pilot study using four subjects in two sessions was accomplished. One of the four Ss was older to ensure that all conditions allowed consistent performance throughout each subgroup with minimal degradation due to physiological limitations. This pilot data was not used in the statistical analysis of the experimental data presented in this study.

Performance Measures. Five performance measures were recorded for each task session. The measures were: (1)

Response latency for each critical stimuli. (2) Correct detection rate. (3) False alarm rate. (4) Background event rate for both self-paced and yoked subjects. (5) Time on task in which background event rate was changed by the subject.

RESULTS

Demographic Data

Forty seven out of the forty eight subjects completed the task. One subject (an older S yoked to an older self-paced S, o-o) voluntarily discontinued after approximately 2 minutes into the task. The mean of the median reaction latency scores for that S's group, o-o, was substituted into the data to facilitate proper statistical analyses.

Descriptive Data

Descriptive demographic data were obtained from each volunteer. Each participant indicated his or her sex, age, occupation, education level, handedness, and subjective self perception of health. Table 1 summarizes this information.

Experimantal Data

Table 2 summarizes the data obtained during the 24 task sessions. Figures 4 and 5 present these data in four graphical representations. For each graph, each group's mean scores are presented in each time interval to illustrate not only differing group performance, but also time on task performance differences.

Table 1

Demographic Data Summary

	Age (in years)		Handedness		Occupation		
	Mean	Median	Left	Right	Blue Collar	White Collar	Ret.
Total	43.938	43.500	6	42	13	30	5
Younger	25.500	25.500	4	20	5	19	--
Male	26.250	26.000	3	13	0	16	--
Female	24.000	21.500	1	7	5	3	--
Older	62.375	61.500	2	22	8	11	5
Male	62.750	61.500	1	15	1	10	5
Female	61.625	57.500	1	7	7	1	0

	Subjective Health Evaluation				Highest level of Education			
	Poor	Fair	Good	Exc.	H.S.	Jr. Coll.	Bach.	Mast.
Total	1	1	25	21	11	6	24	7
Younger	0	0	8	16	3	3	14	4
Male	0	0	5	11	0	0	12	4
Female	0	0	3	5	3	3	2	0
Older	1	1	17	5	8	3	10	3
Male	1	1	11	3	2	2	9	3
Female	0	0	6	2	6	1	1	0

Table 2

Experimental Data Summary

				Self-Paced Ss			Yoked Ss		
	TOT[1]	BER[2]	Mean C.S.[3]	Mean RT[4]	Mean FA[5]	Mean Miss	Mean RT[4]	Mean FA[5]	Mean Miss
y-y*	10	118.039	11.421	607.667	.083	.083	560.333	.083	.250
	20	122.505	11.538	615.000	.000	.000	637.833	.333	.917
	30	125.140	11.664	579.167	.083	.000	681.833	.167	1.000
	40	121.620	11.462	593.333	.083	.083	652.333	.417	.750
	50	113.661	10.234	587.667	.000	.000	626.500	.000	.833
	60	119.095	11.375	577.333	.000	.167	653.500	.250	.500
y-o+	10	111.531	10.143	521.000	.000	.000	630.667	.000	.333
	20	117.715	11.241	539.000	.083	.083	752.500	.167	.500
	30	112.336	10.433	535.000	.000	.250	750.500	.000	.500
	40	109.542	9.635	519.833	.000	.333	776.500	.167	.333
	50	114.108	10.386	565.000	.167	.083	782.500	.167	.667
	60	108.091	9.283	601.667	.250	.333	844.667	.083	.917
o-y@	10	80.838	4.813	733.833	.000	.083	501.833	.167	.250
	20	90.544	5.745	692.000	.083	.250	537.167	.167	.417
	30	87.448	5.383	694.167	.083	.333	551.667	.000	.750
	40	90.876	5.810	747.667	.000	.250	544.167	.000	.417
	50	75.843	4.221	815.000	.083	.333	610.167	.083	.917
	60	71.415	4.024	851.000	.000	.500	641.167	.083	.667
o-o#	10	79.658	4.714	615.333	.083	.417	699.333	.000	.000
	20	82.156	5.383	664.833	.083	.083	689.333	.333	.167
	30	77.658	4.443	741.333	.000	.333	717.000	.250	.250
	40	73.991	4.221	740.500	.000	.083	807.333	.000	.667
	50	72.839	4.143	686.833	.000	.333	820.333	.250	.500
	60	69.475	3.992	714.667	.083	.500	806.000	.083	.333

[1]Time On Task in minutes
[2]Background Event Rate
[3]Critical Signals
[4]Reaction Time in msec
[5]False Alarms

*Younger S yoked to Younger S
+Older S yoked to Younger S
@Younger yoked to Older S
#Older yoked to Older S

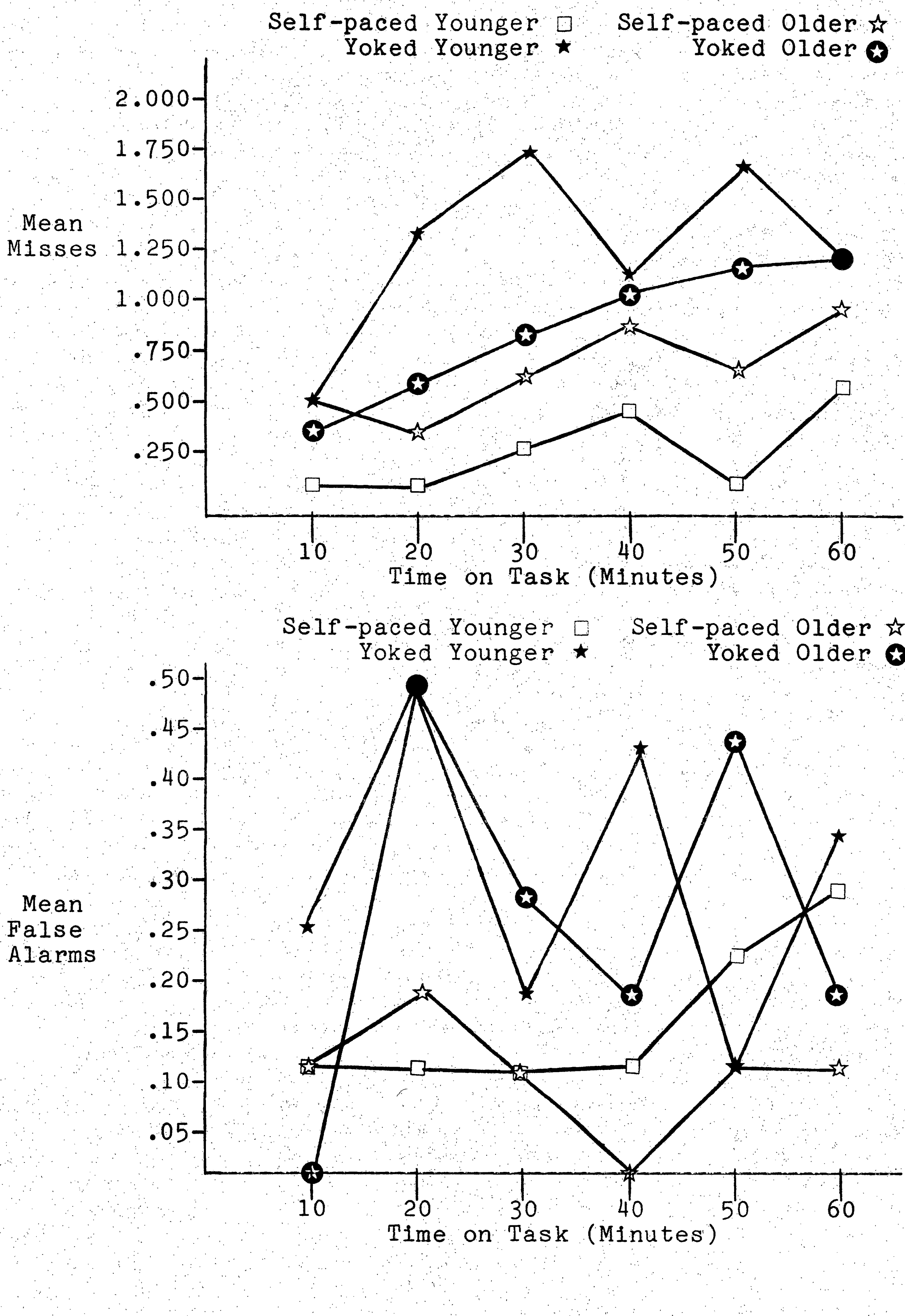


Figure 4. Graphical representation of mean missed critical signals and false alarms as a function of time on task (TOT).

