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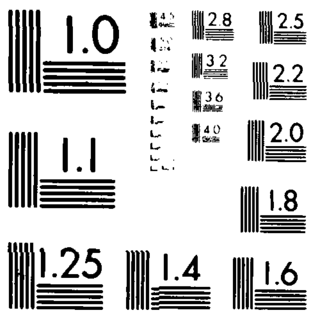

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Monterey, California

THESIS

Comparison of Performance on a Tracking Task Utilizing Binocular, Dominant and Non-Dominant Viewing

by

Madan L. Madan

March 1980

Advisor Douglas F. Neil
Co-Advisor William F. Moroney

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This study was designed to compare performance on a tracking task utilizing Binocular, Monocular (dominant) and Monocular (non-dominant) viewing. Performance was evaluated in terms of number of errors, error time and fatigue. Twenty-eight students at the USN Postgraduate School served as subjects for the experiment. Each subject performed in all three viewing conditions.

Analysis of the data suggests that for the tracking task binocular vision is superior to the monocular vision. Furthermore,

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Comparison of Performance on a Tracking Task Utilizing Binocular, Dominant and Non-Dominant Viewing

by

Madan L. Madan
Lieutenant Colonel, Indian Army

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

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March 1980

Author: ______________________

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ABSTRACT

This study was designed to compare performance on a tracking task utilizing Binocular, Monocular (dominant) and Monocular (non-dominant) viewing. Performance was evaluated in terms of number of errors, error time and fatigue. Twenty-eight students at the USN Postgraduate School served as subjects for the experiment. Each subject performed in all three viewing conditions.

Analysis of the data suggests that for the tracking task binocular vision is superior to the monocular vision. Furthermore, performance when the dominant eye is used is significantly better than when the non-dominat eye is used. Finally, significantly less fatigue was reported under the binocular and dominant viewing conditions than under the non-dominant eye viewing condition.

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I. INTRODUCTION

The real world is three-dimensional and information is normally acquired and processed in a three-dimensional format. However, the inability to transmit information directly is limited by the lack of three-dimensional displays. Current off-the-shelf technology is limited to two-dimensional displays which reduce the cues available to the system operator.

For comparative evaluation of the evolving three-dimensional displays and the extant two-dimensional displays which are proposed to be replaced, comparative costs and effectiveness of the two systems are required. Standard methods are available for estimating costs of a system. However, methods of evaluating comparative human performance on equivalent two-and three-dimensional displays haven't yet been established.

Ideally one should take a two-dimensional and a three-dimensional representation of the same given task and evaluate human performance. But the difficulty is, how to provide equivalent representation? To answer this question, one has to study the process of perception and control variables so as to provide the desired equivalents.

Postman and Egan (1949) have reported that if an observer closes one eye, he has certain depth cues available to him. It was proposed that if these depth cues are eliminated, the third-dimension of depth will be lost to the 'one-eyed' observer who will now perceive only two-dimensions of an actually three-dimensional display. If the observer now opens his second eye, he will correctly perceive the apparatus as a three-dimensional display. Thus by using a three-dimensional apparatus and letting an operator perform in binocular viewing conditions, his performance may be equated to three-dimensional performance. If however, one eye of the operator is blocked and certain depth cues are eliminated, his performance may now be treated as equivalent to a two-dimensional performance. Thus subject's performance in binocular and monocular (controlled) viewing can be used to infer comparative evaluation of two- and three-dimensional displays.

An experiment was designed for the evaluation of subjects performance on a tracking task with provision to control the depth cues available in monocular viewing condtions. Performance was evaluated in terms of number of erros, error time and fatigue. The details of the experiment and findings are discussed in this report.

During organization of the experiment, the subject of ocular dominance was presented as a potential variable. It should be noted that performance with either eye may not be equivalent because one eye may dominate. Therefore, the tracking task was performed under three viewing conditions- binocular, monocular dominant and monocular non-dominant.

A. PERCEPTION

Perception is the process of information extraction from physcial energy which stimulates the organism's senses. The main components of perception are: Physcial energy (stimulation by energy); sensory transduction (of received energy); intervening brain activity (brain reception, selection and modification) and experience or response.

In visual perception, essential information is carried by the stimulus and modified by the organism. Perpetual attention is influenced by short term sensory experience (imprinting, figural after effects, illusions and adaption levels) and long term sets resulting from practice, training and learning. The spatial dimension is an important part of the relationship underlying the perception of motion and certain other physical and social events. The total act of spatial perception can be broken down into sub-processes for study. This involves utilization of interacting cues. (Gibson, 1966)

Since this thesis is concerned with visual performance on a tracking task, the following aspects of visual perception and tracking will be discussed: depth cues; monocular and binocular vision; ocular dominance and tracking skills.

B. DEPTH CUES

Perception of depth is the result of interacting processes. Visual depth determiners can be classified into primary and secondary cues. The primary cues are effective in direct sensory perception. Secondary cues are used to create depth effects in drawings, paintings, displays, and in situations where primary cues are not sufficient.

1. Primary Cues

a. Eye Muscle Adjustments

These are cues of accommodation and convergence. Accommodation is the change of crystalline lens by ciliary muscles to focus objects as distance varies. Changes in accommodation affect the amount of microstructure (quality of detail) perceived. These changes in microstructure provide visual cues of distance.

b. Binocular Disperity

Stimulus coming from points outside the horopter (theoretical circle which connects corresponding points and passes through the point of fixation and the centers of rotation of the two eyes) produce separate images on the retina. This disparity between two images is called binocular disparity and is a cue to relative depth or distance.

2. Secondary Cues

a. Size and Prospective

As the distance from an object increases the size of its retinal image decreased and we have: s/n = S/D where s = size of retinal image (proximal size), n = distance from optical nodal point of eye to retina (constant depending on size of eye ball), S = actual size of object (distal size) and D = distance of object. Thus s is proportional to S/D. If the real size of an object (distal) and its retinal image size (proximal size) are known, we have a good potential indication of its distance. We require past-experience with that particular object to be invoked for the judgment of distance. The proximal stimulus is larger when the object is closer. Apparent relative distance or depth is influenced by relative size, i.e. larger objects appear nearer.

b. Texture and Density Gradient

Texture becomes finer as distance increases. Any angular markings or visible textures undergo a prospective transformation such that in the retinal images, there is a gradient of texture density, i.e. there is a specific rate of change in the density of the texture's projections to the eye that is directly correlated with the way objects and surfaces are arranged in the world. Because any spatial arrangement of objects and distance can produce the same texture density gradients under very different illumination and with very different textures, texture gradient is a stimulus to which the visual system can respond. The gradients in the retinal image are directly correlated with objective arrangements and the subjects perception.

c. Superposition (interpostion)

Junction points between two objects provide the only determiners of interposition. If the view of an object is obstructed by the presence of another, we will see the obstructed one as farther away.

d. Aerial Prospective

More distant objects appear to be bluer. Colors of an object may undergo changes as the light waves reflected from the object travel through the haze of the atmosphere. Thus the distant mountains are blue in the clear country area and buildings a few blocks away are grey when seen through the smog of the city. Green leaves of a distant tree take a bluish tinge. Also, the apparent brightness of an object diminishes as its distance increases. This distance cue plays an important role over relatively long distance.

e. Light and Shade

Appearance of spatial depth of an object is degraded when it completely lacks shadows. Shading of rounded or angular surface is an indication of depth and relief. If the direction of illumination is known then an object standing in a shadow is seen to bear a definite spatial relation to the object casting the shadow. The pattern of shadow and its location help in judging depressions or elevations in the land.

f. Relative Brightness

Brighter surfaces appear to be nearer, duller surfaces appear farther away.

g. Motion Parallax

With one eye closed and two fingers held up one behind the other 10 inches apart, movement of the head from side to side makes the near finger move in the opposite direction of the head. This is called the phenomenon of motion parallax and it aids in judging distance by perception of relative movement. Also, the nearer the object, the faster it appears to move.

h) Clarity of Detail

Perception of depth is a matter of visual acuity. If we cannot see the details of an object, we consider it far away. There exists an innate potential to respond to various relationships which lead to our perception of space. For good depth effect, magnification and contrast should be high, image sharp, tone continuous and surface glossy (Evans, 1948).

If an observer closes one eye, cues available to him for perception of depth are reduced. "One-eyed" observers rely primarily on the following cues: interposition of objects, clearness of detail, changes in colour, lights and shadows, movement parallax and accommodation (Postman and Egan, 1949).

C. MONOCULAR AND BINOCULAR VISION

There is neither psychological nor physiological evidence to support the assumption that the eyes of man represent two independent, parallel, visual channels.

