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A COMPARISON OF PERFORMANCE IN OPERATING THE CRL-8 MASTER SLAVE MANIPULATOR UNDER MONOCULAR AND BINOCULAR VIEWING CONDITIONS

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FOREWORD

This report was prepared by the Maintenance Design Branch, Human Engineering Division, Behavioral Sciences, Laboratory, under Project No. 7184, "Human Performance in Advanced Systems," with Mr. Gerald P. Chubb as Research Scientist. This study was initiated in December 1963 and completed in March 1964.

This technical report has been reviewed and is approved.

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ABSTRACT

Performance times were recorded for six subjects on a simple remote handling task under two direct viewing conditions: binocular and monocular. All subjects performed under both conditions with counterbalancing between subjects and within subjects between sessions (I and II). The subjects used a CRL Model 8 master-slave manipulator to perform a shortened and revised version of the Placing Subtest of the Minnesota Rate of Manipulation Test. Performance times for the monocular viewing condition were 20% greater, exhibited greater variability, and reached an asymptotic level later.

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INTRODUCTION

Before remote-handling techniques can be applied to assembly and repair operations in space, tradeoffs must be made between display fidelity and operator performance. Optimal display fidelity might be hypothetically depicted by an ideal display device that presented the operator with a high-resolution, color-stereo picture of the task environment. Since certain features of this device probably exert a greater influence on operator performance than do others, the performance effectiveness achieved by including all of these features would probably not be commensurate with the increased complexity of such a device. For example, should the operator perform quite adequately without color but quite inadequately without stereo depth cues, the systems designer should have this information in order to design for minimal complexity and weight and for maximal reliability consistent with the performance required relative to task and mission definitions.

Previous research (ref 7) indicated that there were no significant differences in task performance time between 2D and 3D remote-television viewing conditions, although both were significantly inferior to performance with direct visual access to the task. Unfortunately, the generality of this conclusion may be limited by the experimental conditions employed, in that the resolution of the video image was not equivalent between the two television viewing conditions. Moreover, the authors point out that "... direct valid proprioceptive cues were available to the subjects, and this information, being constant over all experimental conditions, may have reduced somewhat the reliance on visual depth cues."

On an intuitive basis, one would hypothesize a priori that the fidelity of displaying visual cues should have a significant effect on performance. Thus, the lack of significant differences between 2D and 3D television viewing in the above study is all the more conspicuous. Binocular vision is known to be superior to monocular vision under laboratory conditions in both acuity and form perception. Consequently, the absence of stereo cues in the 2D television display was expected to produce a detectable difference in performance. Since it did not, the question was raised as to whether the superiority of binocular vision under laboratory conditions really had any great importance under practical or applied conditions. Note, however, that many uncontrolled factors in the remote-handling environment may significantly interact with the experimental variable of stereo-depth cues.

The following study, therefore, was designed to investigate only one aspect of the display problem, namely, whether direct binocular viewing resulted in performance superior to that obtained with direct monocular viewing in a remote-handling task. It was hoped that this preliminary study would provide a basis for evaluating other visual parameters and ultimately allow a valid extrapolation to remote television systems. Any such extrapolation, however, would be valid only to the extent that functional relationships for these other visual parameters (not studied here) could be adequately determined for the system involved. Since the previous study seemed to indicate that the task was learned quicker with 2D than with 3D, this study was also designed to allow comparison of changes in performance under monocular and binocular viewing conditions.

METHOD

APPARATUS

Four pieces of equipment were employed in this study: (1) a Central Research Laboratory, Model 8, master-slave manipulator, (2) a 12-hole formboard and 15 pegs, (3) two stopwatches, and (4) an eyepatch.

Master-Slave Manipulator

The CRL-8 is a mechanical, remote manipulator that translates the operator's movements with a 1 to 1 correspondence and provides direct kinesthetic and proprioceptive feedback. The limits of its reach, its weight limitations, inertia, and other assets and liabilities have been described in detail in earlier reports (refs 1, 2, 3, 4, 5).

Formboard and Pegs

The task consisted of placing pegs in the appropriate holes of a formboard. The pegs were circular, 3.8 cm in diameter and 1.9 cm thick. The holes in the formboard were separated by 5.1 cm (center to center) along both the vertical and horizontal dimensions. They were 4.1 cm in diameter and 1.6 cm deep. Three extra pegs were provided in case the subject dropped a peg and it rolled off the table. The pegs were blue on one side, red on the other, and were placed in front of the formboard with the blue side up.