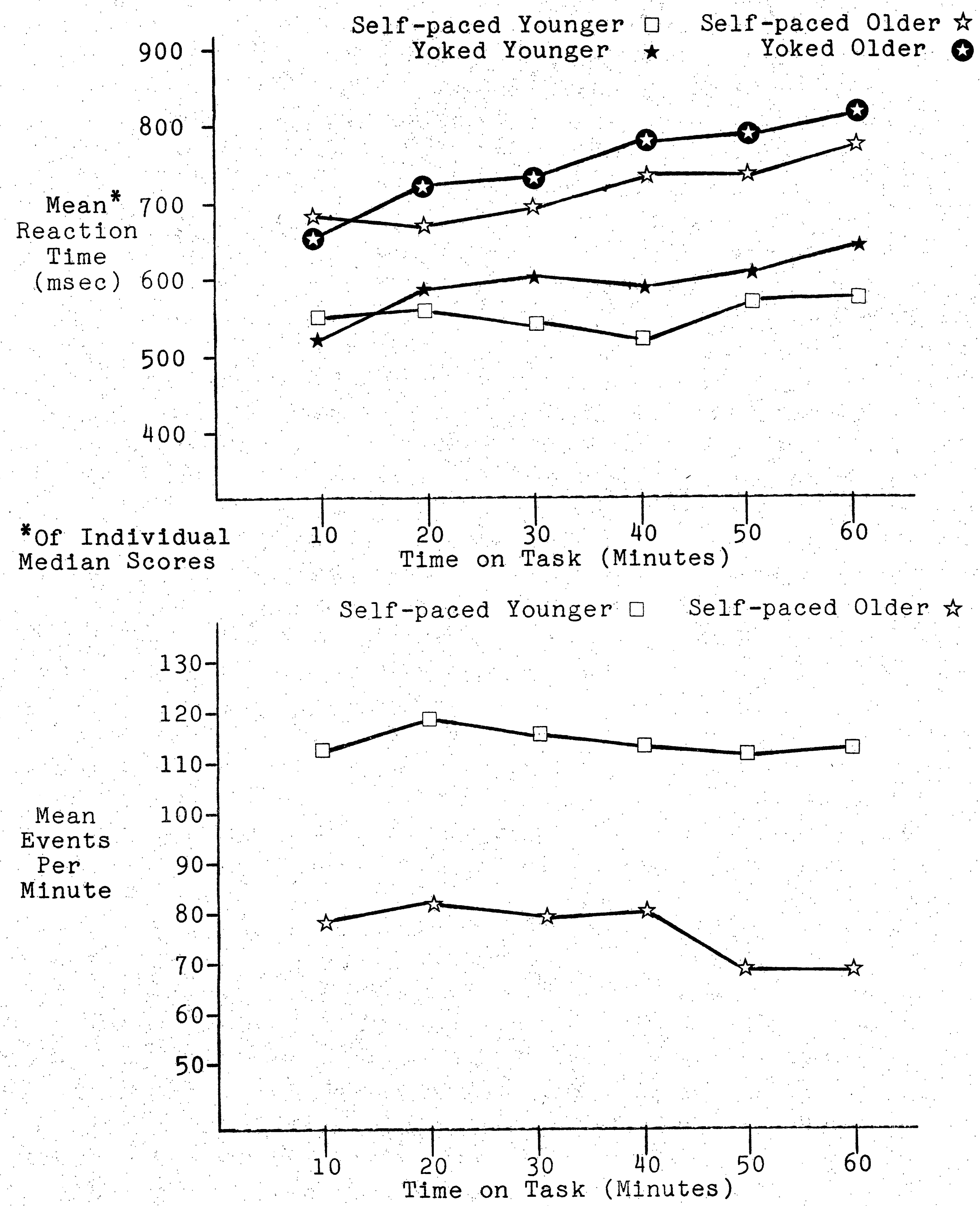


Figure 5. Graphical representation of mean reaction time and event rate as a function of time on task (TOT).

Response Latencies

To reduce the influence of outlying scores in the reaction time (RT) distribution, median RTs were computed and utilized in all statistical RT analyses. A three-factor Analysis of Variance (ANOVA) was performed on the RT data with pacing used as a repeated measure. Table 3 summarizes the results of this procedure. As suggested by the data, the overall performances of the four groups were different. Fundamental analysis of the main effects of age and pacing on RT indicates that while the younger Ss had quicker RTs than the older Ss, $t(46) = 9.496$, $p < .001$, the effect of pacing was not significant, $t(46) = 1.559$. Further analytical breakdown (collapsed over time) indicates that both the younger self-paced Ss had quicker RTs than older self-paced Ss, $t(22) = 7.448$, $p < .001$ and younger yoked Ss had quicker RTs than older yoked Ss, $t(22) = 6.356$, $p < .001$. There was no significant difference in RT between older self-paced Ss and older yoked to younger Ss and older yoked to younger Ss, $t(28) = -.958$. There was also no significant difference in RT differences of older self and older yoked subjects and RT differences of younger self and yoked Ss, $t(46) = .024$. In addition, it is interesting to note that while there was no significant difference in RT between older Ss yoked to either older or younger Ss, $t(10) = .010$, the younger Ss yoked to the older Ss had quicker RTs than

Table 3

ANOVA Reaction Time Summary

Source	SS	df	ms	F	p
Total	5371590.080	288	--	--	--
Between	1511029.600	47	--	--	--
Groups	459187.475	3	153062.492	6.403	.005
$Error_b$	1051842.125	44	23905.503	--	--
Within	3860560.480	240	--	--	--
Pacing	67742.690	1	--	--	--
Time	310097.704	5	62019.541	39.603	.001
G X P	1481404.279	3	107486.580	5.609	.050
G X T	119957.336	15	7997.156	5.107	.001
P X T	43238.083	5	8647.617	3.803	.005
G X P X T	150073.333	15	87267.858	38.377	.001
$Error_1$	843241.031	44	19164.569	--	--
$Error_2$	344529.460	220	1566.043	--	--
$Error_3$	500276.564	220	2273.984	--	--

Conclude:

1. Overall performance of groups was different.
2. The effects of pacing were not significant.
3. The effects of time were significant.
4. There was a groups-by-pacing interaction.
5. There was a groups-by-time interaction.
6. There was a pacing-by-time interaction.
7. There was a groups-by-pacing-by-time interaction.

younger Ss yoked to younger Ss, $t(10) = 2.641$, $p < .05$.

Linear trend analysis of the effects of time on RT is summarized in Table 4. Analysis of the individual effects of time on RT are summarized in Table 5. While the RTs (collapsed over groups) between each successive 10 minute time interval were not significant, there was enough of a gradual, linear increase to cause significant differences between the initial, mid, and final time periods. Therefore, a gradual increase in RTs can be realistically inferred.

False Alarms

False alarm calculations used computed mean scores. Due to the low number of FA scores during the task and the erratic nature of the data, FA analyses involved only rudimentary differences in means. While there was no difference between FA of younger and older Ss, $t(46) = .682$, yoked Ss had more false alarms than self paced Ss, $t(46) = 2.959$, $p < .010$. Further analysis of this yoking effect indicates that the only significant difference in false alarms occurs when a younger S is yoked to another younger S, $t(10) = -2.494$, $p < .050$. Otherwise, there is no difference between yoked and self paced Ss.