1. Size/Distance judgment

Size/distance judgments change as a function of viewing conditions, i.e. monocular vs binocular (Shontz and Trunn, 1958). In binocular viewing conditions the judgment is better whereas in monocular viewing conditions, the cues are curtailed and hence, the process of judgment is less efficient.

2. Apparent Length

Perception of apparent length of a straight line under monocular and binocular conditions was investigated by Fried (1964), who found that for monocular and binocular stimuli to be perceived as equal in length, the monocular stimulus has to be made much longer than the binocular. Without binocular cues, objects appear smaller and hence farther away.

3. Brightness

Eyes have complementary shares in the function of binocular brightness (Levelt, 1966). Binocular visual acuity yields a lower threshold than monocular (Horowitz, 1949). Visual detection capacity under binocular viewing conditions is reported to be about 1.5 times better than under monocular viewing conditions (Kristofferson, 1958).

4. Reaction Time

Reaction time to visual signals has been found to be longer under monocular than binocular viewing conditions (Conticelli and Fujiwara, 1964).

5. Tracking Rate

Central and peripheral retinal areas may be treated as two sensory input channels (Vallerie, 1966). Youngling (1968) found that as target tracking rate is increased, performance on detecting peripheral signals falls off as a function of distance out in the periphery.

D. OCULAR DOMINANCE

The dominant eye has been defined as the eye which is used to sight with or whose input is favored when there is conflicting information to the two eyes. To understand the definition of ocular dominance, attributes being measured by most current ocular dominance tests were studied by Corren and Kaplan (1972). They administerd thirteen of the most frequently used tests for dominance, i.e. two alignment tests, hole test; Miles ABC test, Asher test, two tests employing rivalry; two test of perceptual salience or priority; two tests incorporating aspects of motoric control of the eyes and associated structures; test for laterality of function and one test to measure refractive assymetries. All thirteen tests were administered in one session to fifty-seven volunteer subjects with normal vision. The data was factor analyzed using varimax solution and $\alpha = 0.05$ for establishing the inter-relationship between the measures. This led to ultimate extraction of the three factors mentioned below which accounted for 45 percent of the variance.

1. Sighting Dominance

The primary factor included six of the above thirteen tests (all three sighting tests; both alignment test and one motor function test). This factor accounted for 67 percent of the common variance and included a number of tasks which all required that input from one eye either be excluded or ignored. Coren and Kaplan (1972) suggested that this factor indicated a cluster of tests associated with ocular preference or sighting dominance. The dominant eye is preferred for tasks in which both eyes cannot be used simultaneously.

2. Acuity Dominance

The second factor which accounted for 17 percent of the variance involved two tasks (visual acuity loading and Dichoptic Flash tests) reflecting the system's response to degraded or ambiguous stimulus array, e.g. targets very difficult to resolve or presented very briefly. In such situations, input of the eye with better visual acuity was favored. Coren and Kaplan (1971) have termed this factor as acuity dominance.

3. Sensory Dominance

The final factor included only two of the thirteen tests (both rivalry tests) and accounted for 16 percent of the common variance. Ocular dominance of this type seemed to appear in situations when conflicting inputs were given to the two eyes. Coren and Kaplan (1972) have labelled this factor as sensory dominance. The eye that dominates when there are sustained discrepant inputs is the sensory dominant eye.

E. TRACKING SKILLS

Tracking is concerned with the execution of accurate movements at the correct time. Tracking may involve true motion or relative motion and tracking along a contour of a target and utilization of eyes and/or hands. Most everyday tracking tasks are self paced, but paced tasks are generally studied in the laboratories. Driving an automobile involves tracking with a control system of high order.

For tracking tasks' analysis, test trials should be short. They should be separated by adequate rest periods during which the subject is told how well he is doing. Instructions, number of practice trials, length of practice trials and time between trials influence tracking behavior (Poullon, 1974).

Measures of the error function reflect the interactions reflect the interactions between the track and the subject's responses. Reasonably large quick movements have an average error of about 5 percent of their size. Very small quick movements are a good deal less accurate. In general, to achieve greater accuracy, movements have to be made more slowly so that they can be monitored visually and corrected if necessary.

II. PROBLEM DEFINITION AND HYPOTHESIS FORMATION

A. THE PROBLEM

The real world is three-dimensional and information is acquired and processed in a three-dimensional format but viewed on two-dimensional displays. This conflict has led to the devlopment of three-dimensional displays. Potential applications for three-dimensional displays range from educational and research oriented applications through computer aided design of complicated three-dimensional structures for tactical applications and for air traffic control.

However, three-dimensional display technology is expensive and of no avail if the data presented are not easily understood and assimilated by the viewer. It is, therefore, important to ascertain the theoretical limitations and practical efficiency of much methods. The effectiveness of the display depends on integration of the factors previously mentioned and on the type of task to be performed.

Before adopting any three-dimensional display system for a given type of task, it is essential to examine the cost effectiveness of the three-dimensional display system and the two-dimensional display system which it is proposed to replace. This would enable the decision maker to get a clear picture of cost and performance trade offs.

Standard procedures are available for estimation of costs of various systems. However, procedures for the evaluation of the quantitative comparative effectiveness of two-dimensional vs three-dimensional display system have not been clearly established. The object of this thesis is to compare the effect on a tracking task.

When a subject performs on a three-dimensional tracking apparatus keeping both eyes open, his performance may be assumed to correspond to three-dimensional display performance. He can perceive the length and breadth of the task, depth of the whole apparatus and relative position of the probe and track in a tracking task. But when the subject closes one eye and certain depth cues (Postman and Egan, 1949) are eliminated, his performance may now be equated to performance on two-dimensional display. Thus by using binocular viewing and monocular viewing (with depth cues eliminated), we can perform experiments for comparison of two-and three-dimensional displays. If the same apparatus were used for both viewings, errors due to distortions in representation would be eliminated.

By the above argument, results of this study utilizing binocular and monocular viewing can be extended for two- and three-dimensional display performance comparisons.

B. HYPOTHESIS

Three hypothesis will be evaluated in this study.

1. <u>Binocular vs Monocular (Dominate)</u>

The null hypothesis states that there is no difference between effectiveness of Binocular and Monocular (dominant) viewing for performance in the given tracking task against the alternative hypothesis that there is a difference is effectiveness.

2. <u>Binocular vs Monocular (Non-Dominant)</u>

Null hypothesis to be tested here is that there is no difference between effectiveness of binocular and monocular (non-dominat) viewing for performance in the given tracking task against the alternative hypothesis that there is a difference in effectiveness.

3. <u>Monocular (Dominant) vs Monocular (Non-Dominant)</u>

The null hypothesis states that there is no difference between effectiveness of monocular (dominat) and monocular (non-dominant) viewing for performance in the given tracking task against the alternative hypothesis that there is a difference in effectiveness.

Performance evaluation has been broken down into: number of errors committed; percentage of total tracking time spend on errors and subjective fatigue under different viewing conditions.

III. METHODOLOGY

A. APPARATUS

The apparatus for the experiment consisted of two 12 gauge copper wires placed approximately parallel to each other about .6 cm apart. The track thus formed was zig-zag with random smooth turns (as shown in figurel). The length of the track was about 210 cms. The track was mounted on a board 60 x 75 cm with the help of 24 supports evenly placed throughout the track length. At both ends of the track, there were contact points for starting and stopping the measurement of performance.

A copper wire mesh was laid between the track and the board surface for providing contacts for error in depth perception. The probe (figure 2) consisted of 12 gauge wire with a disc at its head to form a 'T'. The diameter of the disc (1 cm) was greater than the distance between the parallel tracks so that the disc couldn't be removed from the track except at the start and end portions.

The wire connecting the probe to the computer for scoring was attached to the wrist of the subject by a velcro strap. For symmetry of field of view, special goggles were used. They reduced peripheral vision and were capable of blocking a given eye of the subjects.