The formboard was clamped to a stand tilted upward 45 degrees from the horizontal and positioned perpendicular to the subject's line of sight, 91.4 cm from the wall of the hot cell and approximately 1.2 m above the floor (fig. 1).

The subject's operating position was approximately 91.4 cm from the observation window, and the hot cell wall was 91.4 cm thick. Consequently, the subject was located approximately 2.7 m from the task.

The task area was lighted by two horizontally mounted, power-grooved, fluorescent lamps and two vertically mounted sodium vapor lamps. These sources of illumination provided 13,993.2 lumens per square meter at the task surface.

Stop Watches

Navigators' watches were started and stopped in sequence to obtain time measures within trials. The first watch was started when the subject was told to begin. This watch was stopped and the other started simultaneously when the last of three pegs had been placed in the first column. The time was recorded and the watch reset. The times similarly obtained for each of the other three columns were then summed and divided by four. Thus, the score for each trial was a mean performance time, the average of the four column times.

Eyepatch

A simple clinical eyepatch was used to restrict the subject's vision for

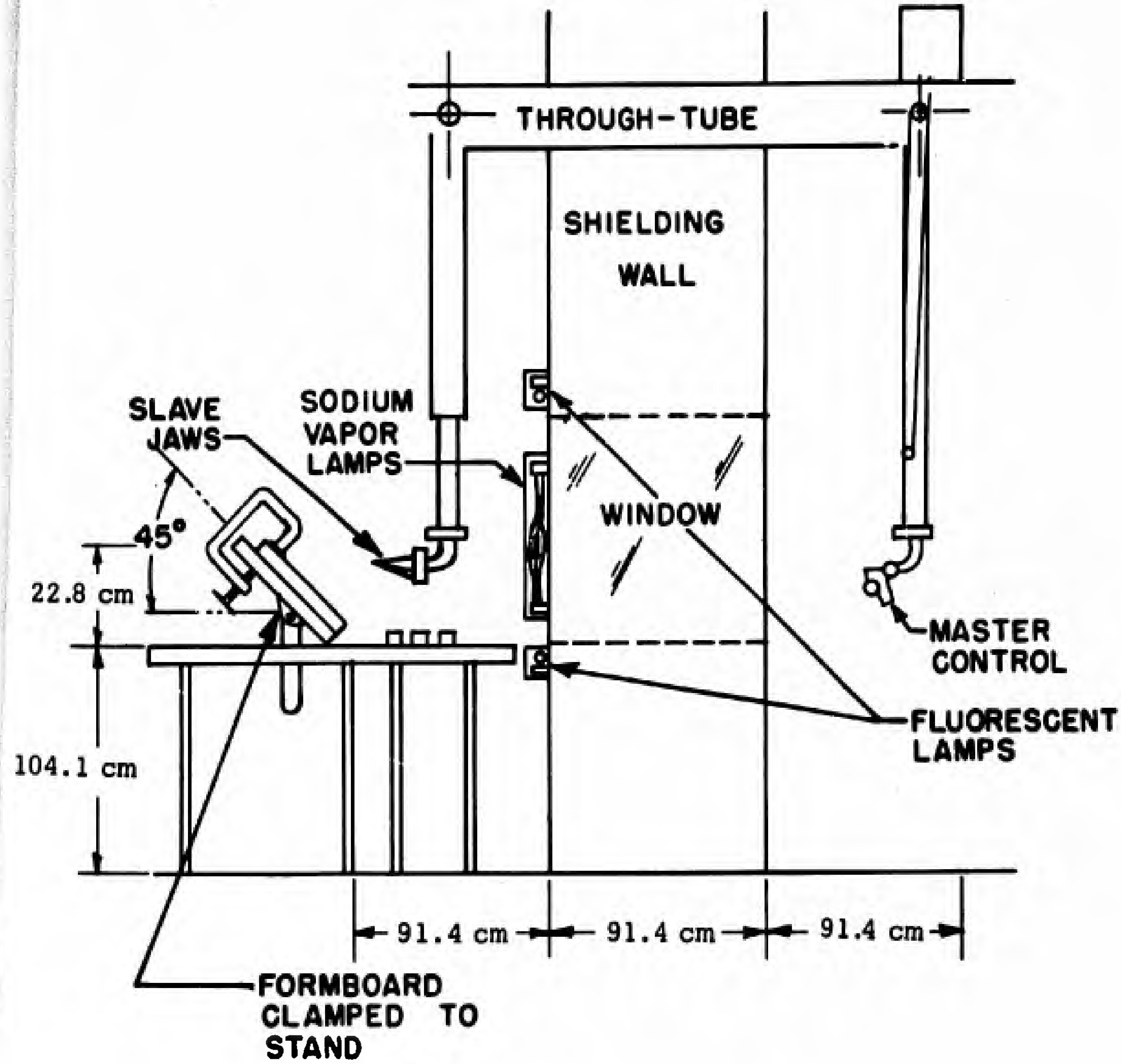


Fig. 1 - Experimental Apparatus

the monocular viewing condition. It was not tight, but prevented the subject from using the covered eye in performing the task.

ERROR MEASURES

Since the experimenter was completely occupied in the task of taking and recording time measures, no error measures were recorded by the experimenter, although several types of errors did occur during the course of the experiment. Subjects initially had difficulty orienting the manipulator claw properly so that the peg could be grasped on the first