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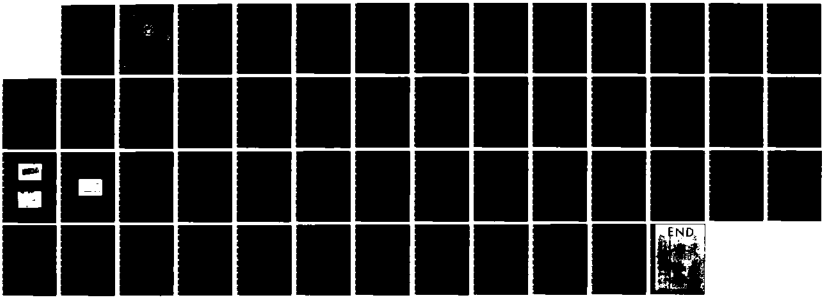

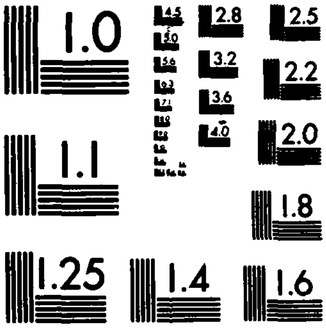

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THE EFFECT OF NOISE AND DISPLAY ORIENTATION ON COGNITIVE PERFORMANCE

by

Seong Hwan Choi

September 1983

Thesis Advisor: C.W. Hutchins, Jr.

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The Effect of Noise and Display Orientation on Cognitive Performance

by

Seong Hwan Choi
Lieutenant Commander, R.O.K. Navy
B.S., R.O.K. Naval Academy, 1975
B.S., Seoul National University, 1978

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Author: Choi Seonghwan

Approved by: Charles W Hutchins Jr
Thesis Advisor

Gary Poock
Second Reader

Chairman, Department of Operations Research

K.T. Marshall
Dean of Information and Policy Sciences

ABSTRACT

Military personnel encounter a variety of noise environments. During exercises, high intensity noise levels are often encountered. 24 subjects were required to respond to symbols presented under two levels of task difficulty, two levels of presentation rate, two levels of display orientation, and three levels of noise intensity. The purpose of the experiment was to determine whether noise intensity and display orientation had any effect on a short-term memory task. Results showed that continuous white noise at intensity levels of 30, 85, and 105 dB had no effect on the short-term memory task. Presentation rate and task difficulty demonstrated a significant relationship with task performance as did their two-way interaction. This two-way interaction between presentation rate and task difficulty exhibited a different pattern for the two levels of display orientation.

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I. INTRODUCTION

A. THE EFFECT OF NOISE

Over the past several years, human beings have been confronted with a constantly increasing level of noise in their working environment. This problem suggests that noise may affect human performance physiologically and psychologically.

Naval officers are exposed to a variety of noise conditions in the engine room and weapons platforms of modern ships. On the other hand, there are lower intensity levels of noise at night vigilance tasks, i.e., mid-watch on the bridge. In each of these different noise environments, Naval officers are required to perform a variety of spatial and cognitive tasks. Shipboard compliance with provisions of the Navy's noise abatement and control program is typically manifested by the presence of protective ear-muffs on the helicopter deck during flight operations, and an occasional sign reading "NOISE HAZARDOUS AREA" in the engine room. Virtually all noise-induced hearing damage is preventable with the use of protective devices now available; however, the tasks can be performed without these protective devices during short-term noise exposure.

There have been many studies concerning the effects of noise on human performance. Unfamiliar noise produces some decline in the efficiency of tasks when it is first encountered. Noises found aboard ship are variable and may consist of vibration, impact, and turbulence. Most military missions involve tasks which are well practiced and noises which are familiar.

Past research provides conflicting results, i.e., studies have found that (1) noise produces a decrement in performance, (2) noise has no effect on performance, and (3) noise produces an increment in performance. When noise has been found to have a decremental effect, the effect has usually been attributed to distraction. When it has been found to have an incremental effect, the effect has been attributed to a loosely defined concept termed "motivational compensation." When noise has been found ineffective as a variable, the results have been attributed to a lack of sensitivity of the task, the organ, or sometimes to compensation.

Broadbent [Ref. 6] presented each subject with a series of letters among which digits were interspersed. The task was to add up the series of digits. When a series of such sums had been completed, the noise was initiated and continued while another series of sums was attempted. Noise was then extinguished and the final series of measurements taken. The noise was provided by an automobile horn mounted 0.6 m from the subject. The effect was that time to compute the first few sums after the onset of noise was increased but the time per sum then returned to normal.

Park [Ref. 32] concluded that once the transient effect (the onset of noise or the sudden removal of noise) has passed, many tasks are performed as efficiently in loud noise as in quiet conditions. Miles [Ref. 28] concluded that if a person was instructed to press a key as fast as possible when a visual signal was seen, and if a warning signal was presented clearly and unmistakably before the main signal, the time taken to react to the main signal was scarcely affected by exposure to noise. Teichner [Ref. [illegible] showed that the size of the effect was related to the size of change in noise level. In his study, subjects were required to search a display of letters looking for particular combinations. They were presented with 150 displays under 81 dB (white noise) and then without warning the noise was changed to 57, 69, 93, or 105 dB for the remaining 50 displays. Performance under these conditions decreased fairly substantially, this decrement was greater for the 24 dB change in level than for the 12 dB change in level. Eschenbrenner [Ref. 16] concluded that for the simulated control of an orbital vehicle, white noise (50, 70, or 90 dB) had a detrimental effect on image motion compensation, and that the magnitude of the decrement varied as a function of both the temporal pattern (aperiodic, periodic, or continuous) and the intensity level of noise. In this study, subjects were given 20 trials according to the pattern and intensity level of noise. Performance was measured in terms of total amount of time image motion was maintained. The aperiodic-noise group exhibited the largest noise-induced performance decrement. As noise intensity increased (50, 70, and 90 dB), performance deteriorated.

