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GROUND-BASED RESULTS OF THE MENTAL WORKLOAD AND PERFORMANCE EXPERIMENT (MWPE)

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.c1.GROUND-BASED RESULTS OF THE MENTAL WORKLOAD AND PERFORMANCE EXPERIMENT (MWPE).

.c2.INTRODUCTION

The projected operational requirements of a space station and the complexity of its systems necessitate onboard computer automation and crewmember supervisory responsibilities. Many of the daily space station tasks will be facilitated by expert systems in which the crew will spend a considerable amount of time deciphering displays and then recording information into databases. While the Mercury spacecraft had 3 panels, 143 control displays, and no computers it is projected that the Space Station will have 200 panels, 3000 control displays, and at least 8 computers operating in 200 different modes (Loftus, 1986). With this level of complexity it becomes critical to understand the demands placed on the astronaut's perceptual and mental capabilities while operating graphic input devices such as joysticks or trackballs. Therefore, the need exists to design space workstations with efficient computer display formats and input devices. It is yet to be determined if ground-based measures and techniques apply in the weightless environment of space. The interaction of neuromuscular cursor control tasks and mental workload in microgravity is unknown. In order to enhance space station design, system engineers and designers require performance data of graphic input devices in conjunction with workload measurements for the microgravity environment.

The Mental Workload and Performance Experiment (MWPE), the topic of this paper, evaluates an operator's mental workload and performance in a computer cursor movement task. Three quantities are measured in MWPE: reaction time, movement time, and subjective ratings. A Sternberg memory search task (Sternberg, 1975) is combined with a Fitts' target acquisition task (Fitts and Peterson, 1964) resulting in a "Fittsberg" dual-task paradigm (Hartzell, Gopher, Hart, Lee, and Dunbar, 1983) for the MWPE protocol. MWPE objectively measures the operator's performance in completing the target identification task through reaction time measurements and the target acquisition task through movement time measurements. Multidimensional subjective workload ratings are recorded for MWPE computer tasks and compared to the objective performance measurements.

The cursor control tasks are achieved by using three input devices, namely, the computer keyboard arrows, a joystick, and a trackball. MWPE computer display variables include response entropy (or size of the memory set in the Sternberg memory search), direction of cursor movement, and index of difficulty of the Fitts' target acquisition task (i.e. the distance to the target and target width). The results of MWPE in microgravity will be obtained in 1991 on the International Microgravity Laboratory Space Shuttle mission, and hence, the independent environmental variable of 1-g versus 0-g will be investigated. Ground-based results validate the MWPE experiment and serve as baseline data.

MWPE ground-based experiments, detailed herein, were executed in two postural orientations, namely, the upright and supine positions to assess performance and workload differences between the two orientations. The difference in static orientation cues, either tactile or vestibular, between the two postural orientations may affect performance and workload measurements. In the upright orientation the subjects operate MWPE from a seated position in a chair. In the supine (or recumbent) position the subjects lie horizontally on their backs and operate the computer which is secured to a vertical workstation hanging at arm's length above their chest.

The interaction of MWPE experimental variables is analyzed statistically and compared with theoretical models. Subjects record slower reaction times and movement times in the supine orientation as compared to the upright orientation. Also, subjects report a slight increase in workload. A comparison of the graphic input devices (computer keyboard arrows, joystick, and trackball) yields that the trackball produces the best performance and least amount of workload for the computer tasks. The reaction time measurements primarily depend on the size of the memory set and secondarily depend on the direction of target alignment. Movement time measurements depend on both target acquisition index of difficulty and direction of target alignment.

.c2.METHOD

Traditionally human memory was studied upon failure, but Sternberg proposed an alternate approach of studying memory. He studied performance when it was almost free of errors; he studied "successful memory." (Sternberg, 1975). Human subjects reveal their memory retrieval mechanisms, not by how the fail, but by how much time it takes them to perform a task successfully. For MWPE, reaction time is measured from test stimulus onset to initial cursor (represented by a '+' on the computer screen) movement, the time it takes the subject to recognize the letter from the memory set and initiate cursor movement toward the letters. Reaction time, RT, increases approximately linearly with response entropy, H, which is related to the number of possible members in a memory set, n. Reaction time is given in Equation 1 as:

$$RT = a + b \log_2(n) \qquad (1)$$

where *'a'* is an intercept which is associated with an overhead and the slope of the RT line,*'b'*, is associated with the rate of increase for each additional bit of information from the memory set. Sternberg's experiments (Sternberg, 1975) yielded a slope of 38 ms/bit of information and an overhead of approximately 400 ms.

In the early 1960s movement time, or response duration, received experimental emphasis for its connection with the information capacity of the human motor system. Fitts (1954) reasoned that the average amplitude, A, of a human movement and the width, W, of the target being acquired defined an index of task difficulty, ID, in bits of information that has the following logarithmic representation:

$$ID = \log_2\left(2A/W\right) \qquad (2)$$

Fitts' Law predicts movement time, MT, to be a linear function of the index of difficulty. Fitts defines movement time of a motor response for target acquisition tasks as the time it takes to enter into a target by the following equation:

$$MT = c + d \log_2\left(2A/W\right) \qquad (3)$$

where *'c'* and *'d'* are constants. It seems logical that MT increases if movement amplitude increases or target width decreases because under these prescribed conditions the target becomes further away and smaller, respectively. The act of actually "capturing the target" requires movement deceleration because the subject terminates movement velocity in order to stop the cursor within the target boundary rather than entering the target and passing through it. In the "Fittsberg" dual-task paradigm it is assumed that the Sternberg memory search and Fitts target acquisition are analyzed separately.