approach. Positioning errors were also made in placing the peg in the formboard. Often a peg previously placed in the formboard was knocked out while the subject attempted either to position another peg or back off after placing the peg in a hole. The feasibility of using a photographic technique to record these data was explored (see Results section).

PROCEDURE

Six male subjects served in the main experiment. Their ages ranged from 18 to 34 with a median of 25. There were five trials within each presentation of the two treatment conditions within each of two sessions, both conditions were presented twice. The order of presenting treatment conditions was balanced over sessions and subject pairs, pairing of subjects depending simply on their initial scheduling (table 1). All subjects, therefore, received both treatment

Table 1

EXPERIMENTAL DESIGN

SUBJECT NO.	SESSION I				SESSION II			
1	B	M	M	B	M	B	B	M
2	M	B	B	M	B	M	M	B
3	M	B	M	B	B	M	B	M
4	B	M	B	M	M	B	M	B
5	B	B	M	M	M	M	B	B
6	M	M	B	B	B	B	M	M
Trials	1-5	6-10	11-15	16-20	1-5	6-10	11-15	16-20

M - monocular viewing　　B - binocular viewing conditions in a balanced design. There was a total of 40 trials for each subject, half under each viewing condition. Acuity measures were taken for each eye, and the subject was allowed to use the better eye. Across subjects, acuity ranged from 20/15 to 20/25. As this was more than adequate acuity for performing the task, all subjects tested were used in the experiment. Since commercial tests of depth perception are of questionable validity, few are reliable, and do not correlate perfectly with each other, normal depth perception was simply assumed. Moreover, it has also been pointed out elsewhere (ref 6) that failure to pass these tests does not always indicate poor binocular depth perception. Scores must be interpreted in light of other clinical evidence.

