HUMAN FACTORS IN REMOTE HANDLING

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INTRODUCTION

At this time I shall say a little bit about the human factors in remote handling as we in the Maintenance Design Section see them. First, a few words about the role of remote handling in advanced systems, and then a quick description of some of our in-house research results which seem to be pertinent.

Until recently, remote handling seemed assured of a role in connection with the nuclear aircraft program. However, some doubt exists now as to the future of the program. Major Dinwiddie is prepared to tell you what he can about the program this afternoon, so I'll not mention it further at this time.

Nuclear devices themselves, however, are likely to be very much a part of future systems, whether we think of munitions, energy sources, or propulsion gadgets. This statement is particularly true in regard to space systems, where remote handling comes into play in a bigger and better way, possibly, than in any other application. In groundborne applications, remote handling has the classic role of enabling man to work safely in dangerously radioactive environments. In space systems, it has that role in addition to many others.

These roles are apparent in connection with the tasks accomplished outside the space vehicle where, because of the quantity and severity of physical hazards, it is improbable that man will be able to work effectively without some means of extending his perceptual and physical skills beyond a considerable amount of protective shielding. Remote handling will allow man to work beyond such shielding in areas of high radiation, near or total vacuum, extremely low temperature, etc. Thus, many current space proposals include notions of use of remote-manipulative equipment, ranging from the simple to the complex, for many jobs in places where man either cannot or would not go without special protective devices (which hamper his mobility and action, and may themselves include remote-handling appendages).

Among the tasks for remote handling in space will be assembly, disassembly, and maintenance of space systems, including inspection, repair, servicing, and checkout; experimentation, including exploration, sampling, and testing; transfer of personnel, supplies, and equipment; and emergency operations, such as escape and rescue. These tasks have much in common with remote-handling tasks involved in groundborne operations. Thus, many of the research results relating to the latter will have application in design for remote handling in space.

It is convenient to classify human factors in remote handling in terms of the variables which affect operations. Thus, we can talk about task variables, equipment variables, and operator variables. I shall mention some in-house research efforts in connection with each of these classes of variables.

Task Variables

These have to do with the way the task to be performed remotely is designed, arranged, or presented to the operator.

Task Distance: The effect of this variable on performance of a manipulative task was investigated with a CRL Model 8 Master-Slave Manipulator (2). Performance time increased significantly as the task was moved from a position seven feet from the operator's eyes to a position at nine feet, and again as it was moved to eleven feet. This is a reflection of the loss in visual resolution and depth perception accompanying increased distance.

Object Size: The effect of this variable was investigated in a task in which different sizes of hexagonal nuts were removed from bolts (3). Performance time was not significantly changed as nut diameter was increased from 3/4 inch to $2\frac{1}{4}$ inches (the practical limit for the manipulator slave hand).

Angle and Height of Task Display: These variables were studied in connection with the nut-removal task described above. For the standing operator working at several different task angles, significantly better performance resulted when tasks were presented at an average height of 45 inches from floor level, by comparison with both lower and higher working heights (3). Without regard to task height, performance was better in the 45° to 65° range of task angles measured from a task in the horizontal plane. The two variables were found to interact, however, such that horizontally oriented tasks were performed best at the lowest height and poorest at the highest working height. Vertical tasks were performed best at intermediate heights.

Complexity: An obviously important variable, but one we have not yet studied experimentally, is task complexity. There are many dimensions of complexity: manipulative, perceptual, sequential, etc. All interact, not only with each other, but also with the task variables mentioned previously.

Equipment Variables

Many remote-handling problems relate to the design of the equipment itself. Many of the people here have already given much attention to the effects of change among the many variables of design of manipulators and accessories (5). Sensory feedback (tactual, kinesthetic, visual, and even auditory), movement ratios, force ratios, power provisions (mechanical, hydraulic, electrical), and auxiliary controls, to name a few, have been studied. We shall hear further of this work from other speakers at this symposium. Two studies of this nature can be reported by me. But first it is worthwhile to look at the effect of the manipulator itself on human performance.

Remote versus Direct Handling: Remote handling is employed at a price. It is generally conceded that use of mechanical master-slave manipulators involves a reduction in efficiency to a very significant degree by comparison with direct manual performance. To calibrate this factor, a standard manipulative task was performed with both modes of handling in an experimental setup which controlled for extraneous effects such as practice and sequence of test (2). Operators of the CRL Model 8 manipulator* took 6 to 10 times longer, depending on task distance, to perform the task than did direct handlers. The factor of 6 was found for the 7-foot task distance, the factor of 10 for the 11-foot distance. The ratio of 8 to 1 (found at 9 feet) was most representative of remote tasks performed at the modal distance.