The track apparatus was placed on a black table top at approximately 80 cms from ground level in a sound proof cubical

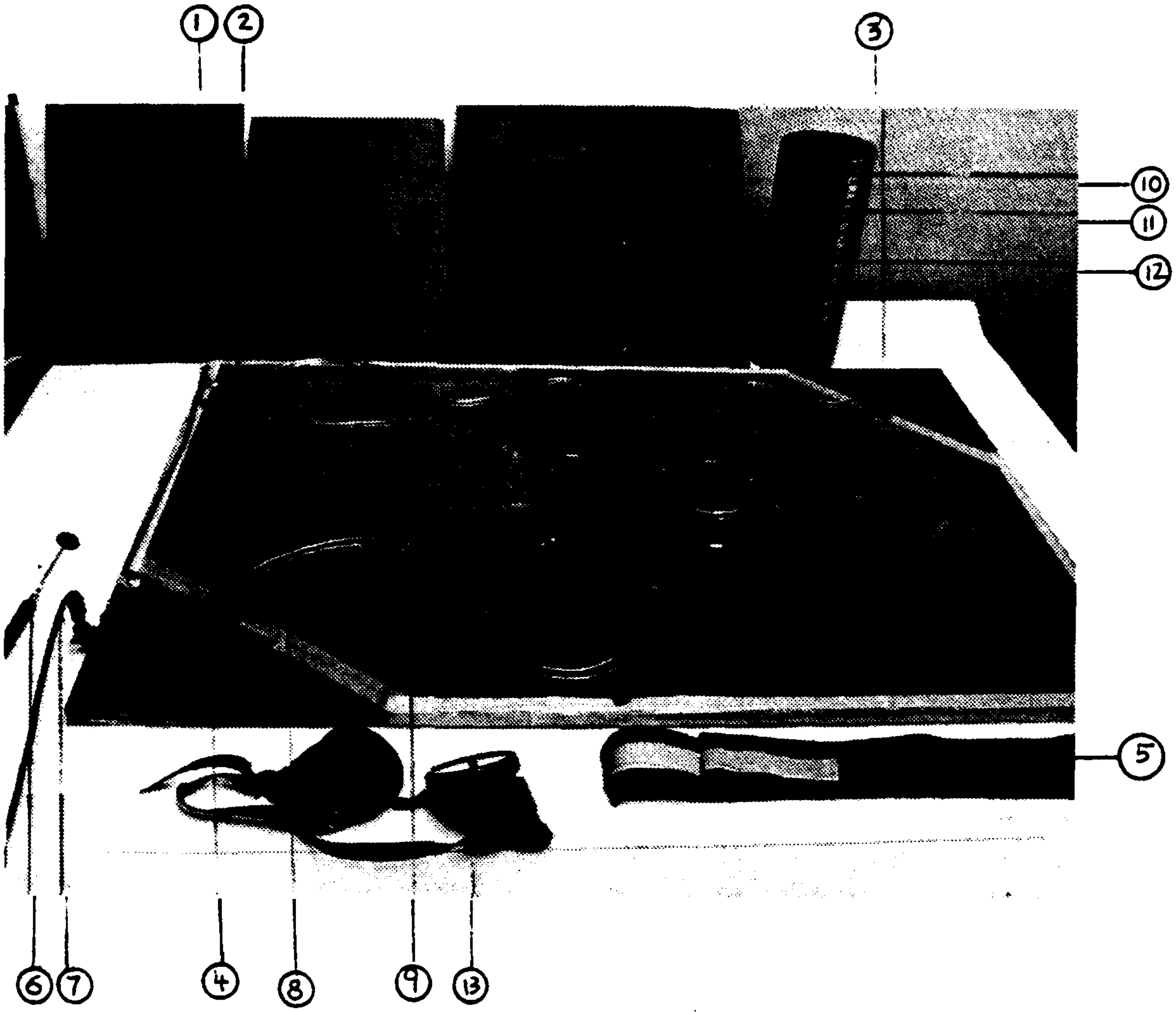


Figure 1: TRACKING APPARATUS

1. Board for track
2. Wire mesh
3. Start contact
4. Stop contact
5. Velcro Strap
6. Probe
7. Connecting wire
8. Copper track (length 210 cm)
9. Supports for track (N = 24)
10. Tube for alignment test
11. Black card with 1.25 cm.dia hole
12. Two cards for Asher Test
13. Goggles

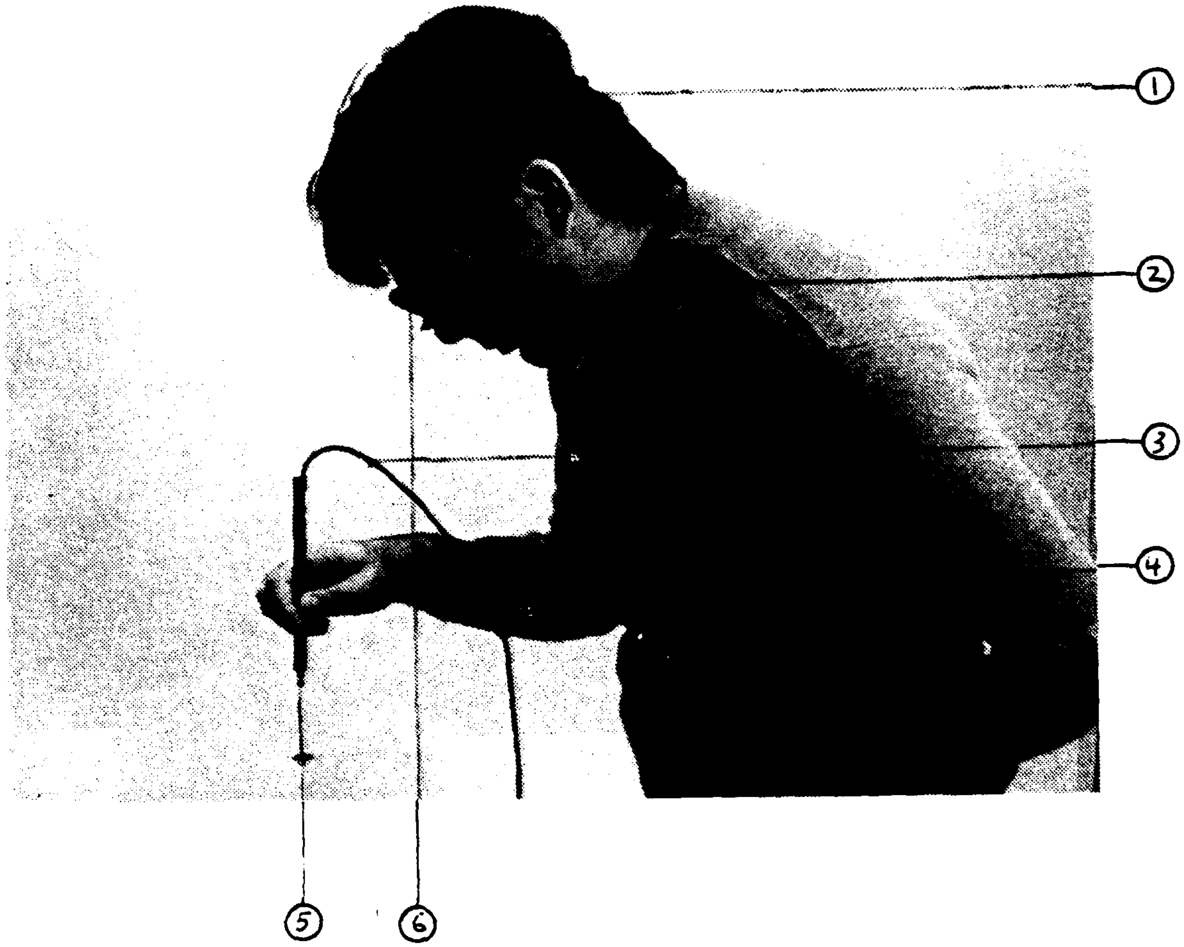


Figure 2: PREPARATION OF SUBJECT

1. Elastic support (adjustable)
2. Blocked peripheral vision
3. Lead to PDP8
4. Velcro Strap
5. Probe
6. Threads for screwing opaque glass

and attached to a DIGITAL PDP8 computer. The cubical was used to avoid distraction and to control illumination on the track. Illumination levels are reported in Appenix A. The PDP 8 recored: number of errors; duration of errors and total time to complete the task (see Appendix B).

B. SUBJECTS

Twenty-eight students at NPS served as subjects. They were international students at the Naval Postgraduate School, Monterey, undergoing Master's programs in various fields.

All subjects were within the age group of 25 to 35 years and had 20/20 vision, 25 percent of the subjects had corrected vision. They had no difficulty in using their glasses with the apparatus for the experiment. Subjects served as their "own controls" during the experiment, i.e. each subject was tested under each viewing condition. Subjects volunteered and received no compensation for participation.

C. PROCEDURE

1. Tracking Task

As illustrated in figure 2, subjects wore goggles while performing under three viewing conditions to have uniformity of peripheral vision. The blocking of vision of the described eye was done by screwing on an opaque piece on threads provided on the goggles. The probe was held in the desired hand and its connecting wire was attached to the forearm with a velcro strap.