Missed Critical Signals (Misses)

Missed critical signal calculations used computed mean

Table 4

Response Latency Linear Trend Summary

Source	SS	df	ms	F	p
$\text{Within}_{\text{lin}}$	71596.855	8	--	--	--
Rep. Meas.	50397.828	1	50398.828	25.648	.010
RM x age_{sp}	5025.059	1	5025.059	2.648	N.S.
RM x age_{y}	2360.934	1	2360.934	1.202	N.S.
RM x age_{sp} x age_{y}	5952.039	1	5952.039	3.030	.010
$\text{Error}_{\text{lin}}$	7860.039	4	1965.010	--	--
Time	310097.704	5	62019.541	39.603	.001

Conclude:

1. RT increased linearly as time on task increased
2. There was no linear age of self-paced by time on task interaction.
3. There was no linear age of yoked by time on task interaction.
4. There was a linear age of self-paced by age of yoked by time on task interaction.

Table 5

Time t-Test Summary

Time periods	Results
10 versus 20 Minutes	Not Significant
10 versus 30 Minutes	$t(94) = 1.916, p < .100$
10 versus 40 Minutes	$t(94) = 2.421, p < .020$
10 versus 50 Minutes	$t(94) = 2.998, p < .010$
10 versus 60 Minutes	$t(94) = 3.987, p < .001$
20 versus 30 Minutes	Not Significant
20 versus 40 Minutes	Not Significant
20 versus 50 Minutes	Not Significant
20 versus 60 Minutes	$t(94) = 2.579, p < .020$
30 versus 40 Minutes	Not Significant
30 versus 50 Minutes	Not Significant
30 versus 60 Minutes	$t(94) = 1.959, p < .100$
40 versus 50 Minutes	Not Significant
40 versus 60 Minutes	Not Significant
50 versus 60 Minutes	Not Significant

scores. Due to the low numbers of missed critical signal scores during the task, missed critical signal analyses involved top level differences in means and linear trend analysis. While there was no difference between misses of younger and older Ss, $t(46) = 1.559$, yoked Ss had more misses than self-paced Ss, $t(46) = 5.106$, $p < .001$. Further analytical breakdown of this yoking effect indicates that yoking was a factor in all situations except when an older S was yoked to another older S, $t(46) = -2.333$. All other situations had varying degrees of yoking effect.

Linear trend analysis of the effects of time on misses is summarized in Table 6. While the number of misses increased linearly as time on task increased, there were no separate age by time on task interaction. However, there was an age of self paced by age of yoked S by time on task interaction.

Event Rate

Event rate calculations used computed mean scores. A separate 1 between, 1 within ANOVA was performed on the event rate data. Table 7 summarizes the results of this procedure. As suggested by the data, the effects of age and time were present in addition to a time by age interaction. Analysis of the effects of age in event rate (collapsed over time) indicates that the younger self-paced Ss chose quicker event rates than the older self-paced Ss, $t(22) = 14.051$,

Table 6

Missed Critical Signals Linear Trend Summary

Source	SS	df	ms	F	p
$Within_{lin}$	83.129	8	--	--	--
Rep. Meas.	63.788	1	63.788	30.980	.010
RM x age_{sp}	2.715	1	2.715	1.319	N.S.
RM x age_{y}	1.301	1	1.301	1	N.S.
RM x age_{sp} x age_{y}	74.983	1	74.893	36.373	.005
$Error_{lin}$	8.236	4	2.059	--	--

Conclude:

1. The number of missed critical signals increased linearly as time on task increased.
2. There was no linear age of self-paced by time on task interaction
3. There was no linear age of yoked by time on task interaction.
4. There was a linear age of self-paced by age of yoked by time on task interaction.

Table 7

ANOVA Event Rate Summary

Source	SS	df	ms	F	p
Total	115148.821	143	--	--	--
Between	97994.175	47	--	--	--
Age	50608.876	3	16869.625	15.664	.001
$Error_b$	47385.299	44	1076.939	--	--
Within	17154.646	96	--	--	--
Time	2036.231	5	407.246	2.652	.050
T x A	1449.369	2	724.685	4.719	.005
$Error_W$	13669.046	89	153.585	--	--

Conclude:

1. The effects of age were significant.
2. The effects of time were significant.
3. There was a time-by-age interaction.

$p < .001$. It is interesting to note that while there was no significant difference in event rates chosen by older self-paced Ss with either a younger or older yoked S, younger self-paced Ss with younger yoked Ss chose quicker event rates than younger self-paced Ss with older yoked Ss, $t(10) = 3.623$, $p < .01$. Analysis of the individual effects of time on event rates are summarized in Table 8. While there were no significant differences in event rates (collapsed over groups) between any time period, the younger self-paced Ss chose a quicker event rate than the older self-paced Ss for every time interval. In addition, there was no significant correlation between RT and BER (collapsed over all groups), $r = .017$, $t(22) = .080$.

Signal Detection Analysis

Using methods outlined by Kantowitz and Sorkin (1983), d' and the associated criterion values were calculated and are summarized in Table 9. These values are also plotted on the Receiver Operating Characteristic (ROC) graphs in Figures 6, 7, and 8 for subject age, TOT, and pacing levels, respectively, to emphasize d' and β differences. It must be noted however, that the ROC curves are approximations based on a single data point. This was necessary because the group differences themselves were manipulated rather than the perceptual and response criterion values within each group.

Table 8

Event Rate Versus Time t-Test Summary

	Time periods	Results
*	All time periods	Not Significant
**	10 Minutes	$t(22) = 2.192, p < .050$
	20 Minutes	$t(22) = 2.030, p < .100$
	30 Minutes	$t(22) = 2.223, p < .050$
	40 Minutes	$t(22) = 2.071, p < .100$
	50 Minutes	$t(22) = 2.587, p < .020$
	60 Minutes	$t(22) = 2.870, p < .010$

*Collapsed over all groups

**Collapsed over younger versus older groups

Table 9

Signal Detection Theory, d' Summary

Age

Younger Ss			Older Ss		
p(Hit)	= 1051/1160	= .906	p(Hit)	= 952/1056	= .902
p(Miss)	= 109/1160	= .094	p(Miss)	= 104/1056	= .099
p(FA)	= 30/1160	= .026	p(FA)	= 42/1056	= .042
y_c = 1.95			y_c = 1.75		
d' = 3.27			d' = 3.02		

Pacing Level

Self-Paced Ss			Yoked Ss		
p(Hit)	= 1049/1108	= .947	p(Hit)	= 954/1108	= .861
p(Miss)	= 59/1108	= .053	p(Miss)	= 154/1108	= .139
p(FA)	= 33/1108	= .030	p(FA)	= 39/1108	= .035
y_c = 1.90			y_c = 1.82		
d' = 3.51			d' = 2.88		

Time on Task

10 Minutes			20 Minutes		
p(Hit)	= 24/31	= .774	p(Hit)	= 29/34	= .853
p(Miss)	= 7/31	= .226	p(Miss)	= 5/34	= .147
p(FA)	= 2/31	= .065	p(FA)	= 3/34	= .088
y_c = 1.52			y_c = 1.38		
d' = 2.32			d' = 2.45		

30 Minutes			40 Minutes		
p(Hit)	= 21/32	= .656	p(Hit)	= 23/31	= .742
p(Miss)	= 11/32	= .344	p(Miss)	= 8/31	= .258
p(FA)	= 2/32	= .063	p(FA)	= 1/31	= .032
y_c = 1.54			y_c = 1.85		
d' = 1.91			d' = 2.53		

50 Minutes			60 Minutes		
p(Hit)	= 20/29	= .690	p(Hit)	= 11/29	= .379
p(Miss)	= 9/29	= .310	p(Miss)	= 18/29	= .621
p(FA)	= 3/29	= .077	p(FA)	= 4/29	= .138
y_c = 1.28			y_c = 1.04		
d' = 1.77			d' = 1.06		

