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MICROGRAVITY CURSOR CONTROL DEVICE EVALUATION FOR SPACE STATION FREEDOM WORKSTATIONS

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ABSTRACT

Computer Workstations will control Space Station Freedom systems and payloads. These microgravity workstations will use direct manipulation as the primary interface. They significantly reduce the number of finite actions required to operate a computer over that for a command-line interface, thus reducing errors and overall task completion times. This research addresses direct manipulation interface (cursor-control device) usability in microgravity. The data discussed are from KC-135 flights and an STS-29 (shuttle) Detailed Test Objective (DTO). Three commercially-available devices: an optical mouse, a trackball and a post-mouse, were chosen to begin investigating the best characteristics required for an optimal microgravity device. A text editing task was performed aboard the KC-135 flights. This included pointing and dragging movements over a variety of angles and distances. Detailed error and completion time data from this task, as well as crew comments from the DTO, provided us with information regarding cursor control shape, selection button arrangement, sensitivity, selection modes, and considerations for future research.

INTRODUCTION

The Man-Systems Division at NASA-Johnson Space Center (JSC) has an active research program pursuing answers to questions about Human Computer Interaction (HCI). This research is currently being applied to the design of the Space Station Freedom (SSF) Workstations, as well as for the modification of the Space Shuttle computer interface for compatibility with the station. Shuttle experience shows that in 0-g, keyboard entry of command line input proves to be a less than optimal means of HCI. Because each astronaut aboard the SSF will have to spend much of his/her day interacting with a computer workstation, it is mandatory that the interface maximizes the productive use of this valuable time. A direct manipulation interface has been determined to be the best choice in microgravity because it reduces the number of finite actions required to operate a computer, thus reducing opportunities for error and overall time to complete a task. One-g research in the Human-Computer Interaction Laboratory (HCIL) has concentrated on human performance modeling with cursor control devices (e.g., Gillan, Holden, Adam, Rudisill & Magee, 1990).

The current research addresses the usability of cursor control devices in microgravity aboard the KC-135 and as part of a DTO aboard the STS-29 shuttle flight. Due to the limited availability of such flights, a representative subset of available devices had to be selected for evaluation. Devices which require minimum "real estate" for operation and allow highly accurate input are desirable for use in the space station task environment. A survey of current research shows that touch screens and light pens provide for faster performance than with a trackball or mouse; however, they are less accurate due to parallax problems, obstruction caused by placing the hand in front of the screen, and the large resolution required for touch activation. Touch technology is not recommended for use under demanding conditions or intensive use and where high resolution is required (Whitfield, Ball & Bird 1983; Beringer & Peterson, 1985). The trackball and mouse allow for the greatest accuracy, with moderate speed, of commercially-available off-the-shelf (COTS) products (Brown, 1989). Also, a post-mouse device called the Felix™ was selected because it is about the size of a standard trackball, it allows absolute cursor positioning by movement of its post/entry button within a one inch square.

KC-135 EVALUATIONS

The Reduced Gravity Program at NASA-JSC owns and operates an experimental aircraft, the KC-135, which simulates a "weightless" environment similar to the environment of space flight for test and training purposes. The specially-modified turbojet transport flies a parabolic arc to produce short periods of 0-g lasting an average of 23 seconds (Williams, 1987) surrounded by a 2-g pull-up and a pull-out. A flight consists of 40 parabolas.

In designing the task to be performed aboard the aircraft, consideration was given to produce a short, repeatable, though realistic task. These characteristics were especially important because: 1) It is not possible to sustain perfect 0-g throughout the 23 seconds; 2) The operators require a few seconds to physiologically adjust from the 2-g pull-up to the free-floating condition; 3) Operator discomfort /illness is not uncommon and often causes the loss of the data from a few parabolas. A text editing task was considered to be realistic because it will be necessary aboard the space station, it requires a great deal of cursor movement and control, and represents a task requiring high accuracy. Text editing incorporates the three basic cursor control actions, pointing, dragging, and clicking. It was also determined that the task could be completed approximately three times per parabola.

The common features of the two KC-135 experiments will be presented here. Additional details will be given in the Procedures and Results & Discussion sections specific to each experiment.

METHOD

Subjects

Two subjects were used in each experiment. All were employed by Lockheed Engineering and Sciences Company (LESC). All were experienced Macintosh and mouse users.