MWPE incorporates the NASA bi-polar subjective rating scales into its experimental paradigm in order to assess mental workload. The bi-polar rating consists of six subscales that are relevant to the subject's experience, namely, mental demand, physical demand, temporal demand, frustration, performance, and effort. Table 1 gives rating scale

descriptions. The Human Performance Group at NASA-Ames found these six categories to have independent contributions on workload. A seventh workload rating, nausea, is used in MWPE Space Shuttle flight software, but not for ground-based experiments. Nausea was added to assess the effect of Space Adaptation Syndrome on workload associated with the experimental tasks. Subjects initially assign a relative importance to each rating category then the ratings are combined to find an overall workload rating (Vidulich and Tsang, 1985). A weighting factor is determined for each of the six elements to account for personal biases and to find the most influential contributor to workload for the human subject operating the experiment. Subjects execute a specific number of trials and then asses the "magnitude" of the six subjective workload ratings for each block of experimental trials.

Table 1. Workload Rating Scales used in MWPE.

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	Very Low / Very High	How mentally demanding was the task?
PHYSICAL DEMAND	Very Low / Very High	How physically demanding was the task?
TEMPORAL DEMAND	Very Low / Very High	How hurried or rushed was the pace of the ask?
PERFORMANCE	Perfect / Failure	How successful were you in accomplishing the task?
EFFORT	Very Low / Very High	How hard did you have to work to accomplish your level of performance?
FRUSTRATION	Very Low / Very High	How insecure, discouraged, irritated, and annoyed were you?
* NAUSEA	None / Vomiting	How much stomach awareness or nausea did you feel?

* The seventh rating scale is only applicable for the Space Shuttle flight version of MWPE.

The experimental design of the Mental Workload and Performance Experiment incorporates variables to measure the performance and workload of a human subject operating a GRiD microcomputer to complete target identification and acquisition tasks. There are four categories of experimental variables: the computer device, the direction of cursor movement, the index of difficulty for target acquisition, and the size of the memory set. The three MWPE graphic input devices are the GRiD computer keyboard arrows, a joystick, and a trackball. MWPE has two pattern layouts for the four targets, either a diagonal or a cardinal arrangement. The third category of variables for MWPE is the index of difficulty which relies on movement amplitude and target width. Target acquisitions are characterized as 'easy', amplitude of 60 pixels from the origin and a width of 20 pixels, or 'hard', 100 pixel amplitude and 10 pixels across. The final category of variables encompasses the memory set size, or response entropy, H. The human subject is presented with a memory set containing one letter of the alphabet or four letters. The experimental task is to select a target on a computer screen display as quickly as possible by

moving a cursor from the center of the screen to inside the target boundary. Figure 1 displays the four categories of experimental variables in MWPE.

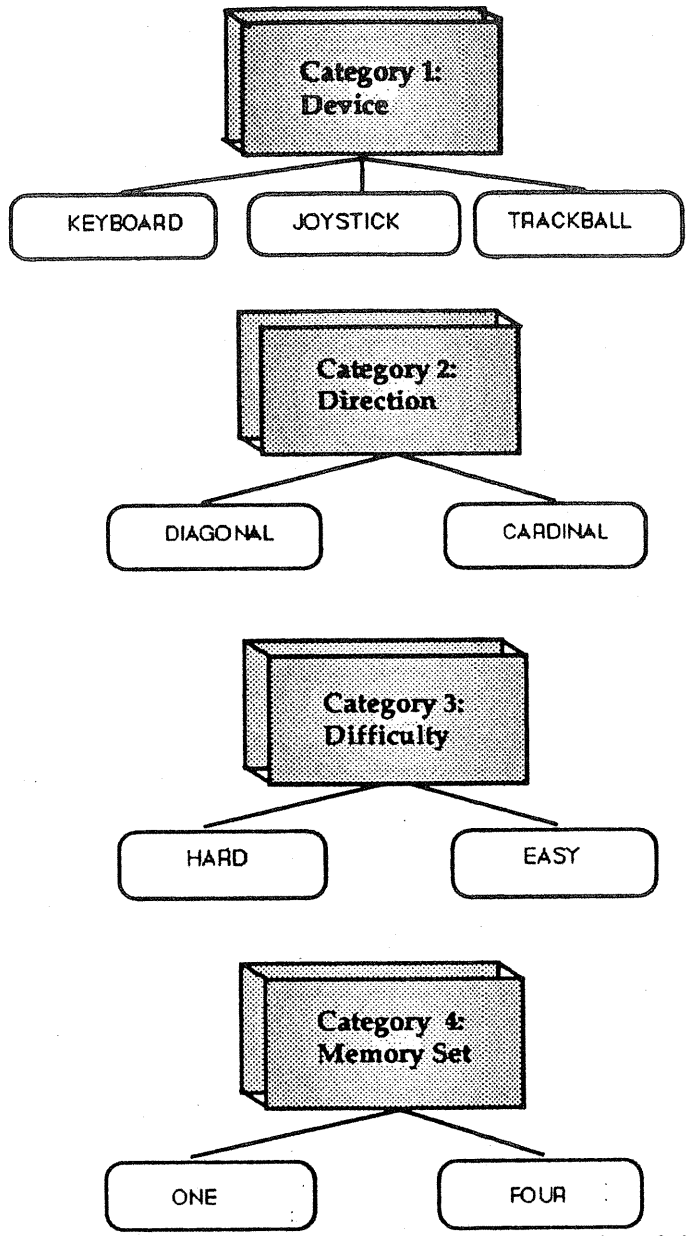


Figure 1. The four categories of MWPE experimental variables.