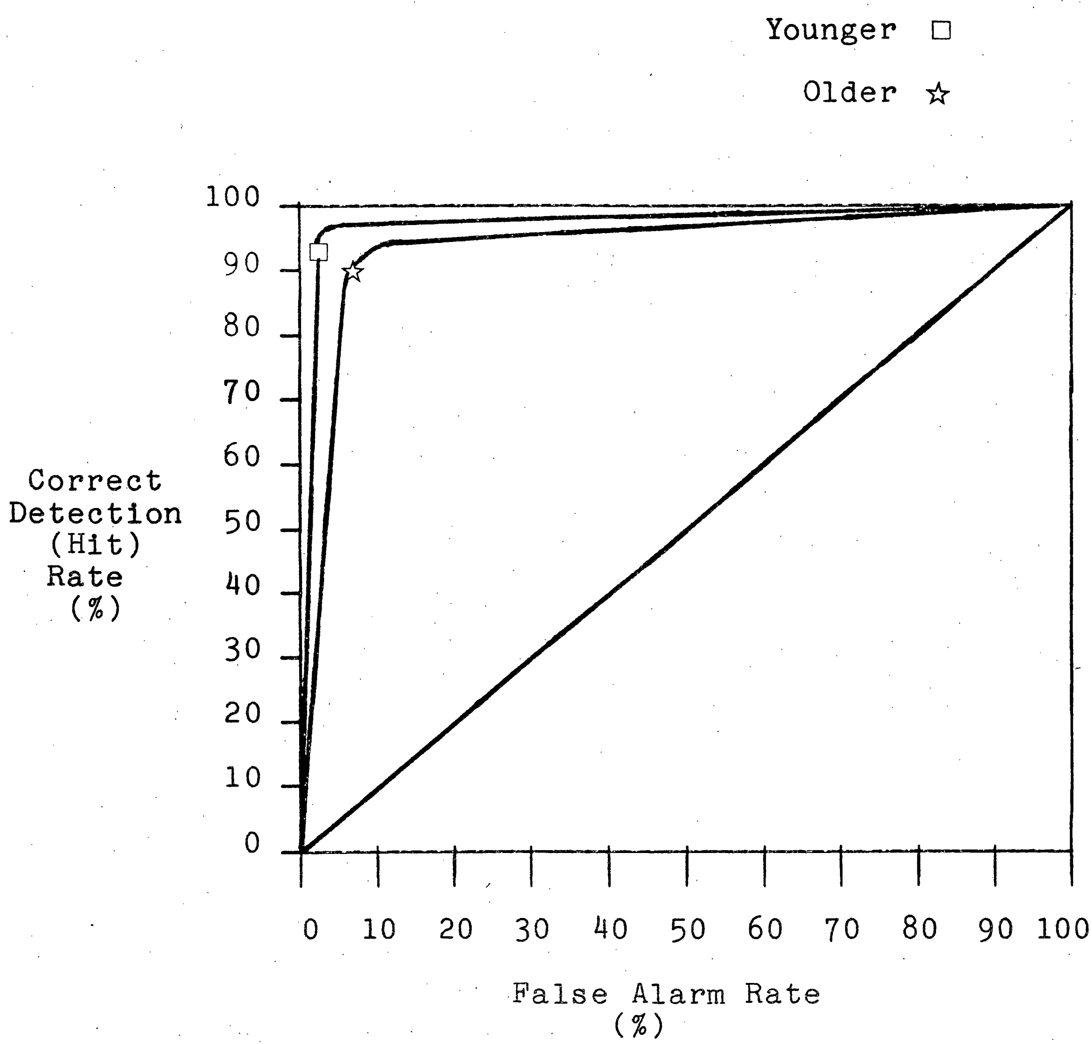


Figure 6. Receiver Operating Characteristic (ROC) for age.

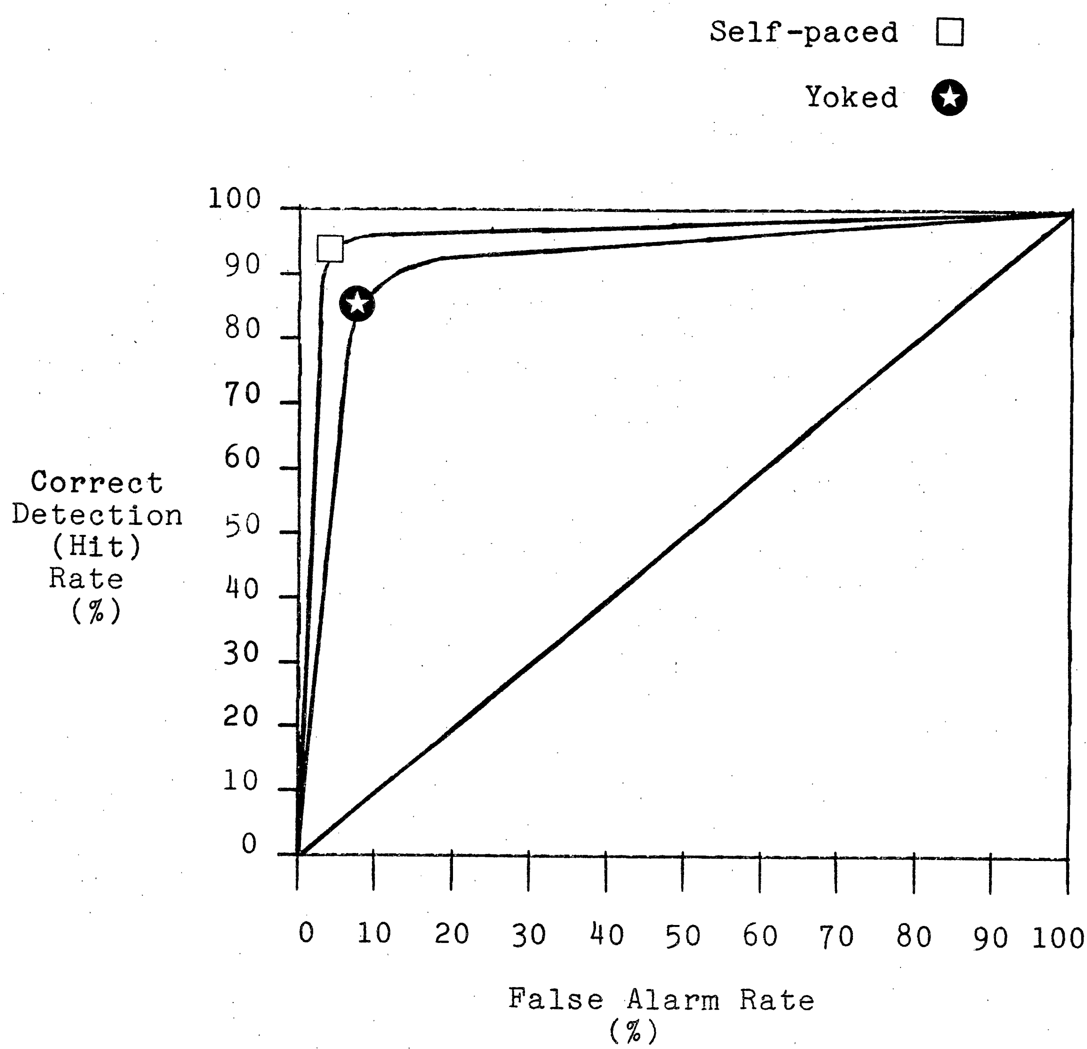


Figure 7. Receiver Operating Characteristic (ROC) for pacing (self-paced versus yoked).