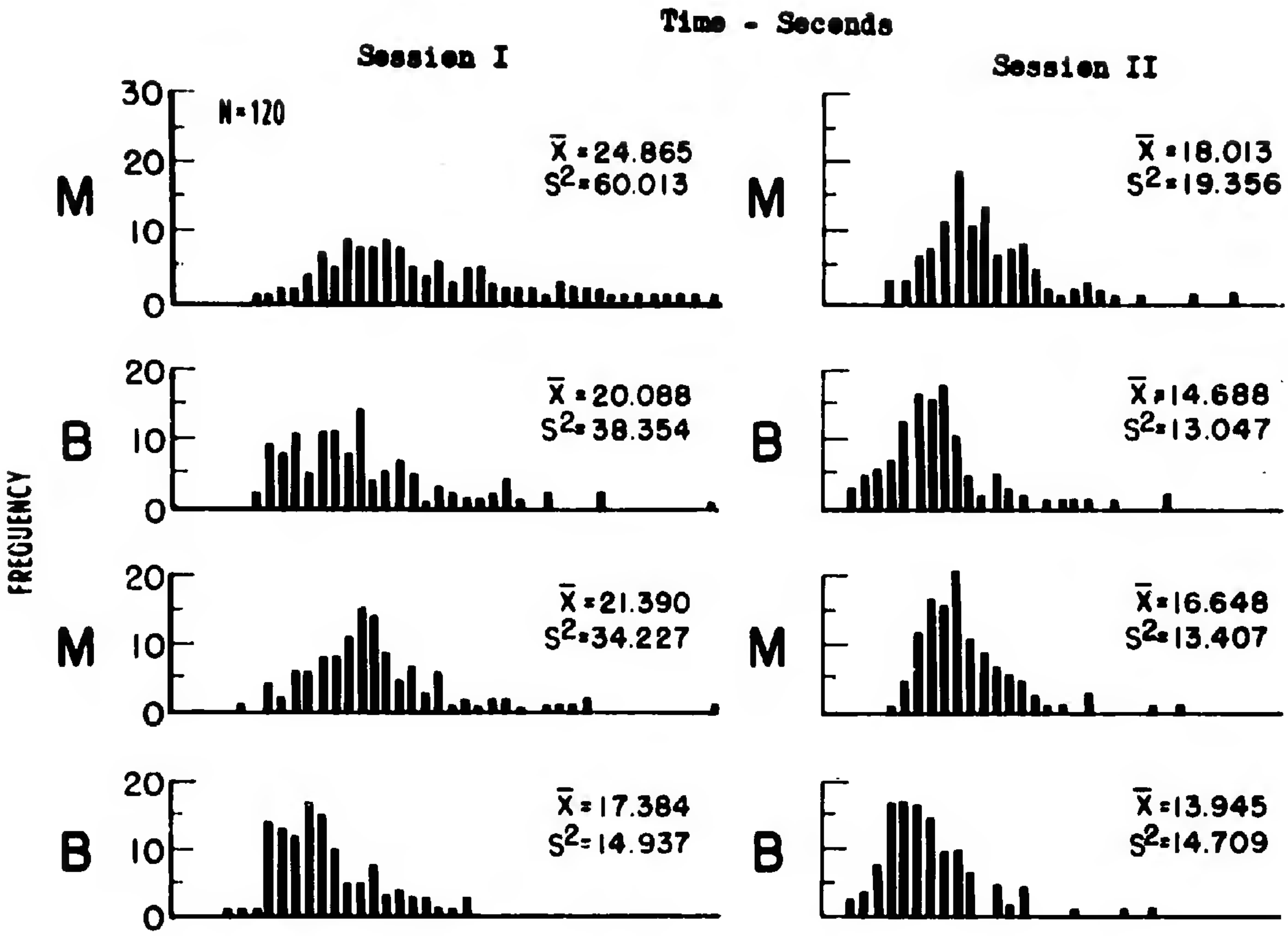
The subject was instructed in the purpose of the study and allowed 5 minutes to practice grasping four blocks, one at a time, with a CRL-8 master slave manipulator adjacent to the experimental apparatus. Following this warm up or practice period, which familiarized the subject with the general aspects of operating the device, the subject was instructed on how to perform the experimental task (see Appendix). The experimenter then went into the hot cell and verbally instructed the subject to start. A trial was completed when all of the 12 pegs had been placed in the formboard. At the end of each trial, there was a short pause while the experimenter took the pegs out of the formboard and arranged them on the table in front of it. After five trials there was a somewhat longer pause while the eyepatch was removed or put on. A 10-minute break occurred after 10 trials. The remaining 10 trials completed the session. The second session followed about a week later, after the results of the first session had indicated that performance had not yet stabilized.