The subject positioned himself in front of the table containing the apparatus as shown in figure 3. The subject was free to use the other hand for support as indicated in instruction set number 1 (Appendix C).

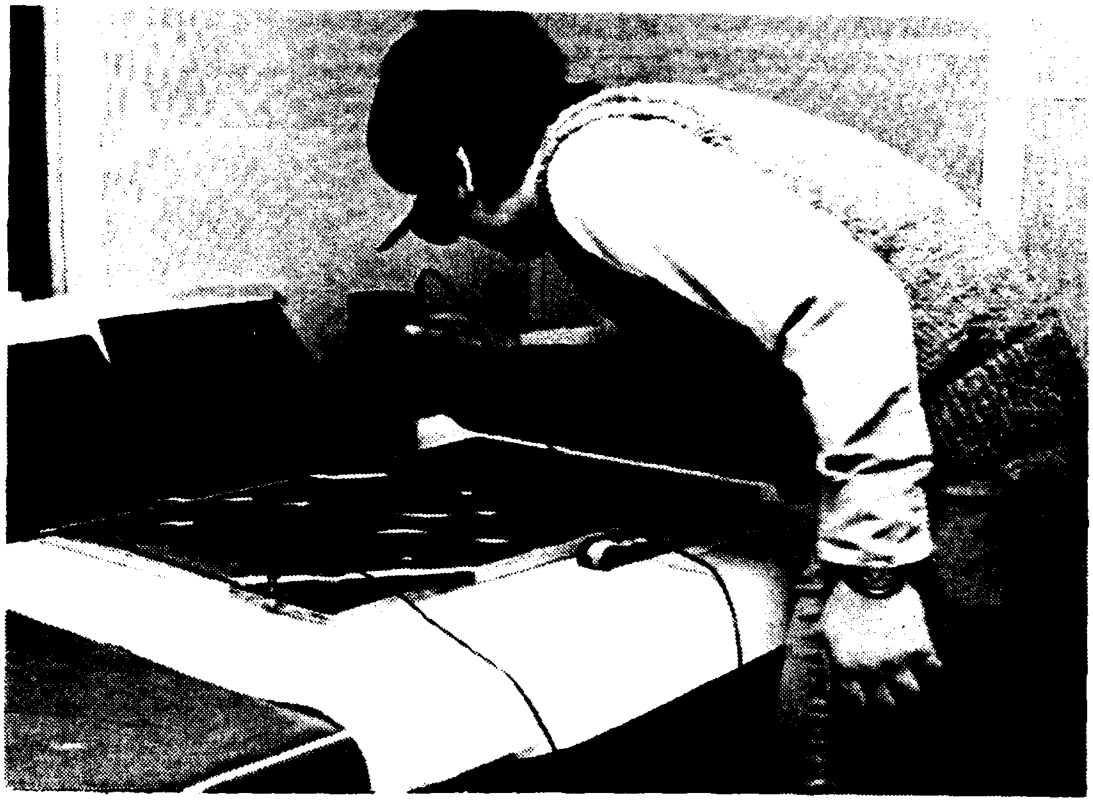


Figure 3: SUBJECT PERFORMING TASK

To eliminate order effect, a 3 x 3 Latin square was used.

2. Fatigue

Fatigue was measured by filling feeling tone check lists (Pearson, 1956) Form A (Appendix D) and form B (Appendix E) as per instruction number 2 (Appendix F). Feeling tone check lists contain randomly arranged statements about subjective fatigue on a scale of 1 to 9. Forms A and B are equivalent and were presented to the subjects in random sequence. One form was completed prior to start of the test and on completion of each viewing condition performance as per instruction number 1 (Appendix C).

3. Ocular Dominance Tests

To test ocular dominance, standard tests were conducted as described by Coren and Kaplan (1949). For all the tests described below, subjects were instructed to keep both eyes open. For detailed instructions to the subjects for ocular dominance tests, see instruction number 3, Appenidx G. Results of these tests were recorded on ocular dominance recording form (Appendix H).

Five sighting tests were used. All these tests required a near and a distant object to be brought in alignment with the dominant eye. The specifics of each test follows:

a. Pointing Test

Subject was asked to point at the examiner's nose. The eye with which the finger was aligned was noted. This was repeated four times. Each right-eye alignment was scored +1 and left eye alignment was scored -1. Hands used to point with were alternated to control for any bias due to handedness.

b. Alignment Test

A tube 8 cm in diameter, 9 cm long with a vertical wire fixed to each end was given to the subject. Subject was instructed to hold the tube in both hands and visually align the wires. The eye in line with both wires is the dominant eye. This was repeated four times and scored as in pointing test.

c. Hole Test

Subject viewed a target through a 1.25 cm dia hole in a 30 cm square black card held in both hands. This was repeated four times and scored as above.

d. Miles Test

Subject covered his face with a truncated cardboard cone which had to be squeezed in order to see through the aperture. With both eyes open, the subject viewed a target. Eye used was noted. The test was repeated four times and scored as before.

e. Asher Test

The subject held two 30 x 27.5 cm cards one in each hand and gradually brought item closer together until all that was seen was the experimenter's nose. The eye aligned with the remaining slit was noted during four trials and scored as above.

D. DATA ANALYSIS

Basic steps in analysis of data in this study were: statement of null hypothesis (H_0); choosing of appropriate statistical tests; specification of significance level (α) and sample size (N); finding sampling distribution of statistical test under H_0; definition of rejection region; computation of values of statistical test and acceptance/rejection of H_0.

As stated earlier, performance with different viewing conditions were evaluated in terms of: number of errors, percentage of total tracking time spent on errors and subjective fatigue. Number of errors and percentage of time on errors was recorded directly by the PDP 8. Because of the distribution of the data, nonparametric analysis techniques were applied or the data was normalized by transformation and parametric analysis techniques were performed.

In the present study, the attempt was to establish whether monocular and binocular performances are different. To eliminate the effect of other variables, the same subjects were tested for performance in all viewing conditions. Thus subjects "served as their own controls." A Latin Square was used to control for order effect, individuals were randomly assigned to Latin Square rows.

IV. DATA COLLECTION AND HYPOTHESIS TESTING

Data collected during the study is tabulated in (Appendix I). Two 28 x 3 matrices were created and called 'ERROR' (giving percentage of total tracking time spent on erros) and 'NUMBER' (number of errors committed during tracking). These matrices are contained in (Appendix J). Analysis of data collected is discussed below.

A. NUMBER OF ERRORS

The output of the square root transformation of 'NUMBER' is attached as (Appendix K). Bartlett's test was conducted on original and square root transformations of 'NUMBER' to test for uniformity of variance in order to justify use of Analysis of Variance (ANOVA). It was found that Bartlett's test (Appendix L) accepts homogeneity of variances in original and square root transformations of 'NUMBER'. The stemleaf plots indicate normality of the data. Hence as these two conditions are satisfied, parametric test ANOVA could be used.

Results from ANOVA indicate that there is a significant difference in number of errors committed by the subjects while under the three viewing conditions. Results also indicate that there are significant differences in subjects' performances within each viewing condition at the given α value.

To establish where the differences lie the Newman Keul Range Test was used. The calculations for this test on '$\sqrt{\text{NUMBER}}$' are attached at (Appendix M).

TABLE I: A COMPARISON OF NUMBER OF ERRORS COMMITTED UNDER THREE VIEWING CONDITIONS

Source	DF	SS	MS	F
Viewing Conditions	2	83.28	41.64	25.02*
Subjects	27	109.11	4.04	2.43*
Error	54	89.83	1.66	
Total	83	282.23		

*$p < 0.01$

On examination of tabulated data and results of the Newman Keul Range test, it appears that the number of errors increase as we proceed from binocular to monocular (dominant) to monocular (nondominant) viewing condition performances.

B. PERCENTAGE OF TOTAL TRACKING TIME ON ERRORS

Data collected during analysis of square root transformation of percentage of total tracking time on erros is contained in (Appendix N). Bartlett's test was conducted on "$\sqrt{\text{ERROR}}$" to test for uniformity of variance to check if ANOVA could be carried out on this data. It was found that Bartlett's test (Appendix O) accepted homogenity of variance. The steamlieaf plots indicated normality of data. Hence as these two conditions were satisfied, parametric test ANOVA could be used.

Results also indicate that there are significant differences between subjects' performances within each viewing condition.