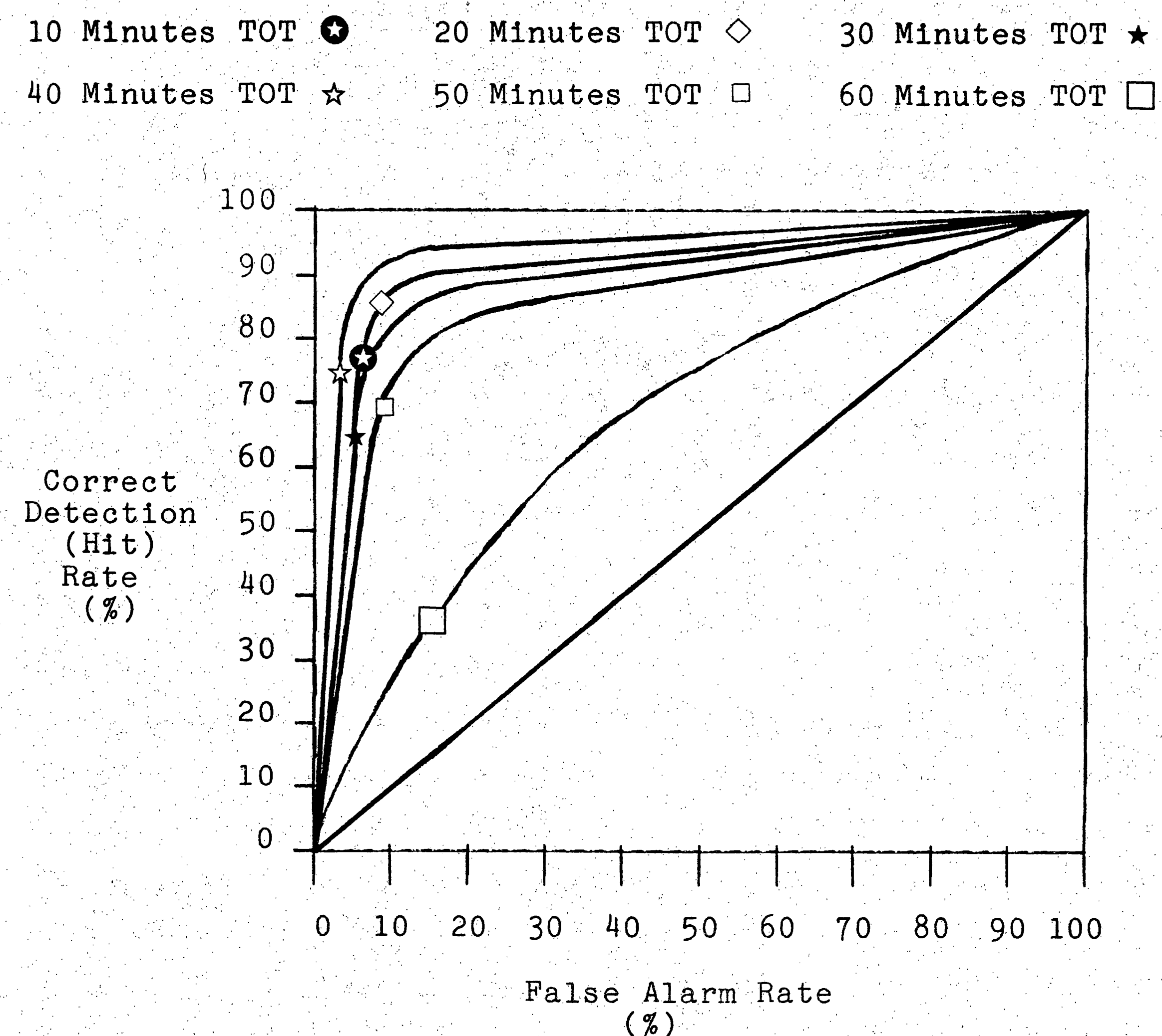


Figure 8. Receiver Operating Characteristic (ROC) for Time On Task (TOT).

DISCUSSION

By concentrating on specific aspects of age-related differences in vigilance performance, this study has facilitated understanding of an important aspect of human-machine interaction, allowing specific systems concepts and designs to incorporate the psychological criteria that results from this research. By identifying various age-related factors that affect vigilance such as temporal uncertainty, d', and β , the likelihood of a deficiency in vigilance can be reduced. Since Decision Theory statistical techniques were applied to this data, any influences to d' and β differences apply only in support of past literature and are intended to emphasize theoretical trends and observations inherent in this study only.

Hypotheses

Main Effects

I. Past research has overwhelmingly demonstrated that older individuals have consistently lower performance during vigilance tasks. The present study partially verifies these findings while adding other dimensions to this phenomenon. Overall, older Ss had longer RTs than their younger counterparts. Their response times collapsed through all groups were longer by 155.569 msec, which represented a 26.593% increase over their younger counterparts. While not signifying differences in d' and β taken alone, the RT differences do lend support for this occurrence. In addition, while it was hypothesized that older Ss would have fewer missed critical signals and FAs, there was in fact no significant difference. While the actual numbers for misses and FAs were small, older subjects had 4.491% fewer misses and 40.384% more false alarms, neither value statistically significant. There was also only an 8.278% increase in d' of older Ss over younger Ss. Thus, if any specific age-related differences in d' and β are to be inferred, it must be on the basis of RT differences alone, a conclusion that is very tenuous at best and is contrary to past literature methodologies and results.

II. The effect of pacing on vigilance performance, while not total, is strong. Nonetheless, the effect of pacing on RT alone was not a significant factor in this study. The RTs of both self-paced and yoked Ss were approximately the same. Yoked subjects had an increase of only 4.739% in response latency, a difference that is not statistically significant and not supportive of d' and β differences. However, the effect of pacing on missed critical signals and false alarms was significant, with self-paced subjects having fewer misses and FAs than yoked subjects. Yoked subjects had a statistically significant 1043.902% increase in misses and a statistically significant 117.865% increase in FAs. But the vast differences in missed critical signals suggest a very strong effect for pacing. This conclusion is further reinforced by the 21.875% increase in the d' of self-paced Ss over yoked Ss. Taking the above findings together, it can be confidently inferred that self-pacing does in fact benefit vigilance performance by affecting d' and β.

III. In keeping with past research findings, RT latencies increased as time on task increased. As stated earlier, this suggests a gradual decline in d' and β. There was a difference in RT between 10 minutes TOT and 60 minutes TOT of 102.500 msec. This represents a 116.838% increase in RT, suggesting a strong time effect. There was also a 200.00% increase in FAs and a 276.836% increase in misses from 10 to 60 minutes TOT, both statistically significant. Again, detection theory analysis adds further support. There was a 17.672% d' degradation between 10 and 60 minutes TOT, a larger 44.503% d' degradation between 30 and 60 minutes TOT, and a substantial 54.310% d' degradation between 10 and 60 minutes TOT. Taken together, these findings are a very strong indication that as TOT increases, d' and β dramatically decline.

Interactions

IV. Contrary to what was postulated, self-pacing did not improve or degrade older Ss' response latencies. Therefore, there was no RT impact on d' or β manifested through pacing. However, it is interesting to note that while FAs for older Ss were not a factor, self-pacing did lower misses for older self-paced subjects, but not as much as for younger self-paced Ss. Yoked older subjects had a 147.603% increase in misses versus self-paced older Ss. While this is significant in its own right, yoked younger subjects had a 541.525% increase over their self-paced younger counterparts. The opposite of what was hypothesized is indicated by these results. That is, younger subjects benefited more from self pacing than older subjects. While d' and β are improved for both older and younger Ss, younger Ss realized a much larger gain, suggesting that older Ss' d' and β are much more stable. It could also signify that the effects of age and pacing are interacting such that younger Ss do well if they can either control BER or are given a slower BER.

V. Response latencies, misses, and FAs degraded at approximately the same rates for all subjects regardless of age. Thus, no age effect was present for TOT performance degradations, contrary to the literature.

VI. As postulated, older Ss did choose a slower background event rate than their younger counterparts. This lends support that there is a d' difference between older and younger Ss and decreasing the event rate compensates for this difference. But this conclusion is tenuous when taking into account the difference in BERs chosen by younger self-paced Ss with younger or older Ss. While no subject was conscientiously aware of the yoking scenario, there may have been an unconscious component. However, older self-paced Ss did not show any differences, and thus no other explanation can be offered for this difference.