The Mental Workload and Performance Experiment is an integrated human factors experiment on the GRiD microcomputer. Software development was targeted for the GRiD because it is currently the only Space Shuttle flight qualified microcomputer. Eight graduate students from the Massachusetts Institute of Technology (MIT), four male (Subjects 1-4) and four female (Subjects 5-8) served as the human subjects for the experiment. They each performed seven experimental sessions, the first was a learning session and the remaining six sessions were used for database results. Of these six sessions, three were performed in the upright postural orientation and three were performed in the supine postural orientation.

A sequence of eight trials is used for each memory set. If the memory set contains one letter then it will be used in all 8 trials, whereas, if the memory set contains four letters then each letter is used twice. Eight trials are used to allow for repeated measurements of the same task. In addition to the memory set, the trials are coded by device, direction, and index of difficulty information. For example, the first eight trials may use the trackball, have diagonally arranged targets, have an easy index of difficulty, therefore, small movement amplitude and large target width, and the memory set containing four letters, namely, Z, C, R, and F. See Figures 2 and 3 for illustrations.

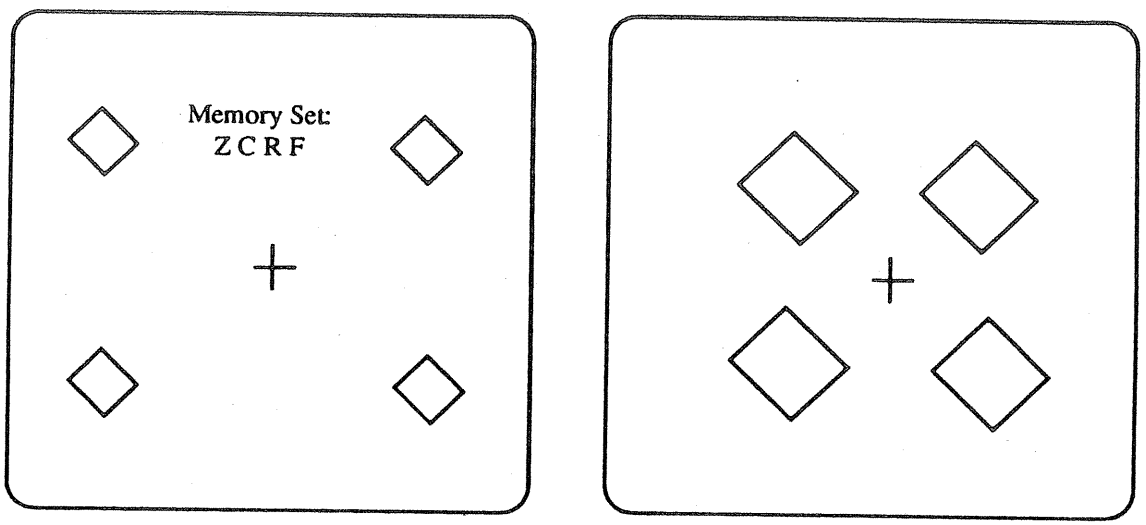
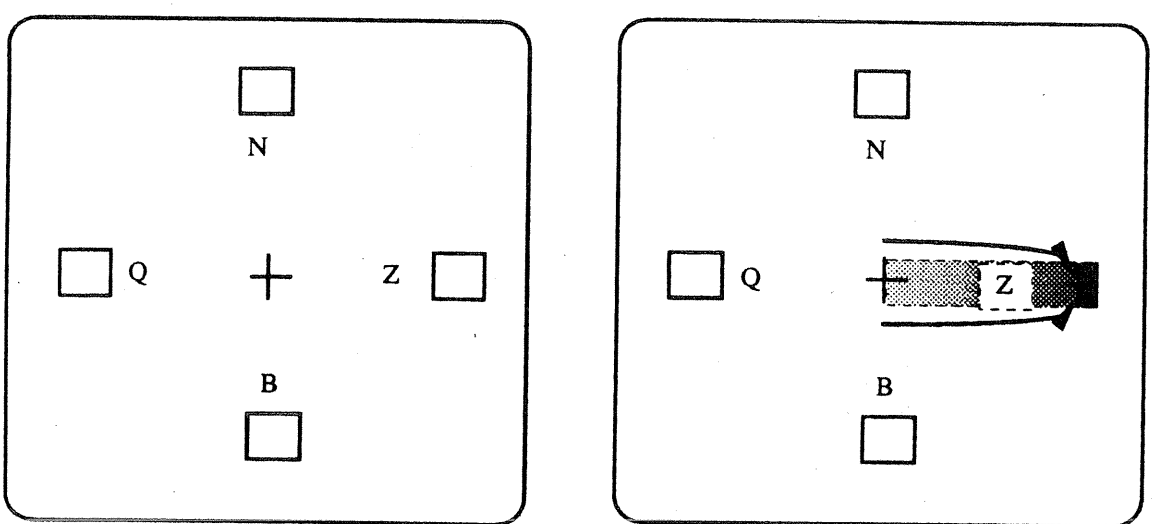


Figure 2A and 2B. (A) **Diagonally** aligned targets, **hard** index of difficulty, and a **four-letter** memory set. (B) **Diagonally** aligned targets, **easy** index of difficulty.