In contrast to the above studies, other investigators have demonstrated that noise has a beneficial effect on performance. According to some studies, task difficulty seems to be the variable that accounts for these apparently conflicting results. Performance on each task is thought to be improved by noise, with the improvement being attributed to arousal. Scott [Ref. 39] concluded that loss of efficiency was directly related to reduction in stimulus variation. When background stimuli are at a minimum and only occasional and often low key critical stimuli are present, rapid deterioration should be expected. The more unchanging are the critical stimuli, the sooner deterioration will occur. Rest periods and introduction of extraneous stimuli serve to increase the variety of stimulation needed to maintain or restore efficient performance. Broadbent and Gregory [Ref. 7] performed a vigilance task in which regular flashes of light were monitored for an occasional flash of greater brightness. They showed that the deterioration occurred in the presence of intense noise (100 dB) at high signal frequencies. Poulton [Ref. 35] reviewed those studies where continuous intense noise reliably degraded performance. He gave the most likely explanations of the deteriorations based upon the masking of the auditory feedback cues or of the inner speech which the man himself produces and uses. In these studies, an increase in behavioral arousal is a non-specific explanation which can account for reliable improvements in performance with noise. But overarousal is not required to explain the deterioration in performance produced by continuous intense noise. If overarousal is to be used, it is necessary to specify independently the conditions under which increased behavioral arousal becomes overarousal.

Theologus, Wheaton, and Fleishman [Ref. 42] investigated the effect of prolonged exposure to two noise stressors (random and patterned intermittent, 85 dB white noise) on the performance of three tasks requiring different abilities (reaction time, rate control, and time sharing). The effect of random 85 dB white noise on performance depended on the type of task and performance measure used. The reaction time task was affected, but the task requiring rate control ability (timing of control action) was not. The time-sharing task appeared affected but only after continued exposure to this noise. The effect of patterned noise of the same 85 dB intensity produced insignificant effects, regardless of task or measure. Plutchik [Ref. 33] concluded that performance impairments are more likely to occur during high intensity intermittent noise than under lower intensity or steady noise and that the relative difficulty of the task is an important variable determining the effect of noise on performance. The more difficult the task, the more likely will noise be disruptive.

In contrast to the above studies, Plutchik [Ref. 34] found that high intensity intermittent noise had no effect on the ability of subjects to track a moving target on an oscilloscope. Hack, Robinson, and Lathrop [Ref. 21] concluded that an initial decrement in tracking performance due to intermittent auditory stimulation was followed by gradual improvement in performance concomitent to noise adaptation. Bailey, Patchett, and Whissell [Ref. 3] found that noise had no effect on the performance of the task, but patterned noise had a greater effect than the quiet (no noise) condition on task accuracy. The task involved stroking out the letter 'e' in a type-written passage for nine minutes under conditions of no noise, continuous 95 dB white noise, 95 dB patterned noise, and random intermittent noise.

An analysis of the above conflict, that is, the facilitative effect of noise and the decremental effect of noise was attempted by Hockey [Ref. 23]. He concluded that these discrepancies could be explained in terms of (1) the levels and characteristics of the noise used, and (2) the demands made on the subjects by different tasks. Where distraction has been invoked as the explanation of noise effects, a decrement in efficiency has usually been found. Where arousal has been assumed to underlie the observed effects, performance has usually been shown to improve.

B. EFFECT OF CHANGES IN LATERAL ORIENTATION

When a person is asked to picture and describe a happy experience, a complex pattern of both cognitive and affective processes is evoked. Some recent research on cerebral hemispheric laterality and cerebral activation support the idea that certain types of complex visual displays might be preferentially located on either the left or right side of the human operator. There are many displays located in the cockpit of modern aircraft and the CIC and engine room of ships. These results may provide a new basis for organizing and locating visual displays which provide systems operators with important information which may be critical to the effectiveness of the man-machine interface.

Schwartz [Ref. 38] concluded that the direction in which an individual is looking can indicate the cerebral hemisphere upon which the individual is primarily relying on by asking questions that were created to make a two-by-two design involving four classes of stimuli, i.e., Verbal-nonemotional (VNE), Verbal-emotional (VE), Spatial-nonemotional (SNE), and Spatial-emotional (SE). In his studies, he found that verbal thought resulted in a preponderance of head and eye movements to the right, and spatial thought resulted in a preponderance of head and eye movements to the left.

These results indicate that the right hemisphere has a special role in regulation of emotional processes in the intact human and in cognitive tasks involving differential hemispheric pattering. Kinsbourne [Ref. 27] supported the findings of Schwartz [Ref. 38]. He found that when solving verbal problems, subjects turned head and eyes to the right, and that when solving spatial problems, subjects looked up and left. The results suggest that the direction in which people look while thinking reflects the lateralization of the underlying cerebral activity.

In contrast to the above studies, some researchers found that a deliberate shift in orientation to the left or right (looking to the left of center or looking to the right of center) should activate the right or left hemisphere respectively. Gopher [Ref. 20] found that by having subjects fixate on a point 20 degrees to the right of center, he was able to alter performance on a dichotic listening task which involved verbal stimuli; looking to the right ostensibly facilitates performance on this type of verbal task by shifting the bulk of cerebral activation to the left hemisphere.