TABLE II: A COMPARISON OF ERROR TIME UNDER THREE VIEWING CONDITIONS

Source	DF	SS	MS	F
Viewing Conditions	2	16.26	8.13	108.01*
Subjects	27	23.34	0.86	11.49*
Error	54	4.06	0.08	
Total	83	43.66		

*$p < 0.01$

Results from ANOVA indicate that there is a significant difference in percentage of total tracking time spent on errors by subjects while performing in the three viewing conditions. Results also indicate that there are significant differences between subjects' performances within each viewing condition.

To establish where the differences were, the Newman Keul Range Test was performed. Calculations for this test on "$\sqrt{\text{ERROR}}$" are attached at (Appendix P).

On examination of tabulated data and results of range test in (Appendix Q), it appeared that percentage of total tracking time spent on errors was greater in monocular (non-dominant) viewing performance as compared to the binocular viewing performance. Differences in performances between binocular and monocular (dominant) were not significant. Differences in performances between monocular (dominant) and monocular (non-dominant) were also not significant.

C. SUBJECTIVE FATIGUE

Because of a number of zeros in the subjective fatigue matrix, this matrix could not be analyzed in the same manner as the number of errors and error time. The results are exhibited in (Appendix Q).

H_o: There is no difference in subjective fatigue between three viewing conditions was rejected and therefore, there was a difference in subjective fatigue caused due to performances in the three viewing conditions.

On examination of tabulated data (Appendix Q), it appeared that there was no difference between binocular and monocular (dominant) viewing performances fatigue levels but monocular (non-dominant) viewing performance caused higher subjective fatigue.

V. SUMMARY AND CONCLUSIONS

A. SUMMARY

There are many potential applications for three-dimensional displays. However, such displays are expensive and are of no avail if the data presented is not easily understood and assimilated by the viewer. It is, therefore, important to ascertain the theoretical limitations and practical efficiency of much displays.

Any rational decision to adopt three-dimensional display systems for a given type of task requires information about cost and effectiveness of two-and three-dimensional display systems. Standard procedures are available for estimation of costs of various systems but procedures for evaluation of comparative effectiveness of two-and three-dimensional display systems don't seem to have been clearly established. The aim of this thesis was to take a step towards this goal for a sample tracking task.

Twenty-eight subjects were selected from the international student population at the Naval Postgraduate School, Monterey, California. They were all undergoing Masters' programs in various curricula. All were within the age group of 25 to 35 years and had normal/corrected vision.

The apparatus consisted of a track about 210 cm long with 2 parallel 12 gauge copper wires in a random zig-zag layout on a horizontal board. Errors were recorded on a PDP8 computer which was connected to the track and probe.

All subjects were given three practices (one in each viewing condition) before conducting the actual test. Performance evaluation was done in three subparts: number of errors; percentage of total tracking time spent on errors and subjective fatigue. The three viewing conditions were: Monocular (dominant); monocular (non-dominant) and binocular.

In the analysis of collected dats, normality of distribution was estimated from steamleaf plots and uniformity of variance was tested by Bartlett's test. Only after these conditions were satisfied, parametric test ANOVA was used to carry out significance tests, α was set at 0.05. Subjects served as their own controls (same subjects performed in all three viewing conditions) giving precise matching. To eliminate order effect, a 3 x 3 Latin Square was used.

B. CONCLUSIONS

1. Number of Errors

Mean number of errors were lowest in binocular viewing conditions (75.5) and highest in monocular non-dominant conditions (123.1). Mean number of errors in dominant viewing conditions were 107.3. Performance of binocular conditions is about 39 percent better than monocular (non-dominant). Monocular (dominant) is about 13 percent better than monocular (non-dominant).

Results from ANOVA for number of errors analysis indicate that there is a significant difference in number of errors committed while performing in the three viewing conditions. Results also indicate that there are significant differences in subject's performances within each viewing condition. Newman

Keul Range Tests indicate that numbers of errors are highest in monocular (non-dominant), lower in monocular (dominant) and lowest in binocular viewing condition performances.

2. Percent of Total Tracking Time on Errors

The means for binocular, monocular (dominant) and monocular (non-dominant) viewing conditions were 8.5, 12.3 and 15.7 percent respectively. THus binocular condition performances were about 46 percent better and monocular (dominant) condition performances were about 22 percent better than the monocular (non-dominant) viewing condition performances.

Significant differences exist in percentage of total tracking time spent on errors in three viewing conditions. Within each condition also, differences between subjects' performances are significant. It appears that the percent of time on errors is greater in monocular (non-dominant) as compared to binocular viewing performances. Differences between binocular and monocular (dominant) viewing performances were not significant. Differences between monocular (dominant) and monocular (non-dominant) viewing performances were also not significant.

3. Subjective Fatigue

Fatigue levels were almost the same for binocular and monocular (dominant) viewing conditions. For both of these conditions, fatigue level was about 11 percent as compared to the same in monocular (non-dominant) viewing condition.

Based on the results of data analysis and above observations, it may be stated that for rough estimates, binocular performance is about 40 to 50 percent better as compared to monocular (non-dominant) performance. Within monocular performance, dominant viewing is about 15 to 20 percent better than non-dominant. There is not much of a difference in fatigue levels of monocular (dominant) and binocular viewing conditions but both account for only about 1/10 of the fatigue level for monocular (non-dominant) viewing for the given tracking task.

When a subject performs on a three-dimensional apparatus keeping both eyes open, his performance may be assumed to correspond to three-dimensional display performance. He can perceive the length and breadth of the task, depth of the whole apparatus and relative position of the probe and track in a tracking task. But when the subject closes one eye and certain depth cues are eliminated, his viewing conditions can now be assumed to correspond to a two-dimensional display. Thus by using binocular and monocular viewing with depth cues eliminated, we can perform experiments for comparison of two- and three-dimensional displays. By this argument, results of this study may be extended for comparison of performances of two- and three-dimensional displays.

Friedman two way ANOVA on subjective fatigue data suggests no differences between binocular and monocular (dominant) viewing performances fatigue levels. However, monocular (non-dominant) viewing performance seems to cause higher subjective fatigue as compared to the other two condition performances.

APPENDIX A

WORKSPACE ILLUMINATION

Measurements of illumination of workspace were taken using a Tektronix J-16 Digital Photometer and are indicated below.

A. ILLUMINATION

Without subject's shadow = 8 to 10 foot candles.

With subject's shadow falling on workspace = 5 to 6 foot candles.

B. REFLECTION

Without subjects shadow = .3 to 1 foot lambert.

With subject's shadow falling on workspace = 0 to .4 foot lambert.

Grey surface = .4 foot lambert.

APPENDIX B

COMPUTER PROGRAM TO RECORD EXPERIMENTAL DATA

```
10   REM -   THIS PREAMBLE MUST PRECEEDE ALL PROGRAMS
20   REM -   USING THE LAB8/E 'SPECIAL FUNCTIONS'.
30   UDEF INI(N), PLY(Y), DLY(N), DIS (S,E,N,X)
40   UDEF SAM(C,N,P,T),CLK(R,O,S),CLW(N),ADC(N)
50   UDEF GET(M,L),PUT(M,L),DRI(N),DRO(M,N)
52   REM ********  DECLARE YOUR ARRAYS  *******
55   DIM E(1000)
60   REM ********  BEGIN MAIN LOOP  *******
70   REM **** EACH LOOP PERFORMING ONE ITERATION OF THE EXPERIMENT **
100  PRINT "ENTER SUBJECT #"\INPUT S
120  FOR I2-1 TO 4
122  PRINT "ENTER TYPE ' \INPUT A$
125  Z=DRI(0)
130  GOSUB 250
140  PRINT\PRINT\PRINT\PRINT
150  NEXT I2
160  PRINT "IF YOU HAVE ANOTHER SUBJECT TYPE 1 ELSE TYPE 2 "
170  INPUT I3
180  IF I3 = 1 GO TO 100
190  GO TO 9998
200  REM
210  REM   ****  END OF MAIN PROGRAM  ******
220  REM
250  REM   **** ONE ITERATION *****
260  FOR I=1 to 1000
270  E(I)=0
280  NEXT I
290  PRINT "YOU CAN START"
300  Z=DRI(0)
310  IF Z=0 GO TO 300
315  Z = DRI(0)
320  REM  ****  STARTED GOING THROUGH. ******
322  IF Z = 1  GO TO 315
323  REM  ****  J1 = INDEX INTO ARRAY E  ******
324  L=99 \ REM   ******   STATE  *****
325  J1=0
330  Z=CLK(2,1,0)
334  Z=CLW(0)
338  Z=DRI(0)
340  IF Z<>1 GO to 342
341  IF J1>1 GO TO 360 \IF E(1)>300 GO TO 360\Z = 0
342  IF Z<>L GO TO 350\ REM  *** CHANGE IN STATE ***
344  REM  **** HERE  WHEN STATE DID NOT CHANGE ***
346  E(J1)=E(J1)+1
347  GO TO 330
```

```
348   REM
350   J1=J1+1
352   E(J1)=1
354   L=Z
356   GO TO 330
360   REM  ***** FINISHED .START ANALIZING RESULTS *****
365   PRINT "INTERATION NUMBER ";I2;"__SUBJECT  # ";S
366   PRINT TAB (15); A$\PRINT
367   PRINT "#  INTERVAL DURATION "
368   PRINT "----------------------------"
370   I=0 \I8  \I9=0
380   I=I+1 \I8=I8+E(I+1) \I9=I9+E(I)+ E (I + 1)
400   IF E(I+1)<> 0 GO TO 420
401   PRINT TAB(10)  ;E(I)/ 100 ;TAB(20)  ;E(I=1)/100
402   PRINT \ PRINT
403   PRINT "TOTAL TRAVERSAL TIME =";I9/100; "SEC"
404   PRINT "TOTAL TOUCH TIME ";I8/100;"SEC"
405   PRINT "AVERAGE TOUCH TIME =";(I8/100)/((I+1)/2);"SEC"
406   PRINT "PERCENTAGE OF TOUCH TIME ='I8*100/I9;"%"
410   GO TO 600
420   REM  *** ARRIVE HERE WHENEVER TOUCHES WIRE ***
430   PRINT (I+1)/2 ;TAB(10):E(I)/100;TAB(20); E(I+1)/100 \I=I+1
450   GO TO 380
600   REM   ****  END OF ITERATION ****
610   RETURN
9998  STOP
9999  END

READY
```