Figures 3A and 3B. (A) **Cardinally** arranged computer display with a letter from the memory set is presented. (B) After **target identification, target acquisition** is simulated by moving the cursor to "capture the target" which is diplayed on the screen by highlighting.

The subject is presented with the six NASA bi-polar rating scales immediately following the eight trials. Once the six workload components have been recorded a single "block" of trials has been completed. The next block of eight target identifications and acquisitions

begins with the presentation of a new memory set on the computer screen. The block of trials is again completed by rating the workload components. Eight different block conditions exist for each device. Then the subject is prompted to switch to the next computer device. This assures that all combinations of variables appear for all three devices. The entire database consists of three upright sessions and three supine sessions for each subject which results in a forty-eight session database.

.c2.RESULTS

The SAS software system for data analysis was used to reduce the experimental data. The statistical significance of interaction and independence of variables was sought. Results which are stated as having 'statistical significance' or 'significance' correspond to data with F ratios of $p<0.05$ and often exhibit $p<0.001$. Table 2 qualitatively represents the Student-Newman-Keuls t-test results of individual subjects for reaction time and movement time and will be referred to throughout this section. The Xs signify statistical significance between two parameters. Detailed thesis results can be found in Newman, 1988.

The effects of the two experimental postural positions, upright orientation and supine orientation, are statistically significant when the entire database is analyzed. However, there is a lack of significance between the two orientations in half of the individual subjects' data. Average reaction time was significantly ($p<0.05$) greater in the supine orientation (662 ms), than in the upright orientation (643 ms), and average supine movement time (1154 ms) was significantly ($p<0.002$) greater than upright movement time (1106 ms).

Table 2. Student-Newman-Keuls t-test results of individual subjects.

		REACTION TIME								MOVEMENT TIME							
		SUBJECT								SUBJECT							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
EXPERIMENTAL CONDITION: POSTURAL ORIENTATION	NOMENCLATURE:																
	UPSUP																
	Upright -0			X		X	X					X	X				X
	Supine -1																
EXPERIMENTAL VARIABLES:	**DEVICE**																
	Keyboard -0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Joystick -1	X				X	X	X		X	X	X	X	X	X	X	X
	Trackball -2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	DIRECTION																
	Diagonal -0	X	X	X	X		X		X	X	X	X	X	X	X	X	X
	Cardinal -1																
	DIFFICULTY																
	Easy -0					X			X	X	X	X	X	X	X	X	X
	Hard -1																
	MEMORY SET																
	One Letter -0	X	X	X	X	X	X	X	X	X	X		X				
	Four Letters -1																

The Xs signify statistical significance between two parameters.
A comparison is made between two variables.
For example, the X in the Upright row and Subject 5 column signifies a statistical significance between the Upright and Supine conditions for Subject 5 during Reaction Time.
The three Xs for all of the devices under Subject 7 shows statistical significance between all three devices for Reaction Time, whereas, the two Xs for Keyboard and Trackball under Subject 2 show statistical significance between the Keyboard and Joystick (the X appears in the row of the variable that appears first) and the Trackball and Keyboard, but there is no statistical significance between the Joystick and Trackball for Subject 2 during Reaction Time.

.c3.Reaction Time Results and Discussion for Experimental Variables

Statistical significance exists between all three devices in both the upright and supine postural orientations. The trackball produced the fastest reaction times, followed by the joystick. The slowest reaction times are recorded when the keyboard was the input device. This is because once the operator makes a decision as to which letter is in the memory set he/she must then choose the proper keyboard arrow(s) and depress the arrows to initiate the correct cursor movement. Whereas, for the joystick and trackball, the subjects have their hand on the device from the onset of the memory search and can readily activate the device.

Memory set size is the largest and most significant contributor to reaction time which is the same result that Sternberg reported. The two MWPE memory sets, one letter and four letters, dramatically effect the memory search task which is measured by reaction time. Average reaction times in the upright position of 505 ms and 780 ms were recorded for one-letter memory sets and four-letter memory sets, respectively. For the same memory set conditions, the reaction times in the supine orientation were 527 ms and 798 ms.

The direction variables, diagonal and cardinal, exhibit significance for the database taken as a whole and for six of the eight subjects during reaction time. (See Table 2) The fastest reaction times were recorded for cardinally aligned targets and averaged 607 ms and 626 ms for the upright and supine positions, respectively. The slowest reaction times of 678 ms and 700 ms in the upright and supine orientations, respectively were recorded when the targets were in a diagonal arrangement. In Table 2 all of the data from male subjects displays significance between diagonally and cardinally aligned targets. Half (2/4) of the data from female subjects shows significance between the directions. Anthropometric characteristics of the subjects coupled with mechanical properties of the devices may explain the differences. Females typically have smaller and more ambidextrous fingers and hands than their male counterparts. Female subjects may show a lack of statistical significance between operating the devices in either the diagonal or cardinal direction because of their increased finger dexterity. I suggest that the significance between the direction of target alignment can be attributed to physical and mechanical phenomena rather than a phenomenon of subjects' mental processing.

Overall, the index of difficulty does not significantly effect reaction time measurements. In addition, the ANOVA reveals a lack of significance for the cross terms of subjects and difficulty (SUB*DIF). This means that there are no significant preferences of subject for level of difficulty; or the concept of difficulty is uniform over the subjects.