Casey [Ref. 12] found that responses to spatial stimuli were significantly faster when the displays were located 20 degrees to the left, and that responses to verbal stimuli were faster when the displays were located 20 degrees to the right. An orientation shift to the right should facilitate right hemispheric processing. Casey [Ref. 13] tested this phenomenon in the Advanced Integrated Display System (AIDS), fighter-attack cockpit mockup. He examined the effect that the left or right orientation of a spatial type peripheral display might have on an operator's performance on a demanding central task. Subjects who were exposed to the 82 dB white noise through earphones had two types of display windows, i.e., in the left or right side of cokpit. In his study, he found that there was a strong trend for peripheral task accuracy scores (percent correct response) on the left-side display window to be better than those on the right-side display window. Examples of spatial tasks are (1) navigation, (2) control of stability, and (3) maneuver profiles and examples of verbal tasks are control communications, lgoical decisions, and threat evaluation. Wickens [Ref. 49] suggested that when the overloaded operator is confronted with two tasks--one spatial and one verbal--that must be time-shared, greater efficiency should result if the spatial control is operated with the left-hand, while verbal responses such as digital data entry is assigned to the right.

Kimula [Ref. 26] showed that motor and sensory pathways from the hands are almost completely crossed so that each hand is served primarily by the cerebral hemisphere on the opposite side. He found that auditory pathways from the ears to the cerebral auditory receiving area in the right and left hemisphere are partially crossed. Although each hemisphere can receive input from both ears, the neural connections from one ear to the hemisphere on the opposite side are stronger than the connection to the hemisphere on the same side. In addition visual pathways are completely crossed, so that when the eyes are fixated on a point, all of the field to the left of the fixation point excites the visual cortex in the right hemisphere and stimuli from the right visual field excite the left visual cortex.

C. THEORY OF SHORT-TERM MEMORY

The results of the present experiment are limited to tasks involving short-term memory (STM). The terms used to characterize STM differ widely among researchers. Some of the terms used are primary memory, immediate memory and temporal store. The capacity of the STM is referred to as a limit or span. According to the suggestion of Fitts and Posner [Ref. 17], "short-term memory is defined as a system which loses information rapidly in the absence of sustained attention. Short-term memory involves about the first sixty seconds after presentation of a new stimulus. After that time, either the items are lost or they are transferred to a long-term memory system."

Crossman [Ref. 15] defined the three stages as analysis of sensory input data (the receptor system), the organization of action in relation to current objectives (the central process), and carrying out the required actions (the effector system). STM is fed by stimuli which are processed before they reach storage to become part of conscious recall through the receptor system. Broadbent [Ref. 8] hypothesized two types of memory storage, short-term memory, which deals with events that have just recently occurred, i.e., within seconds or minutes. Air traffic controllers who quickly store and retrieve information about aircraft in a traffic pattern, or battle staff analysts using rapidly updated displays to estimate characteristics of an order of battle, rely on STM. The second type of memory is called long-term memory (LTM). It involves the integration and recall of information acquired over longer periods of experience, practice, and training. LTM has many implications for training and for training-equipment design. Similarly, Welford [Ref. 47] states two kinds of memory stores. The STM is defined as a buffer store which holds limited amounts of data for brief periods, after which they are completely forgotten. The holding mechanism is commonly assumed to be some kind of brain activity depending on self-regenerating circuits of neurons, analogous to the dynamic memory of some early electronic computers [Hebb, Ref. 22]. Data in the long-term store must be held in some more enduring form, either a biochemical or a submicroscopic structural change in brain cells, which can survive severe insults.

Although some researchers have claimed that the memory stores should not be distinguished, the evidence for their independence comes from clinical studies which show that one store may be severely impaired while the other is little affected (Symonds: [Ref. 40]; Wickelgren: [Ref. 48]. Baddeley [Ref. 2] showed that in STM,confusions tended to occur between words which were acoustically similar, while in LTM confusions tended to take place between words which were similar in meaning (i.e., semantic similarity).

The type as well as the amount of material affects the capacity of STM. Miller [Ref. 29] pointed out that man shows relatively better retention of complex items such as words than simple items such as letters. Thus, the number of letters retained increases if the subject can find simple words which tie together a number of unrelated letters. In his study, he concluded that the limitation on human memory be thought of in terms of the number of chunks or meaningful units. The memory span is longer for simple chunks than for complex ones. Norman [Ref. 31] referred to this chunking process as recoding. He proposed that the operator recoded the input into another code which essentially contained fewer chunks but with more bits of information per chunk.

There appears to be two theoretical explanations for why material is lost from STM--the decay theory and the interference theory. Decay theory proposed that material is lost from memory merely as a function of time, while interference theory attributes loss of material to interference from events occurring both before and after presentation of material to be memorized. Brown [Ref. 10] concluded that when a sequence of items is presented, the interval between the perception of each item and the attempt to recall that item will depend on the length of the sequence. If the sequence exceeds a certain length, decay of the memory traces of some of items will proceed too far for accurate recall of the sequence to be possible (this length is called the memory span). Welford [Ref. 46] stated that if time alone was important, halving the rate of presentation and reproduction (of digits) would havle the memory span. This it clearly does not do. Furthermore, a number of studies have found that memory span falls rather than rises with increased rate of presentation.

Fitts and Posner [Ref. 17] defined serial STM as those tasks which involve continuous presentation and retrieval. These tasks involve both STM and LTM processes. Two general methods for studying these processes have been used. One, called the running memory span, involves the presentation of a string of unrelated items without any fixed end point. The subject is required to recall the part of the series immediately before the experimenter stops. The other method involves the use of skilled tasks such as typing or reading in which the response naturally lags behind the acquisition of new information. Poulton [Ref. 36] defined sequential STM as the requirement to respond in turn to each of a series of signals after they have disappeared, for example, receiving morse code and taking dictation. His experiment was to reproduce an irregular track after a time lag. In his study, accuracy in reproducing the positions of the reversals in direction of the track was found to depend only upon the time lag (the longer the delay, the poorer the reproduction).