RESULTS

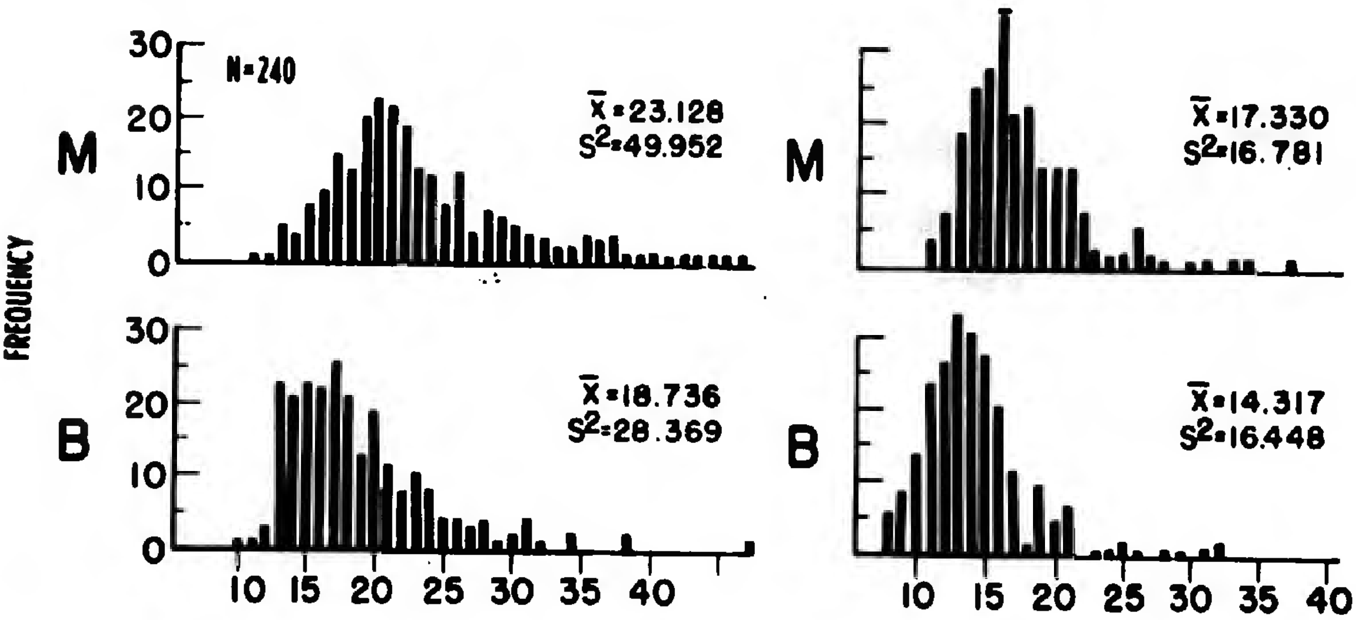
Time scores were recorded for each of the four columns of the formboard. The time score for any one trial was the average of the four column scores. Frequency distributions were plotted across all subjects: (1) across blocks of five trials (within sessions) (fig. 2a), (2) by treatment condition within sessions (fig. 2b), (3) by treatment condition across sessions (fig. 3a), and (4) for all scores (fig. 3b).

Since the distributions by-treatment-across-subjects-trials-and-sessions are positively skewed and leptokurtic, parametric analysis was not performed. A Kolmogorov-Smirnov two-sample test showed that the difference between distributions was significant beyond the .001 level.

Since the Kolmogorov-Smirnov test is sensitive to any differences in the two distributions, the median test was also run to check the hypothesis that the central tendency of the distributions did not differ significantly. The results showed that ($.05 > P > .02$). In that a .001 level of significance was chosen to offset any biases that could have affected the probability of a type I error, such as the superiority of binocular acuity and form perception, the hypothesis cannot be rejected. However, since the obtained probability did reach the .05 level, the results are not conclusive for two reasons: (1) for large sample sizes, the power-efficiency of the median test approaches