.c3.Movement Time Results and Discussion for Experimental Variables

Movement time, MT, for MWPE is the time it takes to acquire a target. Fitts' Law correlates the index of task difficulty, ID, with movement time. The amplitude of movement and the width of the target define the difficulty of the task. The index of difficulty is the largest contributing variable to MT for MWPE experiments. The movement time is also significantly dependent upon input device, direction of target alignment, and memory set. All three devices, the keyboard, the joystick, and the trackball have independently significant effects on movement time. The fastest device is the trackball and hence would be endorsed for computer target acquisition tasks. The rolling ball arrangement of the trackball is easy to operate. The second fastest device was the joystick which is a velocity sensitive device in that the amount of 'stick' movement causes the cursor to move at a proportional speed to stick deflection. Very high velocities are possible with the joystick, but extreme velocity is not required for MWPE target acquisitions since the movement amplitudes are relatively small. When using the joystick, the speeding cursor is hard to control and often overshoots the target. The keyboard arrows move at a

constant velocity which is relatively slow compared to the other devices, thus, an inherent disadvantage exists for the keyboard and the slowest MTs were recorded for this device.

The index of difficulty is the largest and most significant contributor to MT. Target acquisitions which are 'easy' average 818 ms and 855 ms in the upright and supine orientations, respectively. The 'hard' target acquisitions take more time and average 1394 ms and 1454 ms for the two orientations. There is almost a 600 ms difference between easy and hard target acquisitions.

A statistically significant difference exists between the diagonal and cardinal target patterns during the movement time phase of MWPE. The MTs for cardinal targets are faster than for diagonal targets. Movement times of 1291 ms and 920 ms were recorded for diagonal and cardinal target patterns in the upright position, respectively. Increased MTs were recorded for the supine position, namely, 1360 ms and 949 ms.

The size of the memory set has a slight effect on MT. For the upright orientation the memory variables are statistically significant. The size of the memory set does not produce statistical significance for the supine orientation. Do the Sternberg and Fitts models predict the RT and MT of MWPE? The next section compares MWPE data to the theoretical models and then regression analysis is investigated.

The response entropy, H (or $\log_2(n)$), defines the information processing requirements for a memory search and is measured in bits. A memory set of one letter requires 1 bit and a four-letter memory set requires 2 bits of information. Figure 4 was obtained by using Equation 1 and varying only the size of the memory set, while keeping the other variables constant. Linearity is assumed because two points define the lines. Variance in MWPE results and Sternberg's classical model exists.

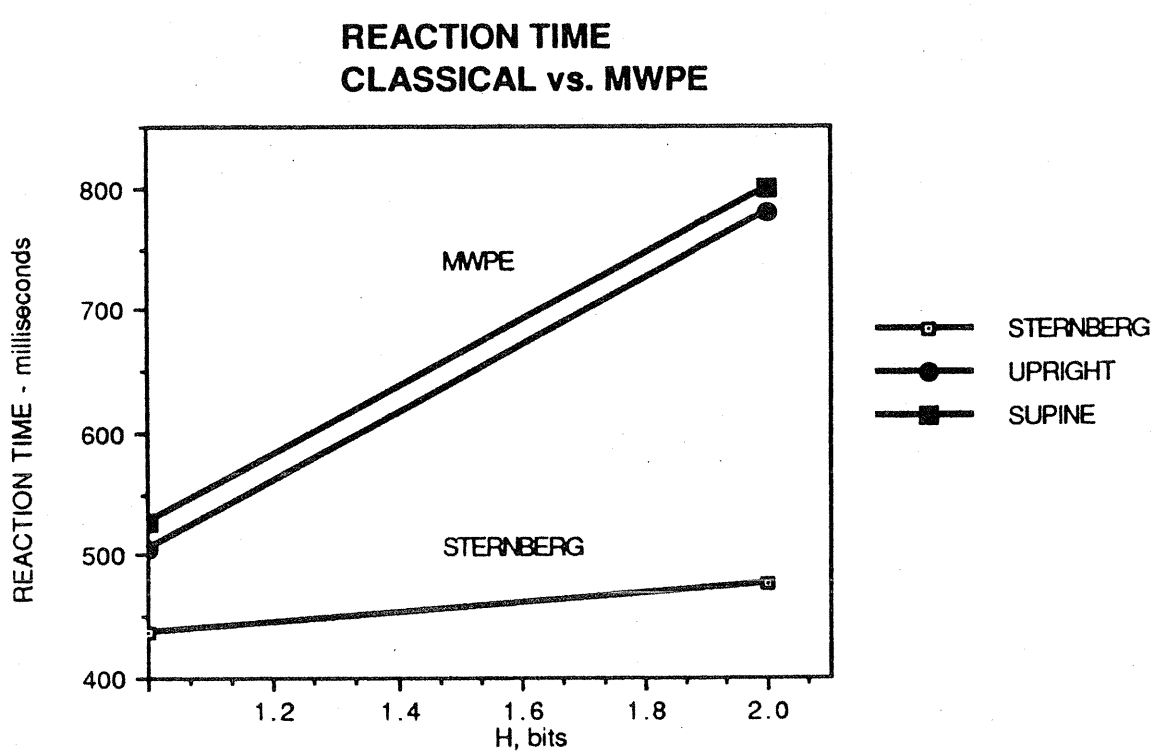


Figure 4. Reaction Time comparisons - Sternberg vs. MWPE.

The amplitude, A, and width, W, for easy targets are 60 pixels and 20 pixels, respectively. The amplitude and width for hard targets are 100 pixels and 10 pixels, respectively. IDs of 2.6 bits for 'easy' targets and 4.3 bits for 'hard' targets were obtained using Equation 3 and the amplitude and width measurements given above. MWPE data is fit to a linear line in Figure 5. From the regression analysis it is known that ID is not the only contributor to movement time and, thus, this figure should be looked at skeptically.