Examples of shipboard tasks involving STM are (1) on-the-spot diagnoses of equipment malfunction, (2) predicting tracks and future position from primary position indicator displays such as RADAR, (3) the flash signal, and (4) battle staff analysts using rapidly updated displays to estimate characteristics of an order of battle.

D. BACKGROUND OF NOISE LEVEL AND EXPOSURE TIME

Noise affects emotions and behavior in many ways. Most of the time human beings are unaware that noise is directly affecting their attitudes. Although noises exist in nature, the noises that are a potential source for impaired hearing are the ones from technology--jet aircraft, weapon systems, power tools, etc. Many studies have examined permissible noise exposure. Navy Times [Ref. 30] says that: "nearly all aircraft used by U.S. forces generate noise above 85 dB, the ears-at-risk point. All individual and crew served weapons in the U.S. inventory generate noise at or above 120 dB, the threshold of physical pain." Most are familiar in principle with standard noise level tables such as the following:

Sound	Decibels (dB)
Whisper	20
Conversation	60
5-ton truck	87-101
Light helicopter	102-111
CVA flight deck	130
45 cal pistol (30' away)	140
M 16 rifle (firer's position)	154-158

Webster [Ref. 45] examined noise level on ships;

Log room	63 dB
Acoustic booth	83 dB
Helo deck	90-110 dB
Engine room	87-103 dB

Cheremisinoff [Ref. 14] showed the permissible noise exposures according to the Department of Labor regulations. He states that if duration per day was 25 minutes or less, the maximum permissible noise level was 115 dB (see Table 1). The U.S. Air Force studied the recommended and mandatory ear protection criteria for various durations of exposure from seconds to 8 hours (see Figure 1).

TABLE 1

Permissible Noise Exposures

Duration Per Day (hours)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1 $\frac{1}{2}$	102
1	105
$\frac{1}{2}$	110
$\frac{1}{4}$ or less	115

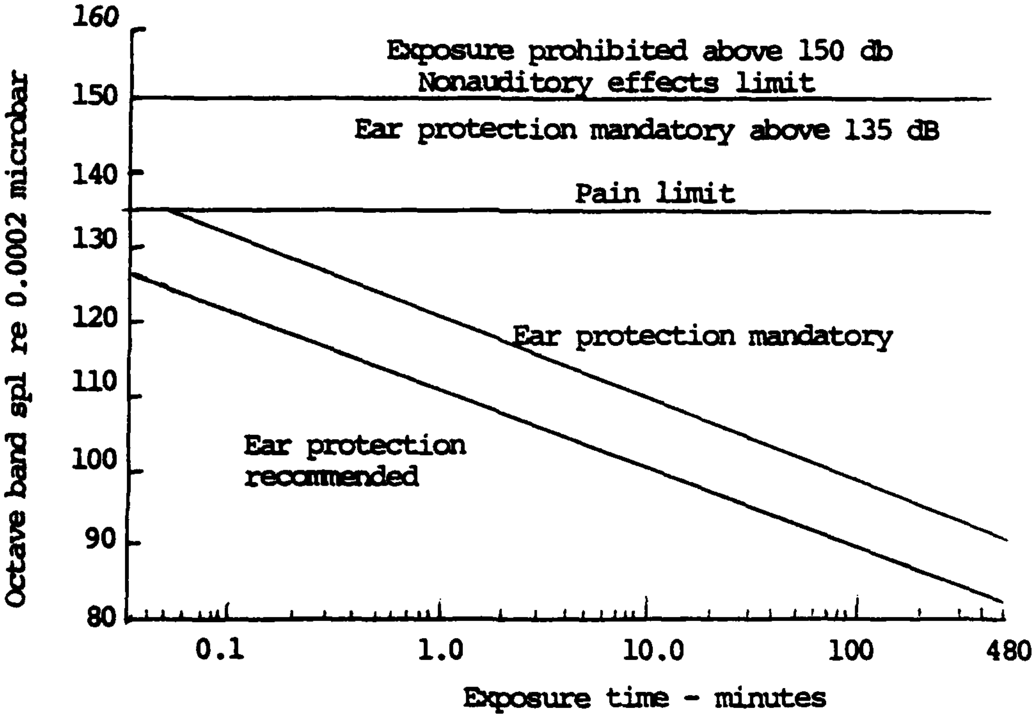


Figure 1. Short-Term Damage Risk Criteria

II. METHOD

A. SUBJECTS

The subjects utilized in this experiment were 24 male students from the Naval Postgraduate School. Subjects ranged in age from 26 to 35 years. They were not compensated for their time. They were screened for good physical condition. Subjects were told that the purpose of this experiment was to determine the effects of noise on a short-term memory task. They were cautioned against talking about the experiment among themselves.

B. STIMULI AND APPARATUS

1. Response Analysis Tester (RATER)

The RATER, Model 3, was used as the experimental device to display the visual stimuli and collect the response data. The device, built by General Dynamics (Convair Division), is a psychomotor testing instrument designed to provide sensitive, reliable measurement of response accuracy for patterned or colored stimuli.

The patterned stimuli (symbols) were used in this experiment. The symbols presented by the RATER were a plus sign (+), a circle (O), a triangle (Δ), and a diamond (◇). The basic task required the subjects to press the correct response button associated with each of four symbols automatically displayed in a continuous, random sequence.

Total presentations, total responses, and total correct responses were determined from counters installed in the RATER control unit (see Figure 2).

The symbols were colored white and presented against a black background. The stimuli-response unit (see Figure 3) which is placed in front of the subject had four response buttons and a small 1.25" × 1.25" viewing screen.

