Space lab
WS# 1102

Quantification of Human Performance in Extreme Environments

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1. MENTAL WORKLOAD AND PERFORMANCE EXPERIMENT (MWPE)

The Mental Workload and Performance Experiment (MWPE) was developed in the mid-80's to look at human performance during spaceflight. MWPE flew on the International Microgravity Laboratory-1 Space Shuttle mission in January of 1992 with four astronaut subjects [1]. Human performance has many aspects that are difficult to measure and distinguish from one another. Space Station operations, however, will put particular emphasis on astronauts' interaction with the Station's many computer control systems. The MWPE experiment was therefore designed to focus on motor and cognitive skills associated with such interactions, specifically computer cursor control and short-term memory. Though narrowly focused, the experiment serves as a prototype for further investigations to pursue broader, multidimensional measures of in-space performance. The MWPE performance assessment test is based on the *Fittsberg* task, a combination of Fitts' Law and Sternberg tasks, that combines tests of short-term memory and motor control [2-4].

2. MEMORY PROCESSES AND MOTOR CONTROL (MEMO)

MWPE was enhanced for the Canadian Astronaut Program Space Unit Life Simulation (CAPSULS) mission and was renamed the MEmory processes and MOtor control experiment (MEMO). This mission studied four Canadian astronauts during seven days of isolation at the Defense and Civil Institute of Environmental Engineering, Toronto, Canada. The CAPSULS 7-day isolation mission offered an ideal opportunity to collect human performance data for individuals in extreme isolation to compliment the data collected in space on the IML-1 mission using a similar protocol and ground hardware. The CAPSULS experiment duplicated the space flight workload and conditions of isolation without the physiological changes due to exposure to microgravity. The experiment then evaluated operator performance on the same short-term memory and fine motor control tasks that were performed for MWPE. MEMO then examined human performance when a sensorimotor transformation was deliberately induced in order to evaluate the limitations of different human operator control strategies. Specifically, our subjects wore left-right reversing prism goggles for approximately one-third of the trials.

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3. METHODS

For both the MEMO and MWPE task, the four subjects used either a position-control device (trackball) or a rate-control device (joystick) to perform the experiment. A Grid 1530 microcomputer was used to present the experimental paradigm and collect the data. Finally, only during the MEMO experiment, the subjects repeated the task wearing left-right reversing prisms to induce a sensorimotor transformation. In other words, while wearing the reversing prisms, when the subject moved the joystick to the left, the cursor was seen to move to the right.

We used the "Fittsberg" experimental paradigm [3] that provides independent control and measurement of two tasks: response selection and response execution, where the former represents a cognitive task and the latter, a neuromuscular task. The selection of a response is based upon the Sternberg memory search task [4] that requires the subject to determine if a displayed item is a member of a previously memorized set. Fitts' paradigm [5] was developed to examine the control and accuracy of movement and was used here to measure response execution. Subjects were required to manually acquire a target of a certain size and distance away from an initial cursor position as quickly and as accurately as possible. The Fittsberg paradigm is illustrated in Figure 1.

From the time the targets appear to the time it takes for the subject to identify the letter is the reaction time (RT) and is a measure of short-term memory. From the time the subject starts to move the cursor on the screen via the computer device to the time he or she reaches the target is the movement time (MT) which is a classical measure of motor control. For each memory set, 8 test stimuli were presented, while 12 memory sets were presented for each device.

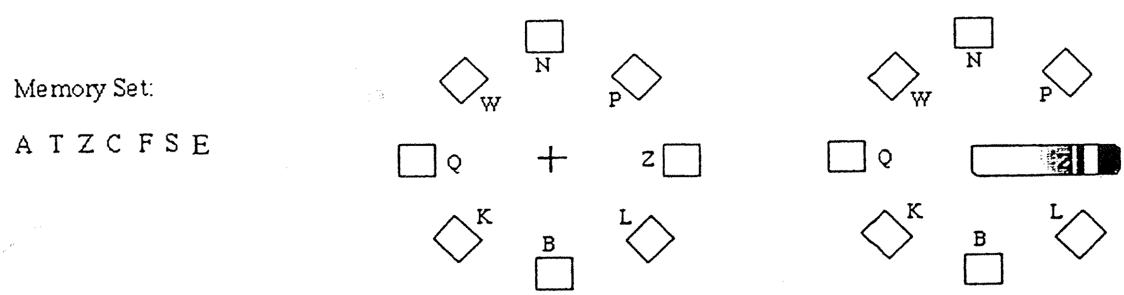

Figure 1: The Fittsberg Paradigm A) The subject was presented with a memory set consisting of 1-7 letters which they were asked to memorize. The subject pressed return on the keyboard to indicate the end of the memorization time. B) The subject was then immediately presented with a test stimulus with a cursor in the center. Only one of the letters from the memory set is presented, the letter Z in this case. C) As soon as the subject spotted the letter, the subject moved the cursor to that location. Once the location is reached, a new test stimulus appears immediately.