APPENDIX C

INSTRUCTION NUMBER 1

1. Your task is to guide the probe through the wires from the start point (upper right) to the end point (lower left).

2. The probe should not touch the wires or the mesh below them.

3. The tracking hand and arm should not be rested on the table or the test board.

4. To begin the task, touch the probe to the flat metal plate at the flat metal plate at the start point. When you have completed the task, touch the probe to the flat metal plate at the end point.

5. The computer will record:

   a. time to complete;
   b. # of errors;
   c. duration of errors.

6. Complete the task with a minimum # of errors and as rapidly as you can.

7. Keeping # of errors low is more important than completing the task quickly.

8. Hold the plastic handle of the probe wherever you feel comfortable.

9. Attach the probe wire to your forearm by velcro strap.

10. Perform the tests standing in front of the table.

11. Wear the given goggles for all tests.

12. Carry out three trials of initial learning - completing the task from start point to the end point each time. First time use both eyes, second time use only left eye and third time use only right eye. Blocking of vision of the unwanted eye should be achieved by using the driving goggles provided.

13. After completing the 3 learning trials, fill in feeling check list form as per instructions # 2.

14. Now draw a card from the set presented.

15. Carry out the tasks in the sequence indicated on the card. There will be a 10 minute break between successive tests.

16. Please don't smoke during the test or during the breaks.

17. Start the tests only after receiving the signal from me to do so.

18. Fill in a feeling check list form during each break and at the end of all 3 tests.

19. Write a brief description of you strategy on the sheets being handed out to you. Also indicate your assessment of comparative task difficulty for the 3 tests.

20. Read and carry out instruction #3 being handed to you.

21. Please don't discuss these tests or your results in them with other potential subjects.

APPENDIX D

FEELING TONE CHECKLIST FORM A

Subject #:

Srl. #	Better than	Same as	Worse than	Statement
1				A little tired
2				Never felt fresher
3				Weary to the bone
4				Quite fresh
5				A little pooped
6				Extremely lively
7				Somewhat refreshed
8				Awfully tired
9				Very rested
10				Dead tired
11				Fairly well pooped
12				Very fresh
13				Tuckered out

Have you checked each statement?

APPENDIX E

FEELING TONE CHECKLIST FORM B

SUBJECT #:

Srl. #	Better than	Same as	Worse than	Statement
1.				Slightly tired
2.				Bursting with energy
3.				Extremely tired
4.				Quite fresh
5.				Slightly pooped
6.				Extremely pooped
7.				Somewhat fresh
8.				Petered out
9.				Very refreshed
10.				Ready to drop
11.				Fairly well pooped
12.				Very lively
13.				Very tired

Have you checked each statement?

APPENDIX F

INSTRUCTION # 2

1. People feel differently at various times for various reasons. We would like to find out how you feel right now. Below you will see 13 statements which describe different degrees of freshness or peppiness and tiredness. For each statement, please determine your feelings at this instant with respect to the feeling described by that statement. Place an 'X' in the appropriate column of 'better than', 'same as' or 'worst than'.

2. Take each statement in order. Don't skip around from one to another. Read each statement carefully so that you understand what it means.

3. This is not a test. You have all the time you need.

APPENDIX G

INSTRUCTION # 3

1. Keep both eyes open at all times during tests.

2. Point at my nose.

3. Bring your hand down and point at my nose again with the other hand. Follow this procedure 3 times.

4. Hold the given tube in BOTH HANDS and align the vertical wires at its ends. Bring the tube down and up again and realign the wires. Do it 4 times.

5. Hold the given black square in BOTH HANDS and look at my nose tip through its hole. Bring the square down and up again to see my nose again through the hole. Repeat the process 4 times.

6. Cover your face with the given truncated cone. See through its aperture to view the indicated target. Now close your right eye and view the same target again. Move the cone ONLY IF it is necessary to align the target. Bring the cone down and up again to view that target - repeating the entire procedure of viewing with both eyes open and then with only the left eye open. Do this 4 times.

7. Hold the given 2 cards one in each hand and gradually bring them closer together until allthat is seen is my nose. Separate the cards again and repeat the process of closing them until only my nose is seen. Repeat the process 4 times.

APPENDIX H

OCULAR DOMINANCE RECORDING FORM

Subject #:

Test #	Test	Result 1	2	3	4	Total
1	Pointing					
2	Alignment					
3	Hole					
4	Miles					
5	Asher					

Score:

+1 for right eye alignment

-1 for left eye alignment

APPENDIX I

SUMMARY OF RESULTS

Subject #	Dominant Eye	Sequence	Binocular			Monocular					
						Non-Dominant			Dominant		
			N	E	F	N	E	F	N	E	F
1	L	LRB	58	6.6	0	83	10.2	1	87	9.8	0
2	L	BLR	87	11.3	0	139	16.5	1	167	15.2	0
3	R	RBL	60	12.9	0	90	17.5	1	77	17.1	0
4	R	LRB	67	12.2	0	80	1[illegible].8	0	48	13.7	1
5	L	BLR	117	10.3	0	152	17.9	1	163	15.2	0
6	L	RBL	111	9.6	0	119	13.1	2	122	10.7	0
7	R	LRB	45	7.4	0	91	12.0	1	86	11.1	0
8	L	BLR	37	3.7	0	72	11.9	1	78	7.5	0
9	L	RBL	79	5.7	0	147	16.1	1	120	12.8	0
10	L	RBL	42	2.7	0	99	7.9	0	83	6.4	0
11	R	LRB	102	13.0	0	96	16.9	1	92	15.4	0
12	R	BLR	47	7.1	1	163	11.7	1	97	9.8	0
13	L	RBL	112	16.7	0	60	25.8	1	142	20.5	0
14	R	LRB	50	6.2	0	118	14.6	1	111	9.1	0
15	R	BLR	76	6.1	0	173	18.5	1	46	8.6	0
16	L	LRB	80	6.2	0	131	15.9	0	117	10.0	0
17	R	BLR	90	7.6	0	166	15.0	1	118	12.1	0
18	L	RBL	122	8.8	0	112	11.0	2	82	9.5	1
19	L	BLR	76	6.7	0	92	16.2	1	109	14.8	0
20	R	LRB	66	10.2	0	109	14.3	1	86	14.2	0
21	R	RBL	86	9.6	1	160	16.6	1	154	10.1	0
22	L	BLR	71	5.0	0	135	9.9	2	126	8.5	1
23	R	RBL	68	3.3	0	174	11.8	1	160	8.8	0
24	R	LRB	45	3.8	0	189	17.9	1	130	7.2	0
25	R	BLR	99	7.8	0	189	17.8	0	136	13.4	0
26	R	RBL	79	8.7	0	127	16.3	1	113	14.7	0
27	R	LRB	75	15.9	0	102	27.7	1	86	21.1	0
28	R	LRB	69	13.7	0	79	22.9	1	70	17.0	0

N = Number of errors.

E = Percent time on errors.

F = Fatigue reported.