2. Noise Generation Equipment

A MAICO dual channel audiometer, Model MA-24B (see Figure 4) generated the continuous white noise at the desired intensity level. The noise was delivered to subjects via headphones. The MA-24B is equipped with two air conduction headsets--a test headset and a monitoring headset. The test headset uses the standard MX 41/AR cushions. The headset was color-coded-blue for the left headphone and red for the right headphone. Each channel is calibrated to its own headphone. The white noise generator was activated and connected for use in broad-band white noise.

3. Environment

The experiment was conducted in a controlled acoustical environment chamber manufactured by the Industrial Acoustics Company of Bronx, New York. The RATER stimulus-response unit and headphones were placed on a desk directly in front of the subject. The RATER control unit and MAICO audiometer were located outside of the chamber.

Figure 2. Control Unit of RATER

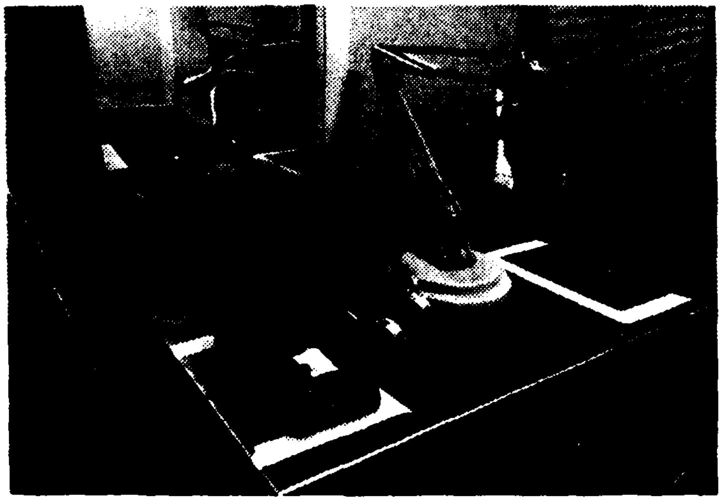


Figure 3. Response Unit of RATER

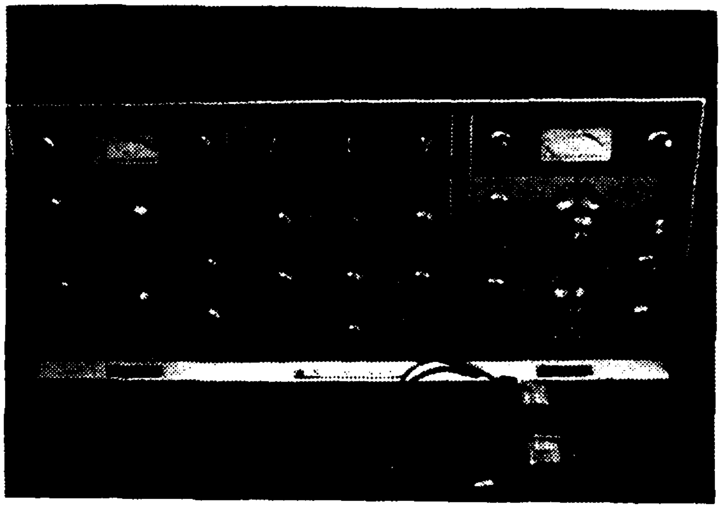


Figure 4. MAICO Audiometer, Model MA-24B

C. EXPERIMENTAL DESIGN

The design for this experiment represents a mixed (between and within subjects) completely balanced factorial design (Winer, Ref. 50). The 24 subjects were randomly assigned via a table of random numbers to one of three noise levels (30 dB, 85 dB, and 105 dB), therefore each group consisted of eight subjects. Each subject within a group received all levels of the three within-subject factors: (1) display orientation (20° to the right of subject's center line vs. 20° to the left of subject's center line), (2) task difficulty (response required to the symbol currently displayed--delay "0" vs. response required to symbol displayed two symbols before the one currently displayed--delay "2"), and (3) symbol presentation rate (.75 seconds between symbols vs. 1.0 seconds between symbols). Each subject therefore received eight trials representing the eight possible combinations of the within-subject independent variables. In order to control for any potential effects due to the order in which a subject received the eight conditions, a separately randomized 8 × 8 latin square was constructed for each of the three noise level groups.

These latin squares are shown in Tables 4 through 5. The numbers in the main body of these tables correspond to the experimental conditions in the following way:

Code #	Conditions
1	$O_1D_1R_1$
2	$O_1D_1R_2$

3	$O_1D_2R_1$
4	$O_1D_2R_2$
5	$O_2D_1R_1$
6	$O_2D_1R_2$
7	$O_2D_2R_1$
8	$O_2D_2R_2$

A four way (noise level (N), task difficulty (D), presentation rate (R), and display orientation (O)) analysis of variance was employed to analyze the data for this experiment.