VII. Even though there was a significant difference in BER between younger and older Ss, there was no time effect on BER. It stayed relatively constant. While fluctuations were present, they occurred at random. Thus Ss may have compensated for d' degradation at random intervals by merely changing BER, not increasing or lowering it.

VIII. Since there was no RT significance with respect to age and pacing, there should also be no additional time influence. Therefore, d' and β decrements are not present in the RT data. However, older, self-paced subjects' misses did benefit more as TOT increased than did younger self-paced subjects. Their improvement was 152.439% greater than their younger self-paced counterparts. This strongly suggests that self pacing manifested over time benefits older Ss more than younger Ss during a vigilance task.

IX. Unlike VIII above, low BERs and self pacing did not benefit older Ss with respect to any performance measure. While both older and younger yoked Ss had improvements in missed critical signals from fast to slow BERs (169.375%and 124.211%, respectively), these improvements themselves were not statistically different. This suggests that while BER plays a large role in vigilance performance by affecting the d' decrement, that affect does not have an age-related dimension.

Theoretical Implications

This research investigation has bolstered results of past efforts, refuted others, and added some interesting dimensions of its own. The findings that age did not have an overwhelming effect on vigilance performance aside from RT differences tends to partially contradict Davies and Davie's (1975), Czaja and Drury's (1981), and Harkin's (1974) findings of degraded execution in all performance regimes with increasing age. This may be due to factors inherent with this study.

First, the a priori age categorizations (18-38 and 53-76 years of age, respectively) may not have had enough age difference to allow marked performance differences.

However, the age categories reasonably reflect those older ages that will comprise the future work force pool additions. This aspect of the study was very important to preserve. Also, the cohort effects of the older age groups may have contained a large percentage of retired or separated military personnel, in which case psychomotor biases may have been elevated. Unfortunately, this data was not requested in the subject consent forms.

Second, the structure of the task itself hopefully had a large influence in the results. As Parasuraman (1984) states, task complexity has a profound impact on β and especially d'. This study's task was designed to be extremely simple, with no complex search patterns or sophisticated responding modalities. This was done to negate the possible effect theorized by Welford (1981) that older people apply excessive amounts of attention to the responding aspect of such tasks. They could therefore concentrate on the task itself. Thus, this study's findings seem to reinforce the implications of his hypothesis that large, age-related vigilance decrements found in both past research and operational settings are due primarily to this responding affect and not to the nature of signal detection or response motivational effects. This is significant because previous widespread opinion is that decrements found in older persons' performance were due to perceptual and motor degradations. While these are no doubt partially true, the response mode appears to also be extremely important to vigilance performance.

Thirdly, the visual display configuration had a very high visual contrast ratio and was very simple in composition. By doing this, d' was artifically raised for all age groups. Since RTs were longer for older Ss and misses and FAs were the same, two concepts are subsequently strengthened. Younger Ss' RTs represented the baseline (best case) physical response capability of humans and the RT decrement of older Ss was in fact due to age-related psychomotor capability decline. In addition, d' and β, the true measures of interest, remained approximately equal throughout differing ages, as evidenced by equivalent misses and FA rates during all time periods. Therefore, it can be argued that both the widespread premise of age-related psychomotor motor degradation and Welford's concept of older Ss excessive responding attention both impacting vigilance performance are supported.

Related to this same notion, the lack of age-related performance differences in this study may manifest Kochnar's (1979) concept that people age at differing rates. If the age categorizations opted for in this study were not differentiated enough, this phenomenon would tend to obscure any differences. Nevertheless, as stated previously, the ages were chosen to sample future additions to the total worker pool that have been forecast in the literature.

While age did not prove to be as big a factor as originally theorized, the effect of pacing did. The findings of this study partially support previous findings such as Eskew and Riche (1984) who found that pacing dramatically affected d' and β. The 1000%-plus increase in misses of yoked Ss versus self-paced Ss support this notion completely, as well as the same findings of Drury, Morawski, and Tsao's (1979) computer printout inspection task. By these interpretations, both β and d' are strongly influenced. The findings of this study also support Grandjean's (1979) and McFarling and Heimstra's (1975) conclusions that boredom and fatigue are reduced by self pacing, again suggesting an elevated d' and β as compared to yoked subjects.

Finally, the theory that older people have an age-related d' decrement at least as an initial baseline was supported by the fact that they chose slower BERs than their younger counterparts. By lowering the BER, Ss increase the time to detect critical signals, thus elevating d' and theoretically, decreasing it's time-associated decline. Of course, the lack of widespread performance differences throughout TOT discounts any differences during task execution. It would appear that while older people may have an initial d' decrement, they compensated by lowering BER, thus effectively elevating their d' to the approximate level of their younger counterparts and maintaining it throughout the task.

Taken together, these findings and their associated implications confirm Davie's and Parasuraman's (1982) vigilance task taxonomic analysis and the need for multi-theory vigilance analyses (Warm, 1985). Their dichotomized task classifications of fast ($>$ 24 events/minute) and slow ($\leq$ 24 events/minute) allows this study's task to approximate either catagory, depending on the BER chosen by the self-paced S. While Davies and Parasuraman chose 24 events/minute as a cutoff limitation figure, an argument can be made for differing values of events/minute depending on task configuration (Weiner, 1977; Monty, 1973). Nevertheless, the results of this study support their observation that the vigilance decrements reflected a d' deterioration for fast signals while an increase in β is reflected in the slower BERs.

Practical Implications

As with any system, poor vigilance performance impinging on the accomplishment of prolonged operational missions in both the private and government sectors can and will arise if the duties and hardware are deficient in their configuration. This study reinforces this concept with regards to the age and pacing dimensions and considers these as critical features of work elements that can be controlled as part of task and hardware design.

Two elements of vigilance performance are important from a practical point of view, the vigilance decrement, or the decline in target detection rate over time, and the level of vigilance, or the overall detection rate. The level of vigilance varies directly with arousal changes induced internally through boredom or externally through environmental distractions. Variations in the person's decision criterion affect time-related vigilance performance changes. Criterion changes are associated with and can be interpreted as reflecting changes in critical signal expectancy. A taxonomic analysis of vigilance tasks shows that sensitivity decrements are consistent when tasks share demand. Thus, for a range of vigilance tasks, individual differences in performance are not consistent but are task-type specific, where the taxonomy describes the various task types.

For the human factors engineer or corporate/agency decision maker, this has important ramifications. If older people are to be effectively integrated into evolving monitoring task situations, their capabilities must influence system configuration. First, the system should be configured so that increased response latency will not cause catastrophic system failure or mission degradation. Second, while machine pacing is necessary in many systems, self-pacing is preferable if the detection and false alarm rates must be tightly controlled and minimized. While hypothesized otherwise, the age-related aspect of this variable was not significant in this study. Therefore, older people may integrate better into the system if machine pacing is required due to their less substantial performance decline when yoked than their younger counterparts. Third, the event rate should be variable so older monitors can compensate for their initial d' decrement and the associated time-related decrement by at least changing BER. Finally, the specific design of the displays and response modalities are most crucial to the performance of older monitors and should have high discriminability and ease of execution. While the capabilities of younger monitors may compensate for low signal/noise ratios and complicated responding, older monitors will encounter lower performance which may prove unsatisfactory.

In summary, future vigilance paradigms with older monitors should have displays with high signal/noise ratios, simple response modalities, variable event rates, involve self-pacing, and incorporate response modalities that are not critically reliant on reaction time.

Directions for Further Research

The current study has illustrated the importance of designing systems to account for performance differences inherent with differing ages. However, as with all areas of endeavor, additional research can be accomplished to further refine its knowledge base. One area open for futher study is the modification of perceptual and response variables with respect to age. The incorporation of machine pacing could create some very elegant manipulations of these variables. For example, the BER, S/N ratio, and display contrast ratio could be modified singly or as a mathematical function according to miss, FA, and RT performance changes during time on task.