APPENDIX J

PERCENT ERROR TIME "(ERROR)" MATRIX

SUBJECTS

BINOCULAR	NON-DOMINANT	DOMINANT
6.6	10.2	9.8
11.3	16.5	15.2
12.9	17.5	17.1
12.2	15.8	13.7
10.3	17.9	15.2
9.6	13.1	10.7
7.4	12	11.1
3.7	11.9	7.5
5.7	16.1	12.8
2.7	7.9	6.4
13	16.9	15.4
7.1	11.7	9.8
16.7	25.8	20.5
6.2	14.6	9.1
6.1	18.5	8.6
6.2	15.9	10
7.6	15	12.1
8.8	11	9.5
6.7	16.2	14.8
10.2	14.3	14.2
9.6	16.6	10.1
5	9.9	8.5
3.3	11.8	8.8
3.8	17.9	7.2
7.8	17.8	13.4
8.7	16.3	14.7
15.9	27.7	21.1
13.7	22.9	17

NUMBER OF ERROR "(NUMBER") MATRIX

SUBJECTS

BINOCULAR	NON-DOMINANT	DOMINANT
58	83	87
87	139	167
60	90	77
67	80	48
117	152	163
111	119	122
45	91	86
37	72	78
79	147	120
42	99	83
102	96	92
47	163	97
112	60	142

NUMBER OF ERROR "(NUMBER") MATRIX

	BINOCULAR	NON-DOMINANT	DOMINANT
	50	118	111
	76	173	46
	80	131	117
	90	166	118
	122	112	82
	76	92	109
	66	109	86
SUBJECTS	86	160	154
	71	135	126
	68	174	160
	45	189	130
	99	189	136
	79	127	113
	75	102	86
	69	79	70

APPENDIX K

OUTPUT OF "√NUMBER" ANALYSIS

COLUMN 1

```
0611
0615779
0711
07167
08112234
081777999
09133
09159
1011
101568
1110

6.1                                                   11
xxxxxxxxxxxxxxxxxx[----------*----------]xxxxxxxxxxxxxxxxxx
```

MEAN: 8.58897
VARIANCE: 1.86774
STD. DEV.: 1.36665
COEFF. OF VARIATION: 0.159117
LOWER QUARTILE: 7.68087
UPPER QUARTILE: 9.40711
MEDIAN: 8.61651
TRIMEAN: 8.61651
MIDMEAN: 8.6037
RANGE: 4.9626
MIDRANGE: 8.56406
MEAN ABSOLUTE DEVIATION: 1.07347
INTERQUARTILE RANGE: 1.72624
COEFF. OF SKEWNESS: -0.0025631
COEFF. OF KURTOSIS: -0.86487

COLUMN 2

```
0717
081599
091155689
10114699
1113468
1213689
1312277

7.7                                                              13.7
xxxxxxxxxxxxxxxxx[------------*--------------------]xxxxxxxxxxxx
```

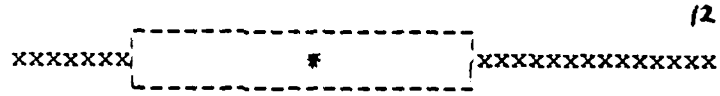
MEAN: 10.9697
VARIANCE: 2.87621
STD. DEV.: 1.69594
COEFF. OF VARIATION: 0.154603
LOWER QUARTILE: 9.56553
UPPER QUARTILE: 12.489
MEDIAN: 10.8857
TRIMEAN: 10.9565
MIDMEAN: 109151
RANGE: 6.00176
MIDRANGE:10.7469
MEAN ABSOLUTE DEVIATION: 1.43214
INTERQUARTILE RANGE: 2.92344
COEFF. OF SKEWNESS: 0.014346
COEFF. OF KURTOSIS: -1.14734

COLUMN 3

06189
071
081488
0911133368
10145689
111002479
1214689

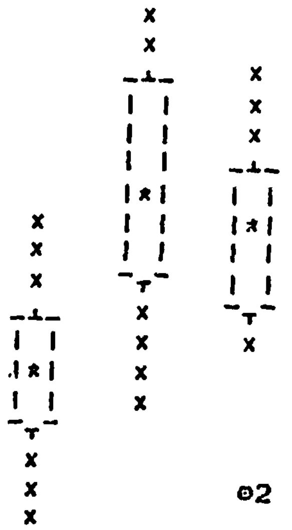
6.8

12.9



MEAN: 10.2385
VARIANCE: 2.6243
STD. DEV.: 1.61997
COEFF. OF VARIATION: 0.158224
LOWER QUARTILE: 9.19203
UPPER QUARTLIE: 11.3134
MEDIAN: 10.488
TRIMEAN: 10.3703
MIDMEAN: 10.2214
RANGE: 6.14052
MIDRANGE: 9.85259
MEAN ABSOLUTE DEVIATION: 1.31857
INTERQUARTILE RANGE: 2.12134
COEFF. OF SKEWNESS: -0.222912
COEFF. OF KURTOSIS: -0.552003

13.7477
6.08276



ANOVA TABLE

SOURCE	DF	SS	MS	F
TREATMENT	2	83.28	41.64	25.03
BLOCKS	27	109.11	4.04	2.43
ERROR	54	89.83	1.66	
TOTAL	83	282.23		

R-SQUARE = 0.682
OVERALL MEAN = 9.93
TREATMENT EFFECTS -1.34 1.04 0.31
BLOCKS EFFECTS -1.25 1.41 -1.26 -1.01 2.04 0.90 -1.43
-2.13 0.72 -1.42 -0.1. -0.11 0.15 -0.44
-0.38 0.47 1.15 0.30 -0.35 -0.65 1.51
0.49 1.43 0.69 1.85 0.33 -0.59 -1.41

APPENDIX L

BARTLETT'S TEST ON "$\sqrt{\text{NUMBER}}$"

$S_1^2 = 1.86774$ $\qquad f_1 = 27$

$S_2^2 = 2.87621$ $\qquad f_2 = 27$

$S_3^2 = 2.6243$ $\qquad f_3 = 27$

$f = f_1 + f_2 + f_3 = 81$

$s^2 = \frac{1}{f} \sum_{i=1}^{3} f_i s_i^2 = \frac{1}{3} (1.86774 + 2.87621 + 2.6243) = 2.456$

$B = -27 (-0.274 + 0.158 + 0.066) = 1.342$

$C = 1.012$

$TS = B/C = 1.327$; $\chi^2(TS) = p(.6)$

$\chi^2(.05) = 5.991$, Bartlett's test accepts homgeniety of variances. The stemleaf plots indicate normality of data. Hence, as these two assumptions are justified, parmetric test ANOVA has been used.

APPENDIX M

NEWMAN KEUL RANGE TEST ON NUMBER OF ERRORS

$\bar{X}$ (Ascending order) = $(8.59)_B$, $(10.24)_D$, $10.97)_{ND}$

Error MS = 1.66 ; DF = 54

n = # of observations = 28

Standard Error of mean for each treatment = $S_{\bar{y}_j} = \sqrt{\frac{MS}{n}}$

$S_{\bar{y}} = \sqrt{\frac{1.66}{28}} = .243$

$\alpha = .05$

From studentized range table (p.322 Hicks)

n_2(DF)	p** (#of quantiles whose range is involved)	
	2	3
54	2.84	3.41

$p^{**}(S_{\bar{y}})$ = .69 (for $p^{**}=2$) ;.83 (for $p^{**}=3$)

Difference between $\bar{X}_B$ and $\bar{X}_D$ = 1.65 > .69 ⇒ ∃ significant difference between these two conditions.

Difference between $\bar{X}_D$ and $\bar{X}_{ND}$ = .73 > .69 ⇒ ∃ significant difference between these two conditions.

Difference between $\bar{X}_B$ and $\bar{X}_{ND}$ = 2.38 .83 significant difference

On examination of tabulated data, it appears that the number of errors increase as we proceed from binocular to monocular (dominant) to monocular (non-dominant) modes of performances.