TABLE 2

Model of the Design

		O_1 (left)				O_2 (right)			
		D_1 (Delay "0")		D_2 (Delay "2")		D_1		D_2	
		R_1^*	R_2^*	R_1	R_2	R_1	R_2	R_1	R_2
N_1	105 dB								
N_2	85 dB								
N_3	30 dB								

R_1^*: .75 sec

R_2^*: 1.0 sec

TABLE 3

Latin Square for 105 dB Noise Group

	order of each presentation							
S1	1	3	6	7	2	8	5	4
S2	2	4	7	8	3	1	6	5
S3	3	5	8	1	4	2	7	6
S4	4	6	1	2	5	3	8	7
S5	5	7	2	3	6	4	1	8
S6	6	8	3	4	7	5	2	1
S7	7	1	4	5	8	6	3	2
S8	8	2	5	6	1	7	4	3

TABLE 4

Latin Square for 85 dB Noise Group

	order of each presentation							
S9	5	3	2	7	1	4	6	8
S10	6	4	3	8	2	5	7	1
S11	7	5	4	1	3	6	8	2
S12	8	6	5	2	4	7	1	3
S13	1	7	6	3	5	8	2	4
S14	2	8	7	4	6	1	3	5
S15	3	1	8	5	7	2	4	6
S16	4	2	1	6	8	3	5	7

TABLE 5

Latin Square for 30 dB Noise Group

	order of each presentation							
S17	2	8	4	5	7	3	6	1
S18	3	1	5	6	8	4	7	2
S19	4	2	6	7	1	5	8	3
S20	5	3	7	8	2	6	1	4
S21	6	4	8	1	3	7	2	5
S22	7	5	1	2	4	8	3	6
S23	8	6	2	3	5	1	4	7
S24	1	7	3	4	6	2	5	8

D. PROCEDURE

Upon arriving at the Man-Machine Systems Design Laboratory at the Naval Postgraduate School, the subject was seated at a desk located in the controlled acoustical environment chamber and read the instructions listed in Appendix A. At this time the subject was given two two-minute practice sessions under the self pace mode (new symbol does not appear until subject elicits a correct response). No noise was introduced via the headphones during the practice sessions. During the first practice session, the "O" delay level of task difficulty was utilized; during the second practice session the "2" delay level of difficulty was utilized. The experimenter determined at the end of each practice session whether the subject correctly understood the task; if not additional time was alloted. After the two practice sessions were successfully completed, the experiment proper began, in which the subject was presented the eight trials (possible combinations of experimental condition) according to the predetermined order shown in Tables 3-5. The entire sequence is illustrated in Figure 5. Each experimental trial lasted for two minutes and was followed by a one minute rest period.

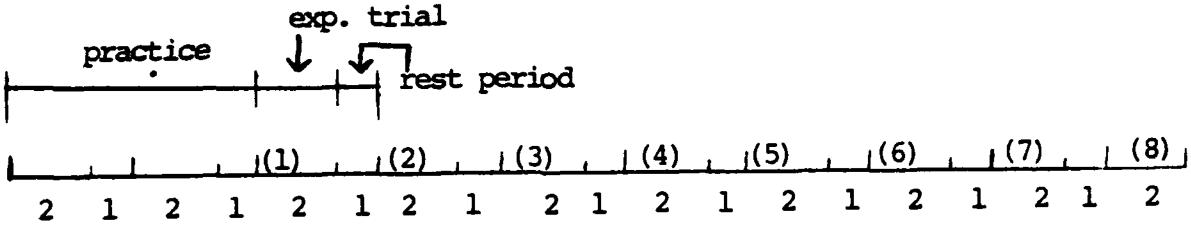


Figure 5. Sequence of Procedure

The response variable used for analysis in this experiment was the number of correct responses in a two minute experimental session divided by the total number of responses for that session. A total of 192 data points were collected, representing all combinations of noise levels (3), by subjects within groups, (8) by task difficulty (2), by presentation rate (2), by display orientation (2). The experimenter-paced mode was utilized during all experimental trials.

III. RESULTS

The results of this experiment are summarized in the ANOVA summary table (see Table 6). The main effects that achieved significance were difficulty of the task and presentation rate. Both noise level and display orientation failed to demonstrate a significant main effect. The significant two way interaction between task difficulty and presentation rate is illustrated graphically in Figure 6. The significant three way interaction between task difficulty, presentation rate and display orientation is graphically illustrated in Figure 7.

TABLE 6

ANOVA Summary Table

SOURCE	D.F.	SS	MS	F
Noise	2	12.193	6.097	0.031
Residual/S	21	4127.719	196.558	
Orientation	1	15.413	15.413	0.785
O×N	2	61.020	30.510	1.554
Residual*	21	412.272	19.632	
Difficulty	1	12358.501	12358.501	100.597***
D×N	2	161.755	80.878	0.658
Residual	21	2579.894	122.852	
D×O	1	49.208	49.208	1.620
D×O×N	2	78.793	39.397	1.297
Residual	21	637.704	30.367	
Rate	1	18695.360	18695.360	259.472***
R×N	2	8.584	4.292	0.060
Residual	21	1513.080	72.051	
R×O	1	20.672	20.672	0.492
R×O×N	2	21.180	10.590	0.252
Residual	21	883.228	42.058	
R×D	1	17706.242	17706.242	309.425***
R×D×N	2	258.160	129.080	2.256
Residual	21	1201.683	57.223	
R×D×O	1	194.005	194.005	8.158**
R×D×O×N	2	130.454	65.227	2.743
Residual	21	499.410	23.781	
Total	191	61626.533		

** < 0.01 *** < 0.01

*Each residual sum of squares was independently chosen based on its expected mean square.

IV. DISCUSSION AND CONCLUSIONS

The results of the analysis of variance show that the level of intensity of the noise did not significantly affect performance on the short-term memory task utilized in this experiment. In order to successfully accomplish the required task, the subjects had to store two prior symbols or the present symbol for a period of time prior to making a response. Therefore, the subjects were required to be attentive to their task at all times. These findings suggest that noise at the intensities utilized will be filtered out. Filter Theory--Broadbent [Ref. 9]--is supported by these results. According to this theory focused attention sets the filter to a particular class of stimuli, rejecting all others, i.e., noise. It is possible that at some intensity level (higher than examined in this experiment) the noise could cause a shift in the filter and result in distraction to the principal task. It is also possible that intermittent noise would have created a distraction to the STM task at the intensities examined.