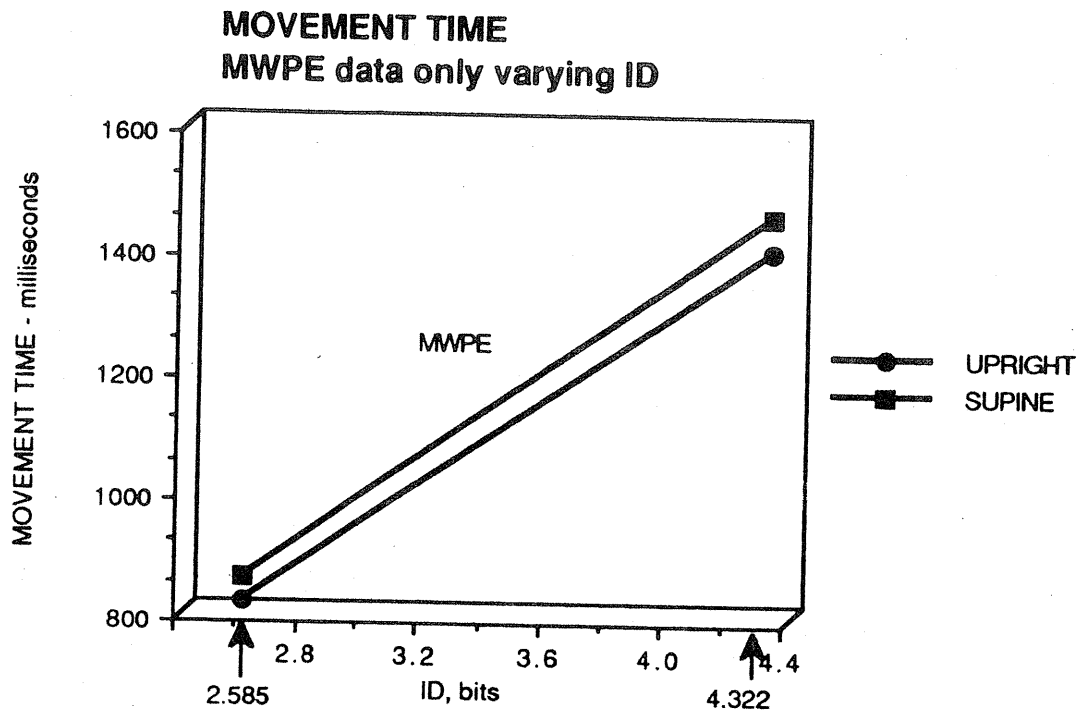


Figure 5. Movement Time model for MWPE data varying only difficulty variable.

.c3.Regression and Interactive Effects

Regression analysis helps to clarify and substantiate claims made for the MWPE database. The purpose of regression analysis is to identify the intercept and regression coefficients for the particular dependent variables. The dependent variables are reaction time, RT, and movement time, MT. The independent regression coefficients coincide with the variables of postural orientation (UPSUP- upright/supine orientation), direction of target alignment (DIR), index of difficulty (DIF), and memory set (MEM). All of the variables exuberate binary choices (i.e. UPRIGHT/SUPINE, DIAGONAL/CARDINAL, EASY/HARD and ONE/FOUR = 0/1). The regression analysis for the database (8 subjects) exemplifies the contributions of each MWPE variable to RT and MT:

$$RT = \{532 + 20UPSUP - 73DIR + 21DIF\} + 136 \log_2(n) \qquad (4)^*$$

{ coincides with *'a'* }

$$MT = \{983 + 48UPSUP - 391DIR + 49MEM\} + 350 \log_2(2A/W) \qquad (5)^*$$

* The negative sign is due to the order in which the variables were analyzed. (i.e. the diagonal target acquisitions took more time than the cardinal tasks.)

The error term for the RT regression analysis is $\pm$ 7 ms and $\pm$ 14 ms for the MT equation. We see from Figure 4 that both the overhead and slope of MWPE results differ from the Sternberg model of Equation 1. The overhead component of the RT Equation 4 is a

function of all significant experimental variables rather than a constant and the rate of increase of response entropy is larger then Sternberg's slope of 38 ms. Likewise for MT, all significant experimental parameters contribute to the intercept term. These discrepancies might suggest that the Sternberg and Fitts tasks of the "Fittsberg" dual-task paradigm should not be analyzed as two separate tasks because operators may start preparing for the target acquisition task while they are finishing their target identification task. Further experimentation is required to substantiate this claim.

.c3.Subjective Ratings of Workload

MWPE incorporates subjective rating scales for two main reasons. The first reason is to compare and contrast the subjective ratings with the objective measurements. The second reason is to account for the multidimensional nature of a person's feelings of workload while executing the specific target identification and acquisition tasks of MWPE. Due to the lack of statistical significance among subjective ratings, the trends of the ratings obtained from MWPE will be discussed rather than the statistical relevance of the parameters.

The supine postural orientation tends to induce slightly higher workload than the upright orientation, but significance is lacking from the data. Overall, the subjective ratings tend to agree with the objective performance measurements with the exception of two devices, namely, the keyboard and the joystick. The trackball and keyboard induce the least amount of workload, while the joystick induces the greatest amount of workload. This trend is substantiated by averaging across all subjects regardless of orientation. However, the results differ if subjective ratings are looked at in relation the the postural orientations in which the subjects performed MWPE. The trackball induces the least workload in the upright position, but in the supine orientation, the keyboard induces the least amount of workload, followed by the trackball, and finally the joystick.