N. K. SUMMARY TABLE

	BINOCULAR	DOMINANT	NONDOMINANT
Binocular		X	X
Dominant			X
Nondominant			

$p < 0.05$

APPENDIX N

OUTPUT OF "$\sqrt{\text{ERROR}}$" ANALYSIS

```
COLUMN 1
1614
    CF
1812
201
2214 J
241799 HJ
2616 CGJ
281 FH
301 AAJ
3211 G
3419 J
3611 A
381 J
4019

1.6                                                                  4.1
    xxxxxxxxxxxxxxxxxx--------------------xxxxxxxxxxxxxxxxxx
                      |         *         |
                      ---------------------
```

MEAN: 2.85146

VARIANCE: 0.41247

STD. DEV.: 0.642239

COEFF. OF VARIATION: 0.225231

LOWER QUARTILE: 2.4799

UPPER QUARTILE: 3.28545

MEDIAN: 2.77483

TRIMEAN: 2.82875

MIDMEAN: 2.82771

RANGE: 2.4434

MIDRANGE: 2.86487

MEAN ABSOLUTE DEVIATION: 0.51538

INTERQUARTILE RANGE: 0.805555

COEFF. OF SKEWNESS: 0.0523593

COEFF. OF JURTOSIS: -0.746273

COLUMN 2

2811

301[FJ]

321[C]

3412456

3612[I]

38127[HJ]

40112467[BI]

421233[A]

441

461[J]

481

5018

5216

2.8

5.3

```
                 -----------------------------
xxxxxxxxxxxxxxxxx|                *          |xxxxxxxxxxx
                 -----------------------------
```

MEAN: 3.92533

VARIANCE: 0.306312

STD. DEV.: 0.553455

COEFF OF VARIATION: 0.140996

LOWER QUARTILE: 3.45687

UPPER QUARTILE: 4.20115

MEDIAN: 3.99998

TRIMEAN: 3.9145

MIDMEAN: 3.93048

RANGE: 2.45239

MIDRANGE: 4.03689

MEAN ABSOLUTE DEVIATION: 0.404316

INTERQUARTILE RANGE: 0.744283

COEFF. OF SKEWNESS: 0.387983

COEFF. OF KURTOSIS: 0.212746

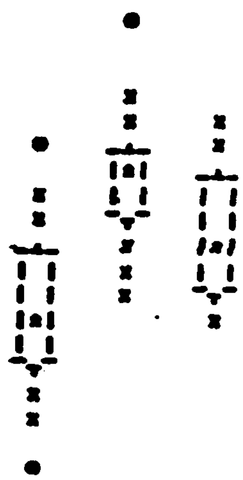
COLUMN 3

241[D]
2618[E]
281[CDH]
30128[DDGI]
3217[D]
3418[I]
3616[AH]
38135[AAC]
401[CE]
421
441[DJ]

```
2.5
                                                                          4.6
                  -------------------
xxxxxxxxxxxxxxxxxx|        *        |xxxxxxxxxxxxxxxxxx
                  -------------------
```

MEAN: 3.46564
VARIANCE: 0.296347
STD. DEV.: 0.544378
COEFF. OF VARIATION: 0.157078
LOWER QUARTILE: 3.04941
UPPER QUARTILE: 3.8729
MEDIAN: 3.40509
TRIMEAN: 3.43312
MIDMEAN: 3.43956
RANGE: 2.06365
MIDRANGE: 3.56165
MEAN ABSOLUTE DEVIATION: 0.460702
INTERQUARTILE RANGE: 0.823483
COEFF. OF SKEWNESS: 0.280609
COEFF. OF KURTOSIS: -0.804724

5.26308
1.64317



ANOVA TABLE

SOURCE	DF	SS	MS	F
TREATMENT	2	16.26	8.13	108.01
BLOCKS	27	23.34	0.86	11.49
ERROR	54	4.06	0.08	
TOTAL	83	43.66		

R-SQUARE = 0.907

OVERALL MEAN = 3.41

TREATMENT EFFECTS -0.56 0.51 0.05

BLOCK EFFECTS -0.45 0.36 0.56 0.31 0.37 -0.08 -0.24 -0.71
-0.09 -1.09 0.47 -0.34 1.15 -0.30 -0.18 -0.20
-0.04 -0.29 0.07 0.17 0.04 -0.65 -0.67 -0.46
0.14 0.19 1.20 0.79

ANOVA was updated 1/3/79, see anovahow for changes.

APPENDIX O

BARTLETT'S TEST ON "$\sqrt{\text{ERROR}}$"

$S_1^2 = 0.41247$

$S_2^2 = 0.306312$

$S_3^2 = 0.296347$

$f_1 = f_2 = f_3 = 27$

$f = f_1 + f_2 + f_3 = 81$

$s = \frac{1}{3} (\sum_{i=1}^{3} s_i) = \frac{1}{3} (1.015) = .338$

$B = -27 (.198-.1-.133) = 0.935$

$C = 1.012$

$TS = \frac{.935}{1.012} = 0.925$

χ^2 (TS) = p(.7) Bartlett's test accepts homogeniety of variance. Steamleaf indicate normality of data. Hence as these two assumptions are justified, parametric test ANOVA has been used.

APPENDIX P

NEWMAN KEUL RANGE TEST ON ERROR TIME
(DATA EXTRACTED FROM APPENCIX N)

$\overline{X}$ (Ascending order) = $(2.85)_B$, $(3.47)_D$, $(3.93)_{ND}$

ERROR MS = 0.08; DF = 54

n = # of observations = 28

Standard error of mean for each treatment = $S_{\overline{y}} \sqrt{\frac{ms}{n}} = \sqrt{\frac{.08}{28}} = .053$

$\alpha = .05$

$p^{**}(S_{\overline{y}}) = .69$ (for $p^{**} = 2$) and .83 (for $p^{**} = 3$) (as in Appendix M)

Difference between $\overline{X}_B$ and $\overline{X}_D = .62 < .69 \Rightarrow \nexists$ significant differences between these two conditions.

Difference between $\overline{X}_D$ and $\overline{X}_{ND} = .46 < .69 \Rightarrow \nexists$ significant differences between these two conditions.

Difference between $\overline{X}_B$ and $\overline{X}_{ND} = 1.08 > .83 \Rightarrow \exists$ significant differences between these two conditions.

On examination of tabulated data and above results, it appears that the percent of time on errors is greater in monocular (nondominant) as compared with binocular performance. Differences in performance between (binocular and monocular (dominant)) and (monocular (dominant) and monocular (nondominant)) are not significant.

<u>N.K. SUMMARY TABLE</u>

	BINOCULAR	DOMINANT	NONDOMINANT
BINOCULAR			x
DOMINANT			
NONDOMINANT			

$p < 0.05$

APPENDIX Q

FRIEDMAN TWO WAY ANOVA FOR SUBJECTIVE FATIGUE

	RANKS		
		MONOCULAR	
Subject #	BINOCULAR	Nondominant	Dominant
1	1.5	3	1.5
2	1.5	3	1.5
3	1.5	3	1.5
4	1.5	1.5	3
5	1.5	3	1.5
6	1.5	3	1.5
7	1.5	3	1.5
8	1.5	3	1.5
9	1.5	3	1.5
10	2	2	2
11	1.5	3	1.5
12	2.5	2.5	1
13	1.5	3	1.5
14	1.5	3	1.5
15	1.5	3	1.5
16	2	2	2
17	1.5	3	1.5
18	1	3	2
19	1.5	3	1.5
20	1.5	3	1.5
21	2.5	2.5	1

FRIEDMAN TWO WAY ANOVA FOR SUBJECTIVE FATIGUE CONT'D

	RANKS		
		MONOCULAR	
Subject #	BINOCULAR	NONDOMINANT	DOMINANT
22	1	3	2
23	1.5	3	1.5
24	1.5	3	1.5
25	2	2	2
26	1.5	3	1.5
27	1.5	3	1.5
28	1.5	3	1.5
TOTAL (R_j)	44.5	78.5	45.0

N = 28 (# of subjects)

α = .05

K = 3 (# of Columns)

H_o: There is no difference in subjective fatigue between the 3 modes. (Binocular, monocular (nondominant) and monocular (dominant))

H_1: There is some difference in subjective fatigue caused as a result of the three modes of tracking.

$$TS = \left[\frac{12}{NK(K+1)} \left[\sum_{J=1}^{K} (Rj)^2 \right] - 3N(K+1) \sim \chi^2_{(K-1)} \right]$$

$$TS = \frac{12}{28(3)(4)} \left[(44.5)^2 + (78.5)^2 + (45.0)^2 \right] \left[- 3(28)(4) \right]$$

$$TS = \frac{1}{28}(1980.25 + 6162.25 + 2025) - (336)$$

$$TS = \frac{10167.5}{28} - 336 = 363.125 - 336 = 27.125$$

$\chi^2_{(2)} = 13.815$ with probablity 0.001

Reject Ho

There is a difference in subjective fatigue between the three modes.

On examination of tabulated data, it appears that there is no difference between binocular and monocular (dominant) performance fatigue level but monocular (nondomiant) performance causes higher subjective fatigue even in such short tracking type tests of 1 to 2 minute duration.

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