The highly significant effect of presentation rate on performance was in the predicted direction (slower rate (1.0 sec) resulting in better performance) as was the effect of task difficulty (easier task (delay "0") resulting in better performance). Since these experimental variables were included in the study to provide a broader context to investigate the effects of noise on performance, no further discussion is necessary with respect to their individual effects on task performance. The significant interaction between these two variables (see Figure 6) indicates that at the high stimulus presentation rate (.75 sec) there is little difference in performance between the two conditions of task difficulty (53.7 % vs. 50.6 %), while at the low presentation rate (1.0 sec) there is a large difference between the two conditions of task difficulty (54.3 % vs. 89.5 %).

The three way interaction between presentation rate, task difficulty and orientation of stimulus display reflected the above interaction of presentation rate and task difficulty at both levels of display orientation with the exception that for a left oriented display, performance associated with high task difficulty decreased from high to low presentation rate, while the opposite occurred for the right oriented display--performance for the high task difficulty condition increased from high to low presentation rate (see Figures 6 and 7).

Although the present study did not find any significant relationship between noise level and performance on the STM task, it cannot be concluded that the type of noise found in the typical ship environment does not degrade operational task performance. Since the typical ship environment involves a variety of noise sources (frequency, intensity, and patterning) and a variety of required cognitive tasks, it is recommended that further experiments be conducted on the effects of noise on performance. Independent variables that should be investigated are frequency of the noise, higher intensity levels than these studied and intermittent vs. continuous noise. Difficulty level of the task should also be increased in order to determine where the shift in the filter would occur. These conditions are of particular importance to the Korean Navy since there are many high speed patrol boats where complex decisions must be made under time pressure in a high noise environment.

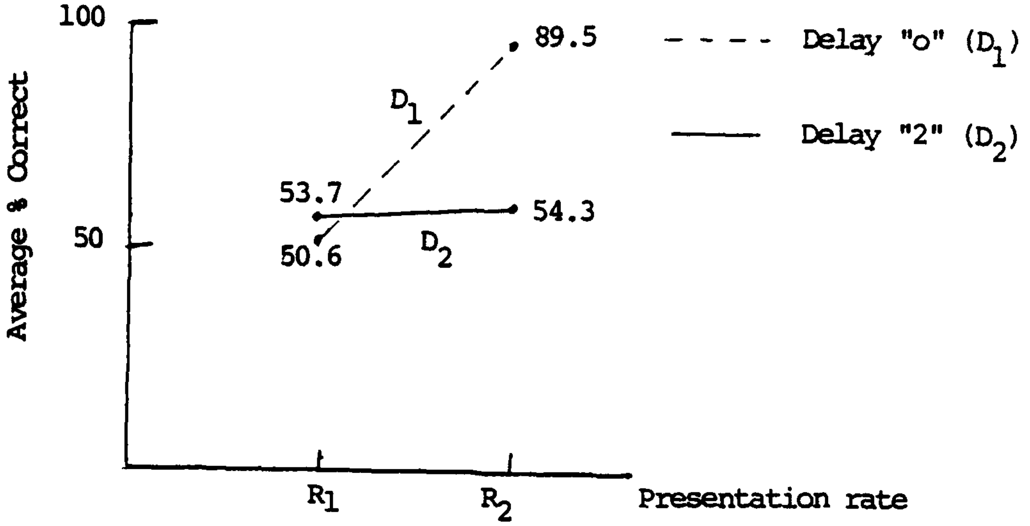
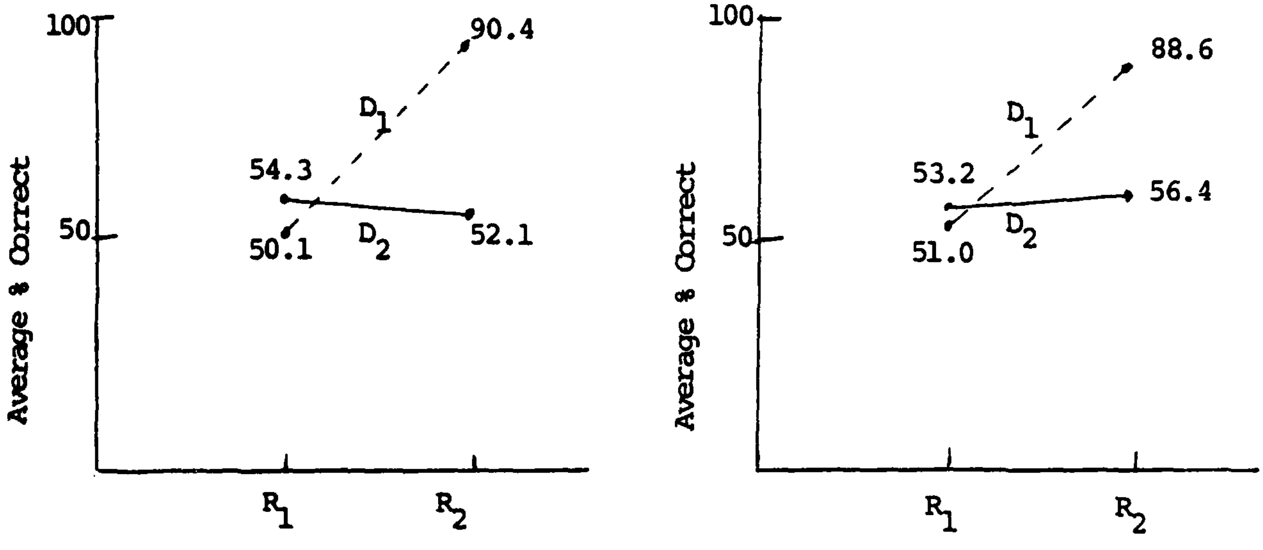


Figure 6. Interaction of R×D



O_1 (left)

O_2 (right)

Figure 7. Interaction of R×D×O

APPENDIX A

INSTRUCTIONS TO SUBJECTS

Read the following instructions according to the experimental condition. RATER is a test of your psychomotor skill. Four different symbols (a plus sign (+), a triangle (△), a circle (O), and a diamond (◇)) will appear in a continuous random series in the viewing window. Each of the four response buttons below the viewing window corresponds to one of the four symbols, your task is to respond to each symbol as it appears by pressing the corresponding correct button.