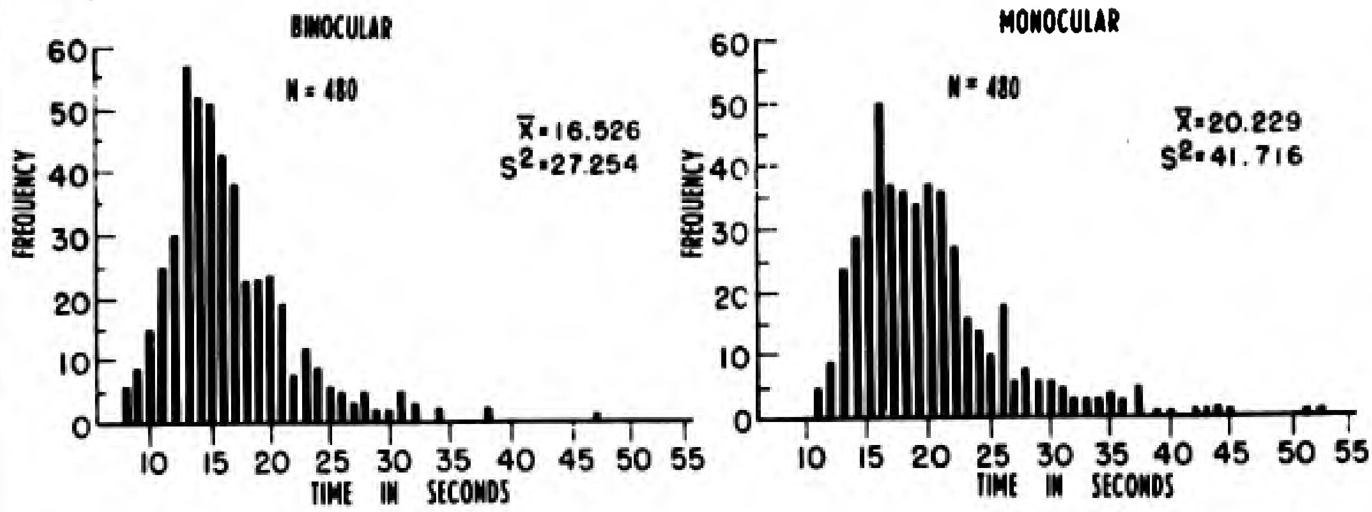


(a) Times by treatment condition and session for columns, trials, and subjects on each presentation where M is the monocular viewing condition and B is the binocular (N = 120 column times in each case).

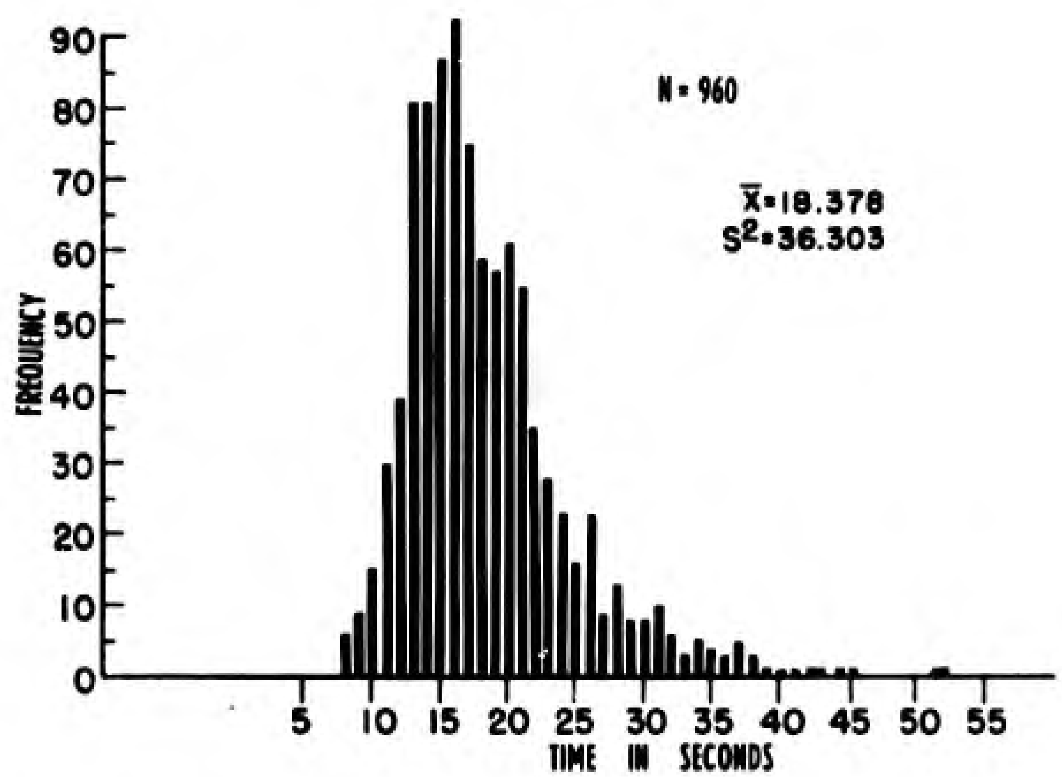


(b) Times by treatment condition and session for columns, trials, subjects and presentations (the above figure collapsed across viewing condition)

Fig. 2 - Frequency Distributions of Column Times Categorized to the Nearest Second.



(a) Times by treatment condition for columns, trials, subjects, presentations, and sessions (Figure 2b collapsed across sessions).