The keyboard induces less workload than the joystick. However, objective measures of joystick performance rank it ahead of the keyboard because faster times are attained with the joystick, but the subjective ratings suggest that this better performance with the joystick is at the cost of increased workload. Figures 6 Figure 7 illustrate subjective ratings as a function of input device.

Temporal demand and effort are the two subjective rating subscales which receive the highest workload ratings. Mental demand and frustration subscales are reported to induce the least amount of workload. Physical demand and performance contribute an average amount to workload.

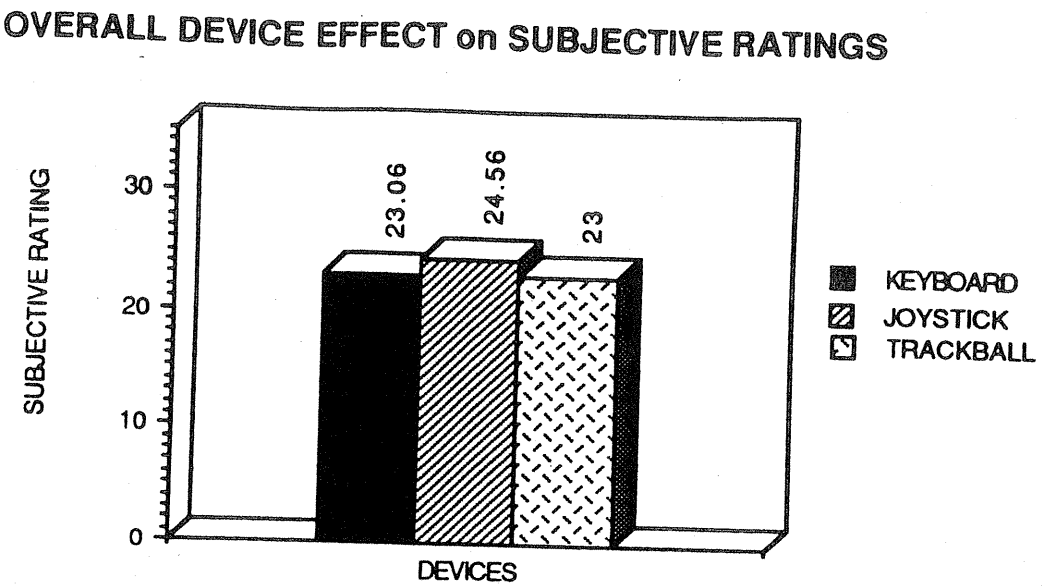


Figure 6. Device effect on subjective ratings.

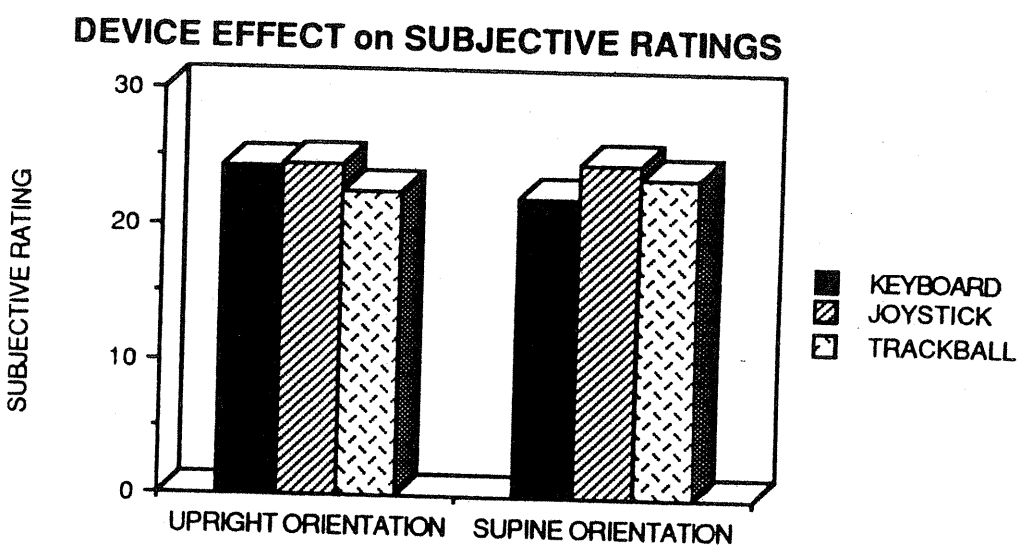


Figure 7. Device effects on subjective ratings according to device.

.c3.Summary of Results

The simple models displayed in the previous figures do not fully explain MWPE reaction time and movement time measurements. RT for MWPE is not solely dependent on the size of the memory set. The MT data for MWPE depends on index of difficulty, as well as, direction of target alignment, and to a lesser degree postural orientation, and size of the memory set.

The regression analysis models in Equations 4 and 5 show the complex interactions between variables for RT and MT for the MWPE protocol. The RT equation suggests a nominal neural processing time of 532 ms for the memory search task. The experimental variables contribute varying magnitudes to the RT model. The size of the memory set contributes 71%, direction of target alignment contributes 19%, and postural orientation and index of difficulty each contribute 5% to the RT model. MT has a 988 ms intercept. Index of

difficulty contributes 54% to the MT model and is closely followed by a 36% contribution from the direction variable. Postural orientation and size of the memory set each contribute 5% to the MT model. Figure 8 illustrates the composition of RT and MT.