When you press the correct button, this is indicated by the fact that the display will dim until a new symbol appears in the viewing window. If you press an incorrect button or fail to press the correct button in the time allowed, an error will be recorded. Press each button with a quick touch so that you will have time to make additional responses if you make an error initially.

Press only one button at a time. If you press more than one button simultaneously, an error will be recorded automatically. You will be given a series of practice trials in which to learn the correct button for each symbol. Remember that the sequence of the symbols is completely random. Runs of the same symbol may occur. Do not try to anticipate which symbol will appear next. Unless you are told otherwise, the correct button for each symbol will be fixed and will not change during the test.

Place the thumb and forefinger of each hand on the response buttons. Maintain this position throughout each trial. Watch for the ready light. A trial begins three seconds later when the Test Light comes ON. Each trial will last 2 minutes, followed by a 1 minute rest period. Now you will have 8 trials under different conditions. Please put the earphone on. You will have two practice runs.

A. INSTRUCTION FOR CONDITION, $O_1D_1R_1$ and $O_1D_1R_2$

Place the response unit on the left side of the desk (there is a special marked position). Press the corresponding correct button when each symbol appears in the viewing window.

B. INSTRUCTION FOR CONDITION, $O_1D_2R_1$ AND $O_1D_2R_2$

Place the response unit on the left side of the desk (there is a special marked position). Your task is to respond to the symbol that was displayed two-back from the one that is currently displayed. You will see each symbol for 1 second or .75 seconds.

For example, the sequence of representation is a diamond (◇), a plus sign (+), a triangle (△), and a circle (O). The first symbol is a diamond and the third one is a triangle. While the triangle is showing, you would press the diamond button. At that time you will see the circle. Now you would press the plus sign button (i.e., two back).

C. INSTRUCTION FOR CONDITION, $O_2D_1R_1$ AND $O_2D_1R_2$

Place the response unit on the right side of the desk (there is a special marked position). Press the corresponding correct button when each symbol appears in the viewing window. You will see each symbol for 1 second or .75 seconds.

D. INSTRUCTION FOR CONDITION, $O_2D_2R_1$ AND $O_2D_2R_2$

Place the response unit on the right side of the desk (there is a special marked position). The procedure is the same as that in paragraph B.

Do not change the position of the chair and the desk during the experiment. Do you have any questions?

APPENDIX B

THE FORMAT OF DATA COLLECTION

SUBJECT # ______

CONDITIONS

	$O_1D_1R_1$	$O_1D_1R_2$	$O_1D_2R_1$	$O_1D_2R_2$	$O_2D_1R_1$	$O_2D_1R_2$	$O_2D_2R_1$	$O_2D_2R_2$
Order of Presentation								
Number of Correct Responses								
Total Responses								
% Correct $(\frac{\#\ \text{correct}}{\#\ \text{total}})$								

APPENDIX C

RAW DATA

	$O_1D_1R_1$	$O_1D_1R_2$	$O_1D_2R_1$	$O_1D_2R_2$	$O_2D_1R_1$	$O_2D_1R_2$	$O_2D_2R_1$	$O_2D_2R_2$
S1	55.4	85.9	50.0	43.8	72.0	84.2	40.6	32.2
S2	39.4	85.6	45.9	35.6	52.3	75.6	42.0	47.9
S3	40.0	93.3	40.8	61.3	40.1	91.9	57.4	69.1
S4	42.6	96.7	57.5	48.3	56.9	85.6	64.2	66.3
S5	55.6	86.5	54.0	47.8	43.5	88.7	46.8	52.2
S6	66.0	93.7	65.9	59.4	70.4	95.1	57.9	76.0
S7	46.6	93.6	55.6	58.9	55.9	90.8	49.6	60.8
S8	48.6	86.9	51.7	48.3	49.7	89.4	50.8	50.9
S9	46.5	95.1	52.7	32.5	35.9	91.1	36.9	47.5
S10	55.1	90.3	54.5	44.5	60.7	90.5	61.6	47.1
S11	38.7	98.3	56.3	53.7	39.5	94.2	59.3	51.1
S12	56.8	86.0	59.8	67.3	54.8	77.7	64.2	68.6
S13	45.4	96.7	64.6	44.2	50.9	95.0	55.8	43.1
S14	36.3	76.8	60.4	62.8	48.6	82.4	53.5	58.8
S15	64.1	90.0	67.3	53.7	46.2	95.0	53.2	66.0
S16	40.7	90.9	56.5	63.6	46.4	91.6	53.8	61.4
S17	50.9	85.6	38.6	46.8	34.8	83.1	47.6	46.0
S18	34.0	81.7	58.6	58.4	33.8	80.4	60.0	63.7
S19	52.9	91.0	41.4	59.7	57.5	85.6	54.2	59.1
S20	50.7	91.4	45.8	49.5	42.3	86.2	45.0	51.5
S21	62.3	93.3	56.9	50.0	63.1	95.0	64.1	63.4
S22	55.6	93.4	58.1	51.3	51.1	93.3	46.1	54.1
S23	61.0	95.0	51.6	55.6	58.9	93.4	63.1	55.4
S24	57.6	93.3	58.1	54.3	59.5	90.9	48.8	61.0

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