(b) For All Scores

Fig. 3 - Frequency Distributions of Column Times Categorized to the Nearest Second

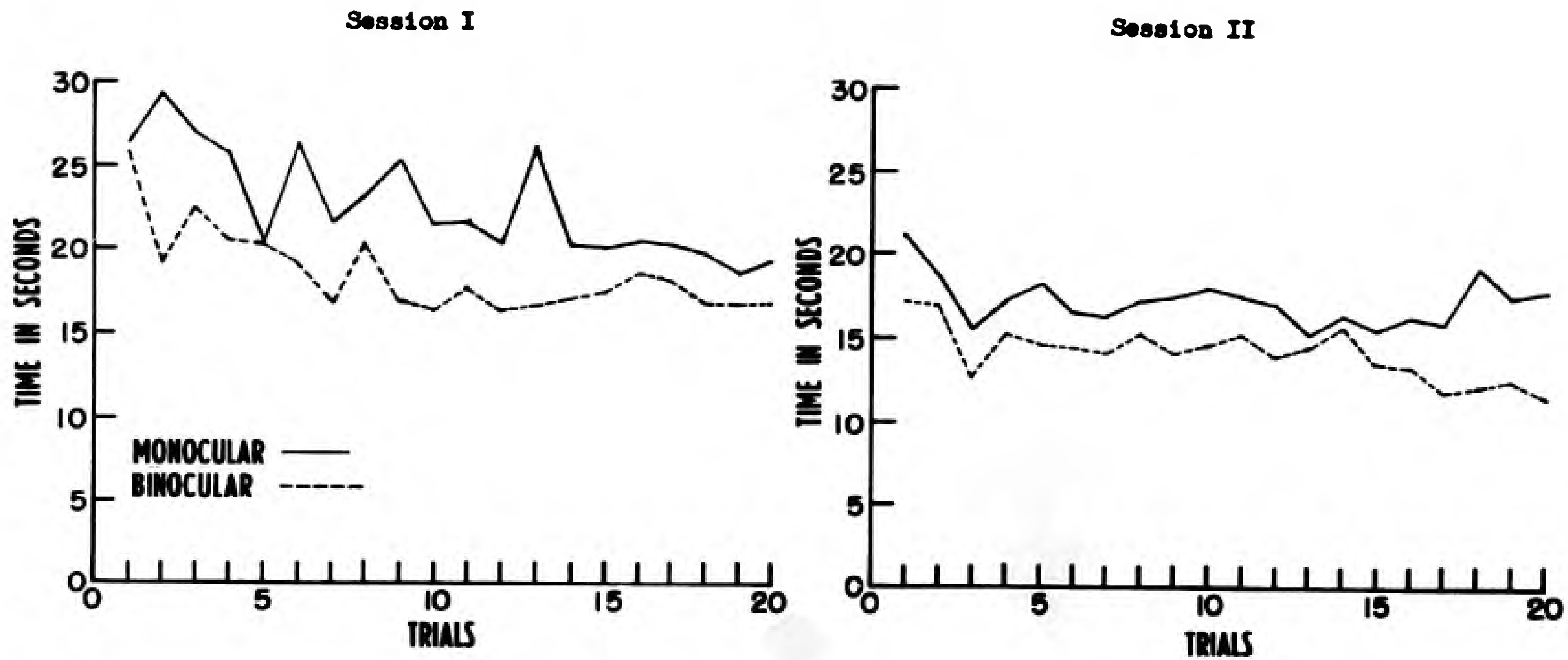


Fig. 4 - Performance Times as a Function of Trials for Each Session. Each curve represents the average of the column scores summed across subjects.

only 63% (ref 9)*, and (2) some aspects of the experimental conditions and procedure could have affected the probability of a type II error (no rationale exists for taking steps to statistically offset these biases as exists in the case of a type I error). The difference in variance and skewness between the two distributions should be considered in evaluating the tradeoffs between viewing conditions. These parameters are significantly different (on the basis of the Kolmogorov-Smirnov test) even if the difference in central tendency does not reach the a priori established level of significance (as suggested by the median test).

Trial means were plotted by subject for each session and the average across all subjects was similarly plotted (fig. 3). The magnitude of difference between the curves in figure 4 was not appreciable, but monocular performance times were consistently greater than binocular (approximately 20% greater than under binocular conditions).