Weight Discrimination: Studies were conducted to determine the effect of remote handling on ability of subjects to make both absolute and differential judgments of weights (6, 7). By comparison with direct handling, remote handling produced absolute estimates which were higher and more accurate on the average but more variable. There was less tendency for remote estimates to be influenced by immediately preceding handling operations, i.e., less contrast effect. Difference thresholds, the amounts by which two stimuli must differ to be perceived as different at least 50% of the time, were nearly doubled with remote handling. Thus, sensory feedback is attenuated by remote handling such that two objects differing less than 8% in weight cannot be effectively discriminated, whereas the critical difference is only 5% for direct handling.

Mass Discrimination: Since objects in space will not have weight, it is useful to know what the difference threshold for remotely handled masses will be. The discrimination study was repeated (8), using objects supported by compressed air over an air-bearing table which made them effectively weightless. It was thus a mass discrimination study. The critical difference in this case was 23%, approximately double that for remotely handled weights. Since another study (10) had shown a similar reduction in discriminability of directly handled masses (versus weights), it appears that loss of weight as a cue leads to doubled difference thresholds, which are in turn doubled by remote handling.

*CRL-Central Research Laboratories, Red Wing, Minnesota

Basis of Discrimination	Type of Handling	Difference Ratio
weight	direct	.05
"	remote	.08
mass	direct	.10
"	remote	.23

Mode and Rate of Indexing: Mechanical master-slave manipulators have auxiliary devices by which the slave hand is moved to areas not reachable by normal articulation. This is called indexing. It is normally controlled by a hand-operated, two-way switch. Performance with the hand switch was compared with performance with a foot-operated switch on a task requiring indexing (4). Three representative rates of indexing were used. No advantage in task speed was found for either mode of indexing, but fewer errors (dropping objects, or indexing in the wrong direction) occurred with the foot control. There was also evidence of faster learning (to an asymptote of performance time) with the foot control. These results were not altered by change in rate of indexing, even though such change was shown to affect speed of performance significantly (higher rate—shorter task time) for most tasks. For tasks involving only short indexing distances, there was no advantage in faster indexing.

Color-Coding of Jaws: In another study, involving intricate manipulations of small objects, different colors were used for the slave fingers to see if task performance could thereby be improved (2). Significant differences were not found. This suggests that more appropriate use of color to improve remote-handling performance may be made in design and layout of the task to be performed.

Operator Variables

As in any task requiring skill, individual differences exist in remote-handling performance. These can result from inherent differences in manual dexterity, coordination, visual acuity, depth perception, and other such factors. Operator screening is a means of controlling them. Beyond this, there are still many other operator variables which affect performance. Two have been studied.

Practice: Naive subjects were used for remote performance of a block-manipulation task. Performance time decreased to a practical asymptote within just a few trials, indicating that beginner operators adapt to the grosser aspects of the master-slave manipulator with little difficulty (2). For satisfactory performance of more intricate tasks, several hours of training may be required.

Seated versus Standing Operators: A study was conducted to determine the extent of limitations upon the work range of the manipulator resulting when the operator is seated (1). This was thought to be a way of approximating the effect of confined quarters which may exist in space applications. Contours of effective performance were found to be progressively reduced in area as the plane of the task was lowered to the level of the knees and below. In general, the range of effective performance for the seated operator was approximately one-third the range for an unrestricted standing operator.

Visual Acuity: Operators differ greatly in basic visual acuity, and the differences have an important influence on remote handling; but this factor can be controlled. A further acuity factor may exist in the space environment. It is known that increased positive and negative accelerative forces produce losses in visual acuity. To see if zero gravity would also affect acuity, subjects were tested while they were exposed to weightlessness aboard an aircraft (9). Significant decrements were found in zero-g scores compared with control scores in one-g flight. The average decrement was of the order of a 6% increase in visual angle of targets at threshold legibility. While this is not of practical significance for ordinary purposes of vision, it may be important in remote handling where acuity and depth perception are often critical.

Further Research Needs

This paper deals only briefly with results of a very limited program of research on human factors related to performance of remote-handling tasks. A great number of other research efforts pertinent to these problems are being carried out by many different agencies. Successful operation of advanced systems will depend a great deal on the success of the total of these and future efforts to come.

While complete enumeration of the necessary additional human factors efforts cannot be accomplished, it is possible to identify further work which should be done to extend the usefulness of the results reported in this paper. Research is needed to develop basic remote-handling concepts, and to establish criteria for comparing and evaluating different types of remote-handling systems with respect to their usability in future systems. Solutions to perceptual problems connected with remote operations in space are needed. Problems of remote visual access, including use of closed and open circuit TV, depth and movement perception, illumination, glare, contrast, and tactual and kinesthetic feedback are representative.

These are just a few of the many considerations important to effective remote-handling operations in advanced systems. Research is underway to provide needed answers for many of the questions. Much more has yet to be undertaken to satisfy the over-all need.

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