Another potential direction is to investigate the cohort influences on sustained performance. Identifying various cohort effects could have important ramifications on system design of vigilance-type scenarios. This same concept could be applied to also investigate personality influences on sustained performance

Finally, further research on the specific impact of β, d' and aging on vigilance is needed. Data gathered by varying β and d' during TOT would shed further light on the system configuration design criteria for a multi-age user population.

Appendix A: Experimental Data Form

Date____________________

Start Time____:____:____

Stop Time____:____:____

Response Only I.D.________				Response & Control I.D.________			
RT	FA	RT	FA	RT	FA	RT	FA

Appendix B: Computer Command Listing of Main Operating Program

```
]LOAD MOHNEY
]LIST

 2  HOME
 3  INPUT "SUBJECT #1 NAME:  ";A$
 4  INPUT "SUBJECT #2 NAME:  ";B$
 6  GOSUB 6000
 8  PRINT D$;"MON O"
 10 P = 19[illegible]
 15 B = 49664:A = 49327
 30  DATA ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,1,,,,,,,,,,,,,,
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 45  DATA ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,1,,,,,,,,,,,,,,,,,,,,,
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96 DATA 2
100 POKE A,0: GOSUB 5000
120 POKE A,1: GOSUB 5000
140 POKE A,3: GOSUB 5000
160 READ D: IF D = 1 GOTO 190
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170  IF D = 2 GOTO 999
180  GOTO 405
190  PRINT D$;"WRITE";A$
200  POKE A,15:C = C + 1: GOSUB 5000
201  PRINT ":": GOTO 100
405  PRINT D$;"WRITE";A$
410 S =  PEEK (B)
415  IF S = 0 THEN  GOTO 500
420  IF S = 1 THEN  GOTO 519
425  IF S = 2 THEN  GOTO 524
500 P = P: PRINT ".": GOTO 100
519  GOSUB 7500
520 P = P + 5: PRINT "-": GOTO 100
524  GOSUB 7000
525 P = P - 5: PRINT "+": GOTO 100
999  PRINT D$;"CLOSE";A$
1000  FOR I = 1 TO 10000: PRINT "": NEXT I
5005  RETURN
6000  REM  DATA FILE
6010 D$ = "": REM  CTRL D
6020  PRINT D$;"OPEN";A$
6030  RETURN
7000  IF P < 90 THEN  GOTO 7200
7100  RETURN
7200  PRINT "(+)":P = 95: RETURN
7500  IF P > 200 THEN  GOTO 7700
7600  RETURN
7700  PRINT "(-)": RETURN
9999  END

]
```

Appendix C: Computer Command Listing of Data Access/Format Program

LOAD DATA
LIST

```
1  ONERR  GOTO 60
2 D$ = ""
5 T = 100000
8  PRINT D$;"MON I"
10  INPUT "FILE NAME  ";F$
15  INPUT "SUBJECT #2 ?";S$
20 D$ = "": REM  CTRL D
30  PRINT D$;"OPEN";F$
40  PRINT D$;"READ";F$
50  FOR I = 1 TO T
52  GET L$
53  GOSUB 1000
55  NEXT I
60  PRINT D$;"CLOSE";F$
70  PRINT : PRINT "END OF DATA"
100  END
1000  IF L$ = "." THEN  GOTO 101
   0
1002  IF L$ = ":" THEN  GOTO 101
   2
1004  IF L$ = "+" THEN  GOTO 101
   4
1006  IF L$ = "-" THEN  GOTO 101
   6
1008  RETURN
1010  PRINT ".";: RETURN
1012  PRINT ":";: RETURN
1014  PRINT "+";: RETURN
1016  PRINT "-";: RETURN

PR#3
```

Appendix D: Computer Command Listing of Data Printing Program

```
]LOAD PRINT
]LIST

5 P = 1
10  ONERR  GOTO 270
20 A = 60.0000
30 D$ =  CHR$ (13) +  CHR$ (4)
35  PRINT D$"PR#3"
40  DIM Z$(300),F$,C$,G$,H$,L$,B
50  INPUT "FILE NAME  ";F$
60  INPUT "INPUT SOURCE DRIVE  ";G$
80 F$ = " " + F$
90 C$ = F$ + "1"
100 G$ = "," + G$
120  PRINT D$;"OPEN";F$;G$
150  PRINT D$;"READ";F$
160  FOR T = 1 TO 300
170  FOR R = 1 TO 80
160  GET L$
190  IF L$ = "." THEN  GOTO 230
200  IF L$ = "+" THEN  GOTO 500
210  IF L$ = "-" THEN  GOTO 600
220  IF L$ = ":" THEN  GOTO 1000
230 Z$(T) = Z$(T) + "."
240  NEXT R
250 F = P + 1
260  NEXT T
270  PRINT D$;"CLOSE";F$
280  GOTO 2000
500 A = A * 1.05
505  IF A > 130.9725 THEN A = A / 1.05
510 Z$(T) = Z$(T) + "+"
520  GOTO 240
600 A = A / 1.05
```

```
605  IF A < 46.4269 THEN A = A * 1.05
610 Z$(T) = Z$(T) + "-"
620  GOTO 240
1000 Z$(T) = Z$(T) + ":"
1010 B = A / 100
1030  FOR Q = 1 TO 3
1040 E =  INT (B)
1050 L$ = L$ +  CHR$ (E + 48)
1060 B = (B - E) * 10.0
1070  NEXT Q
1080 L$ = L$ + "."
1090  FOR Q = 1 TO 4
1100 E =  INT (B)
1110 L$ = L$ +  CHR$ (E + 48)
1120 B = (B - E) * 10.0
1130  NEXT Q
1140  FOR Q = 1 TO 8
1150  IF R = 80 THEN  GOSUB 1500
1160 R = R + 1
1165  LET M$ =  MID$ (L$,Q,1)
1170 Z$(T) = Z$(T) + M$
1180  NEXT Q
1190  GOTO 240
1500 T = T + 1
1510 R = 0
1520 P = P + 1
1530  RETURN
2000  PRINT "ENTER 'S' FOR SCREEN DISPLAY OR"
2010  PRINT "'P' FOR PRINTER"
2015  GET L$
2020  IF L$ = "S" THEN  GOTO 2100
2030  IF L$ = "P" THEN  GOTO 2200
2040  GOTO 2015
2100 P = P + 1
```

```
2105  FOR Q = 1 TO P
2110  PRINT Z$(Q)
2120  NEXT Q
2130  END
2200 S = 54.0
2205 P = P + 1
2210 R = P / S
2220  IF R <  = 1.0 THEN  GOTO 2500
2230 P = P - S
2240 R = S
2245  PRINT D$"PR#1"
2250  GOSUB 2300
2260  PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT :
    : PRINT : PRINT : PRINT
2265  PRINT D$; PR#3
2270  HOME
2271  PRINT "CHANGE PAPER IN PRINTER AND PRESS '1'"
2272  GET L$
2290  GOTO 2210
2300  FOR Q = 1 TO R
2310  PRINT Z$(B)
2320 B = B + 1
2325  NEXT Q
2330  RETURN
2500 R = P
2510  PRINT D$"PR#1"
2520  GOSUB 2300
2530  PRINT D$;"PR#3"
2540  END
```

}

Appendix E: Instructions to Subjects

Thank you very much for participating in this research. The purpose if it is to investigate sustained attention on a task to improve equipment design.

For the response AND rate control subject:

In front of you is a telegraph key and a lighted display which has three lighted blocks. These blocks will flash in succession. Generally, only two lights will flash on each trial. However, every now and then, all three will flash. Your task is to rest your index finger on the dot in front of the key and respond as fast as you can by pressing the key when all three lights flash. It is very important that you rest your finger on the dot when you're not responding. Also, every great now and again, the lights will temporarily freeze. Pay no attention to this. In addition, you have a control box in front of you which can regulate how fast or slow the lights flash. Change this rate at any time you want during the task to any speed you want. Just hold down either switch and the rate speeds up or slows down with each presentation.