One additional subject was run to explore the feasibility of using a film record to collect error data. The subject did not participate in the experimental study, but his background was similar, and his performance was comparable to the other subjects. Ten trials were filmed (800 feet of film) amounting to approximately 20 minutes running time. Though grasping and positioning errors occurred with some frequency, no attempt had been made to assure accuracy of measurement, which actually would require special equipment and technical skill in laying out the task, in establishing camera positions, and in reducing the data (ref 8). Moreover, it was found that behavioral patterns occurred that could not be unambiguously classified as errors, yet, they did affect the time scores. These often occurred after a peg was dropped or knocked out of the formboard. The film record quite graphically demonstrated that improved performance over trials was a function of several factors interacting simultaneously. Movements became more sure and decisive as errors and aberrant mannerisms became less frequent. Quantification of all of the factors involved would take considerable effort, and it appears that the results would not be commensurate with the investment required.

DISCUSSION

Several consistent characteristics should be noted. Monocular conditions resulted in greater variance as well as larger mean times to perform the task. Performance stabilizes quicker under binocular viewing conditions and reaches an asymptotic value sooner. The greater slope of the monocular curve (session I) is not significantly different from the binocular curve, and it should not be interpreted as being indicative of faster learning under the

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*Power efficiency = 100x(sample size needed for significance with the appropriate parametric test (had it been applicable)/the sample size needed for significance with the nonparametric test). Power in this equation being equal for both tests, the implication is that with equal sample sizes, the parametric test is more powerful, and it is therefore easier to commit a type II error with the nonparametric test.

monocular condition. The savings for binocular viewing was greater than for monocular and may be indicative of a recurrent unfamiliarity with monocular viewing as imposed here, namely, the eyepatch. However, this initial discrepancy dissipates rapidly and the slopes for both curves appear almost equivalent.

The sharp increase in performance times under the last presentation of the monocular viewing condition may signal the onset of fatigue effects. Again, this may be an artifact of the means of implementing the monocular condition and may not be found in the case of a 2D display. Nonetheless, deterioration of performance with visual fatigue may be an important determinant of manipulator performance and should be investigated in later studies to ascertain whether the effects observed here are, in fact, significant.

CONCLUSION

A previous study indicated there was no significant difference between performance times under 2D and 3D television conditions. However, the resolution of the 3D image was not equivalent to the resolution of the 2D image. This study found significant differences in performance times under monocular and binocular direct-viewing conditions. It thus appears that the lower resolution of the 3D television used in the previous study may have tended to offset the benefits of increased fidelity of depth cues. Other visual factors not yet investigated in either of these studies could also be contributing to performance time.

Six subjects performed the same task with the same apparatus that was used in the previous study. Trials (40 per subject) were administered in blocks of five within each viewing condition during two sessions. Blocks were balanced over subjects and sessions.

Both the mean and variance of performance times were greater for monocular viewing, mean time being 20% greater for monocular viewing. Under binocular viewing, performance became asymptotic and stable quicker than under monocular conditions. Forgetting and fatigue seem to have greater effect on monocular performance, but this may be an artifact of the novelty of the monocular viewing condition. Extrapolation to television systems should not be made without including the effects of other visual parameters not studied.

APPENDIX

INSTRUCTIONS

This study is part of a project investigating the importance of various cues in operating remote handling devices. The two manipulators under study are representative of currently available apparatus. With the development of nuclear propulsion and orbiting spacecraft, maintenance procedures are complicated by the necessity of carrying them out in hostile environments. Until suitable protective devices are produced, maintenance will have to be carried out by means of a remote manipulator. Hence it is important to determine the importance of various cues used by operators performing remote handling tasks. This will allow human factors engineers to specify the kind and quality of information operators will need to adequately perform maintenance tasks with a remote manipulator.

The experimental task has been designed to find out whether your performance is better when you use both eyes than when you use only one eye. It is not designed to test your ability against other operators, so your lack of experience in using the device will not count against you.

To familiarize you with the remote manipulator, you will be allowed to practice with the set of blocks shown. After approximately five minutes I will read instructions for the experimental task and give you a practice trial.

The experimental task involves picking up the pegs on the table and putting them in the holes of the formboard. Start with the right hand hole of the bottom row and work upward; then go to the bottom hole of the next column to the left, etc. Are there any questions?

If you grasp only the upper portion of the pegs, it will be easier to place them in the holes, and you will be less likely to drop them. Try not to vary your viewing position. Interpretation of the results of this study will be valid only to the extent that you approach the task similarly whether using one or both eyes. Consequently it is important that you maintain a fixed position throughout the experiment. Do not move your head; neither right, left, up, or down. All corrections necessary for performing the task should be made only by shifting your view from point to point, not by reorienting your head or body.

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