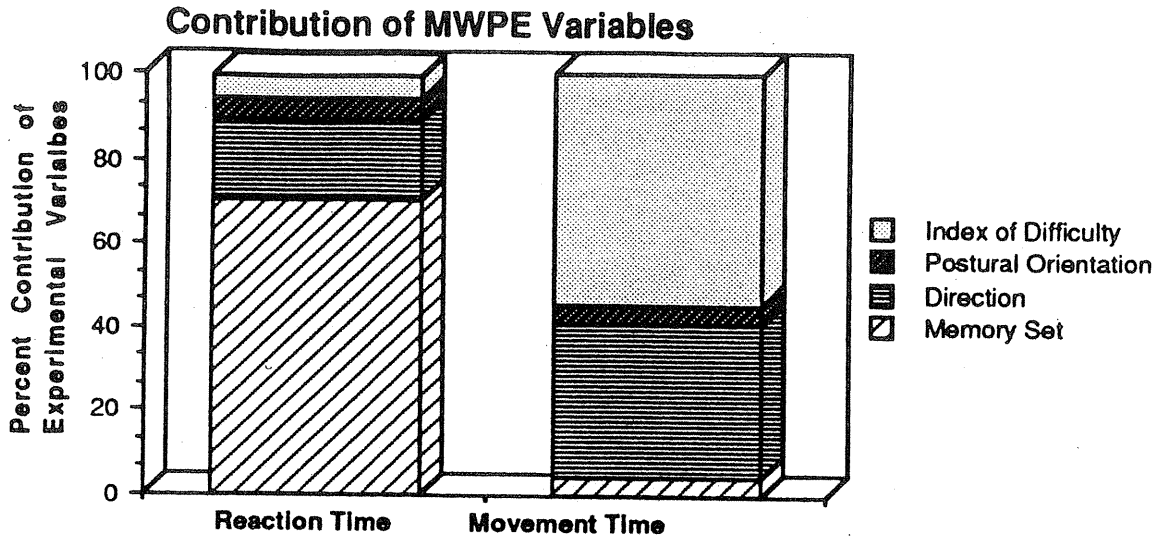


Figure 8. Contribution of MWPE Experimental Variables on Performance Time Measurements.

Subjects report that the trackball and keyboard require similar amounts of workload and they report that the joystick induces the greatest amount of workload. Cardinally aligned targets induce less workload than diagonally aligned targets. There is an average of a 19% increase seen in the subjective ratings between the two directions. The index of difficulty variables effect the subjective ratings to a lesser degree than the previous MWPE variables. There is an average of a 14% increase in subjective ratings of hard target acquisitions than easy target acquisitions. Subjects reveal that they encounter the greatest workload for memory set with four letters rather than memory set with one letter. This makes intuitive sense and there is an average increase in workload of 27% associated with a four-letter memory set as compared with a one-letter memory set.

In conclusion, MWPE results show similar trends to the classical models for RT and MT. Yet the results show interaction among many experimental variables which are not accounted for in the classical models of reaction time and movement time. RT is not solely dependent on size of the memory set; the direction of target alignment was also a substantial contributor to RT. MT is not solely a function of ID, but was also a function of the direction of target alignment. Subjective mental workload ratings tend to agree with the objective measures of RT and MT for MWPE. The only noticeable difference being the increased amount of workload for the joystick as compared to the keyboard. Although a lack of a statistical significance was noted, the supine orientation induced higher amounts of workload on the operator than the upright orientation. Temporal demand and frustration were the largest contributors to the subjective workload ratings, while mental demand and frustration contributed less to workload. The trackball was the 'best' device for MWPE because subjects obtained the fastest target identifications and acquisitions and least amount of subjective workload with the trackball.

.c2.RECOMMENDATIONS FOR FUTURE MWPE DEVELOPMENT

In addition and prior to spaceflight the following recommendations are suggested. The first MWPE enhancements should incorporate additional memory sets and target amplitudes and widths. Then the comparisons between the classical Sternberg and Fitts models and the multiparameter MWPE models in Equations 4 and 5 can be further substantiated.

Further understanding of human motor control during manual tasks would be gained by recording the initial trajectories of cursor movements. Comparing the direction of the target to be acquired and the initial direction of cursor movement results in a tracking error. This error measurement could be very useful in providing investigators with movement control and data, especially for the weightless environment. Movement data for ground-based experiments abounds, but our knowledge of arm, wrist, and hand movements and adaptation in microgravity is limited. This MWPE software enhancement would lead to increased understanding of human performance and muscular control for arm movements while executing manual tasks in space.

Before the recommendations regarding graphic input devices are implemented into space workstation design, further experiments should be run in which the input devices are mechanically equivalent. Currently, there is an inherent disadvantage for the keyboard because the cursor moves at a slower rate than for the other devices. Also, additional input devices should be tested. Given the explosive popularity of mouse-type input devices, future ground-based experiments should include the use of a mouse and development of a microgravity mouse should be investigated. It may be possible to have a mouse device work in microgravity by means of a vacuum or suction mouse pad to keep the mouse attached to the working surface rather than floating away.

The final recommendation relates to the subjective ratings. Further research should be done on the applicability of subjective ratings to computer target identification and acquisition tasks. Statistical significance is sought for the MWPE subjective rating system. It is important to keep in mind the laborious time constraints of flight qualifying experiment enhancements.

MWPE is a simple self-contained experiment designed to investigate the workload and performance of a cursor control task in the weightless environment. Similar human factor experiments will help to explore the effects the weightless environment has on the operator. The space station will offer investigators a unique opportunity to conduct space laboratory research.

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