You will first do a 1 minute practice session and then the actual session which lasts approximatley 1 hour. While this may seem like a long time, the results are very important. Please work your hardest on this task. I will end this experiment when the hour is up. At the end of the task, you will be fully debriefed. Do you have any questions I can answer?...If you have a watch, I need to hold it during the task.

For the response subject only:

In front of you is a telegraph key and a lighted display which has three lighted blocks. These blocks will flash in succession. Generally, only two lights will flash on each trial. However, every now and then, all three will flash. Your task is to rest your index finger on the dot in front of the key and respond as fast as you can by pressing the key when all three lights flash. It is very important that you rest your finger on the dot when you're not responding. Also, every great now and again, the lights will temporarily freeze. Pay no attention to this.

You will first do a 1 minute practice session and then the actual session which lasts approximately 1 hour. While this may seem like a long time, the results are very important. Please work your hardest on this task. I will end this experiment when the hour is up. At the end of the task, you will be fully debriefed. Do you have any questions I can answer?...If you have a watch, I need to hold it during the task.

Appendix F: Consent Form

____

My name is Jack D. Mohney. As a Master's student at California State University, San Bernardino, I am gathering data that is directly related to my professional and educational pursuits. Therefore, I am respectively soliciting your help and cooperation in participating in an hour long monitoring task. Your contribution to my research will be very much appreciated as well as entitling you to a summary of my findings as soon as they are available. Your participation is strictly VOLUNTARY and all information collected will be kept strictly CONFIDENTIAL and used only for my research purposes. Please fill in the information below, read the following statements, and sign at the bottom. Thank you.

1. Name______________________________

   Sex______________ Age______________

   Occupation______________________________

   Education Level______________________________

   Handedness______________________________

   Health______________________________

---

2. I understand that:

   a) My participation is voluntary and I will receive no personal reimbursement for participation in this experiment.

   b) I may discontinue the task at any time for whatever reason I feel necessary.

   d) I will be fully debriefed at the end of the session and all questions I have will be completely answered.

3. Signature______________________________

   Date______________________________

GLOSSARY

Arousal. A general state varying from coma and drowsiness to alertness and frantic excitement.

β. A measure of a person's inclination to perform the actions necessary to correctly respond to a critical signal that has in fact been observed and acknowledged. Also known as response bias.

Background Event Rate. The rate at which all signals, both critical and "noise", are presented to the subject. Usually expressed as events per minute.

Cohort Effect. The impact that numerous, complicated past happenings have on a group of individuals' shared experience that other groups do not. Usually manifested as measured dependant variables.

Contrast Ratio. The difference in the luminance of the visual display and the background (ambient) luminance as defined by the following relationship:

$$\text{Contrast Ratio} = \frac{\text{Display Luminance} - \text{Background Luminance}}{\text{Display Luminance}} \times 100$$

Counterbalance. Assign subjects to all experimental variations or treatments according to predetermined criteria to alleviate the lack of random assignment or to emphasize experimental differences that result from those criteria.

Critical Signal. An occurrence that is different and distinguishable from other signals or "noise" and upon which a response is required.

Cross Sectional Study. A research method in which measures are taken across presently different ages to find between-subject age-related discrepancies.

d'. A measure of the efficiency with which an observer can distinguish signals from nonsignals. It is also expressed as a measure of the distance between the means of the signal and noise distributions scaled to the standard deviation of the noise distribution in statistical decision theory (Parasuraman, 1979).

External Validity. A study's ability to be applicable to all segments of the intended population.

Factorial Experimental Design. A method to vary several experimental conditions to discover complex interactions during sophisticated behavior and to facilitate the testing of many hypotheses in one experiment.

False Alarm. Synonymous with a Type I error, to conclude falsely that a difference (or critical signal) does exist when in fact it does not.

Human Factors Engineering. The discipline whose goal is to optimize the relationship between people and technology to form a better total system. Synonymous with human factors, biomechanics, engineering psychology, and (in most European countries) ergonomics.

Internal Validity. A study's ability to accurately test or sample the situation or phenomena about which conclusions are to be drawn.

Isoperformance Age Function. An analytical method that specifies a performance level at differing task difficulty levels (Fozard, 1981).

Level of Vigilance. The overall level of detection performance on a vigilance task, averaged over the duration of the task (Davies and Parasuraman, 1982).

Longitudinal Study. A research method in which measures are taken from the same subject pool over a protracted time period to find within-subject, age-related discrepancies.

Missed Critical Signal. Synonymous with a Type II error, to conclude falsely that a difference (or critical signal) does not exist when in fact it does.

Monitoring. A process in which the observer has to attend actively to a source or many sources of stimuli to identify a previously specified signal, or infer the presence of a "signal," or estimate the "parameters" of some process from data presented on the sources. Related to vigilance, but generally applied to either more complex tasks or to continuous tasks.

Receiver Operating Characteristic. In signal detection theory, a figure that plots and compares various hit and false alarm rates using the observer's perceptual sensitivity, d', and operating criterion values (Kantowitz and Sorkin, 1983).

Response Latency. Synonymous with reaction time (RT), it is the time (usually in msec) from the onset of the critical signal to the moment the subject physically responds to the detected critical signal.

Search. A process in which an observer attempts to locate a stimulus characterized by various degrees of spatial uncertainty (Sinclair and Clare, 1979).

Self-Paced. The ability to selectively choose the background event rate during a vigilance task.

Sensitivity Decrement. A deterioration over time in perceptual sensitivity, d', as assessed using the methods of signal detection theory.

Signal Detection Theory. The systematic study of an observer's perceptual sensitivity, response criterion, and propensity to choose one response alternative over another during an extended task (Kantowitz and Sorkin, 1983).

Spatial Uncertainty. An aspect usually predominant in inspection tasks, it is the ambiguous and unpredictable area in which a critical signal will appear.

Sustained Attention. A process of maintaining attention to a critical stimulus or aspects of a stimulus for a sustained period of time. Synonymous with vigilance (Davies and Parasuraman, 1982).

Temporal Uncertainty. An aspect usually predominant in monitoring tasks, it is the ambiguous and unpredictable time in which a critical signal will appear.

Vigilance. A state of the central nervous system presumed to mediate performance on prolonged vigilance tasks. N. H. Mackworth (1957) defined vigilance as "a state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment. . ." (pp. 389-390) (Davies and Parasuraman, 1982).

Vigilance Decrement. A deterioration in the ability of the observer to remain vigilant for critical signals with time, as indicated by a decline in the rate of correct detection of signals over a continuous period of performance (N.H. Mackworth, 1950).

Yoked. In a vigilance task, having a display connected to another subject's display and being exposed to the variables controlled by the other subject.

LIST OF ABBREVIATIONS

Grammatical Abbreviations

ANOVA	- ANalysis Of VAriance
BER	- Background Event Rate
β	- Beta
cm	- centimeters
d'	- d prime
FA	- False Alarm
fc	- foot candles
fL	- foot Lamberts
GND	- GrouND
HFE	- Human Factors Engineering
Hz	- Hertz
msec	- millisecond
o-o	- older subject yoked to older subject
o-y	- younger subject yoked to older subject
ROC	- Receiver Operating Characteristic
RT	- Reaction Time
S	- Subject
S/N	- Signal to Noise ratio
Ss	- Subjects
TSD	- Theory of Signal Detection
TOT	- Time On Task
y-o	- older subject yoke to younger subject
y-y	- younger subject yoked to younger subject

Statistical Abreviations

age_{sp}	- age of self-paced subject
age_{y}	- age of yoked subject
df	- degrees of freedom
$Error_{b}$	- between groups Error
$Error_{w}$	- within groups Error
F	- F-Test for significance
G x P	- Groups by Pacing
G x P x T	- Groups by Pacing by Time
G x T	- Groups by Time
ms	- mean squares
p	- probability level
P x T	- Pacing by Time
RM	- Repeated Measures
SS	- Sum of Squares
t	- t-Test for significance
T x A	- Time by Age

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