4. MOTOR PERFORMANCE DURING SPACEFLIGHT

One of the major results of MWPE was that all four subjects showed a significant increase in movement time (MT) during spaceflight as shown in Figure 2 by the white bars. In other words, a decrease in fine motor control performance was observed in the microgravity environment. However, distinguishing between changes due to sensorimotor adaptation to the microgravity environment or changes due to the fatigue and high stress of spaceflight was uncertain. Performing MEMO during the CAPSULS mission allowed us to distinguish between these two hypotheses by performing the same experiment under a similar workload environment, without the effects of microgravity. In fact, no changes in fine motor control were observed over the course of the seven day CAPSULS mission. Therefore, it is likely that the decrease in fine motor control seen during the IML-1 mission was in fact due to changes in sensorimotor loops from exposure to the microgravity environment, rather than workload or fatigue.

In addition, no significant changes were seen in cognitive performance during either mission as measured by the short-term memory task. None of the four subjects tested on the IML-1 mission reported any symptoms of space motion sickness. This may account for their ability to maintain cognitive performance.

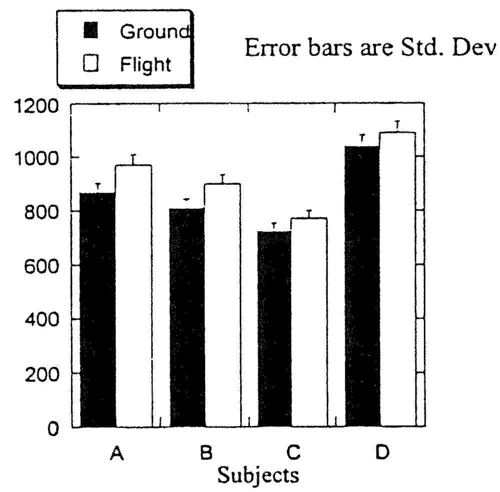

Figure 2: MWPE data from ground and spaceflight experimentation. All 4 subjects showed an increase in movement time ($p<0.001$).

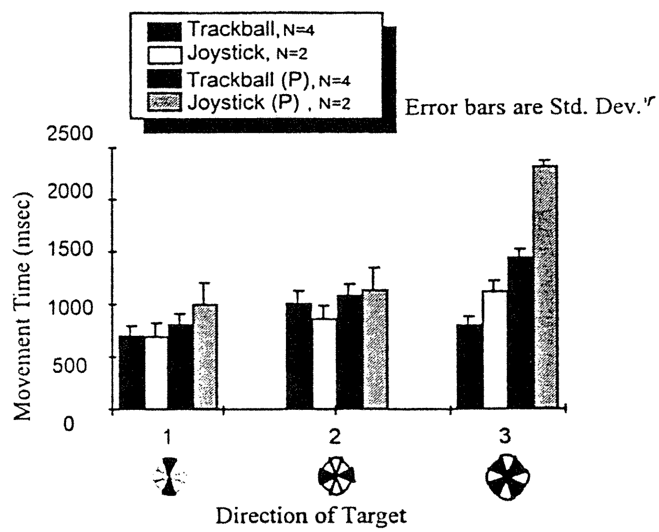

Figure 3: There were no significant differences in the cardinal positions for either devices or adaptation state. Only the diagonal target directions showed significant increased in movement times.

5. CONTROL STRATEGIES

When using the joystick as a rate-controller to acquire the targets, movement time was slower in the diagonal directions in both the normal and prism-adapted state. However, in the position-control mode, using the trackball, movement time was unaffected by target direction in the normal state. Fine motor control performance decreased (MT increased) in the diagonal directions, only in the adapted state (Figure 3).

Remembering that these were *left-right* reversing prisms, it is interesting to note that the motor control performance in *all* of the cardinal directions (i.e., up, down, left, right) was unaffected by control mode or adaptation state. However, movement time to the diagonal targets was affected by both control mode and adaptation state.

One confounding factor was that left-right reversing prisms actually induce different transformations depending on target direction. The north and south targets are not subject to any transformation while the east and west targets are subject to the equivalent of a 180 degree rotational transformation. The diagonal targets are subject to a 90 degree rotational transformation. The subjects can perform just as well with a 180 degree transformation (transformation in one axis) as in the normal unaltered condition. However, a 90 degree rotational transform (transformation in two axes) results in a decrease in performance. In other words, this could imply some transformation threshold (e.g. more than one axis) that if exceeded, results in a decrease in human operator performance.

6. CONCLUSIONS

Establishing a human presence in space, teleoperations, and virtual environment training are all examples of complex human-technology interactions. System design for all of these tasks assumes a knowledge of human performance in "normal" as well as altered or extreme environments. One way to build models of these complex interactions is to understand limited range tasks such as the ones described here. This may be one of the first attempts to look at position versus rate-control devices in the context of altered sensory motor loops to evaluate human operator performance. One of the most interesting results was that both the position and rate-control devices had similar relative performances in their prism-adapted state as in the normal condition. In other words, both control devices had a decrease in performance only in the diagonal target directions. This predictability may imply that a human operator model developed from results using simple transformations may be applied to human-computer interface design for more complicated tasks.

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