Apparatus, Stimuli, and Data Recording

Both experiments were conducted using a standard Macintosh Plus with 1.0 MB of memory and an external disk drive. The four control devices evaluated were a Macintosh mechanical mouse, an A Plus™ Optical Mouse with a reflective pad, a Turbo Mouse™ trackball and a Felix™ post-mouse. The computer was mounted on an aluminum stand which provided a worksurface for the use of the cursor control devices. The trackball, Felix™ and mouse pads were restrained with velcro. Foot and waist restraints were used to secure the subject while performing the task. In practice trials aboard the aircraft, it became apparent that during microgravity the ball of a Macintosh mechanical mouse floated into the housing, making it unusable. The control/display ratio for the optical mouse and trackball was set to the second slowest setting for mouse sensitivity on the Macintosh control panel. The Felix™ required that the tablet (or very slow) setting was used.

The Apple software product, Hypercard™, was used for presentation of the text editing task. The stimuli included: 1) a two-line block of text with a portion underlined (5, 14 and 26 characters i.e., 1.4, 3.0, and 5.7 cm. respectively); 2) a Select button which varied in location among the four corners of the display screen; 3) a NEXT button for user selection of the next trial screen (see Figure 1). The text block was located to produce three different pointing distances with respect to each Select button. Each of the 36 conditions (three text selection lengths x three pointing distances x four pointing angles) was presented in a randomized order as a block of trials. Each flight was composed of four sets of ten parabolas.

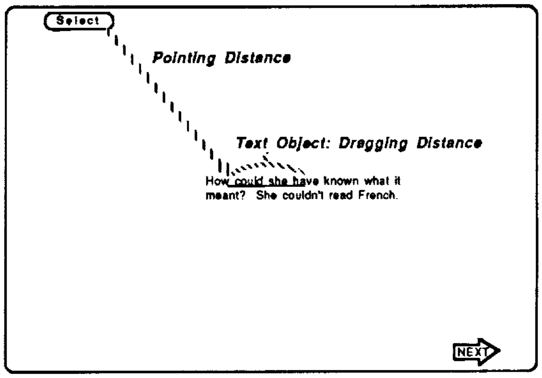

Figure 1. Elements of the basic display

A macro-recording program, Automac III™ (Genesis Software), was used to record a time stamp and cursor location every time the cursor control device select button was depressed and every tick (one sixtieth of a second) while it was depressed.

KC-135 EXPERIMENT 1

Procedure

Two subjects used each device twice during four testing sessions which were held for pretest, flight, and posttest conditions. Sessions (1) and (2) each consisted of one block of 36 text selection trials using one device. Sessions (3) and (4) were composed of two blocks of 36 trials, each performed with a different device. The pre- and posttest sessions were held over three consecutive days because session (1) & (2) were combined. The flight sessions were held over four consecutive days, where sessions (1) & (2) consisted of only two parabolas rather than four.

Results & Discussion

The trials in which subjects made incorrect selections were eliminated for the examination of movement times. With each device pointing times by pointing distances were similar across all gravity conditions. Dragging times for each of the drag distances were also similar across gravity conditions. However, it is apparent that learning occurred due to the decrease in overall selection times from pretest to postest sessions. The learning effect appeared to continue across the flight conditions except that for the longest drag target, 26 characters (5.7 cm), selection times,

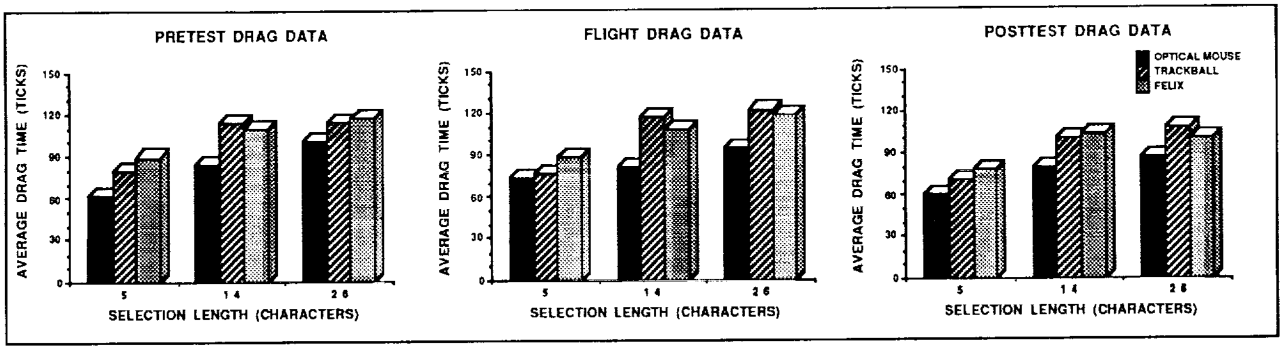

Figure 2. Drag times by selection length and device for Experiment 1

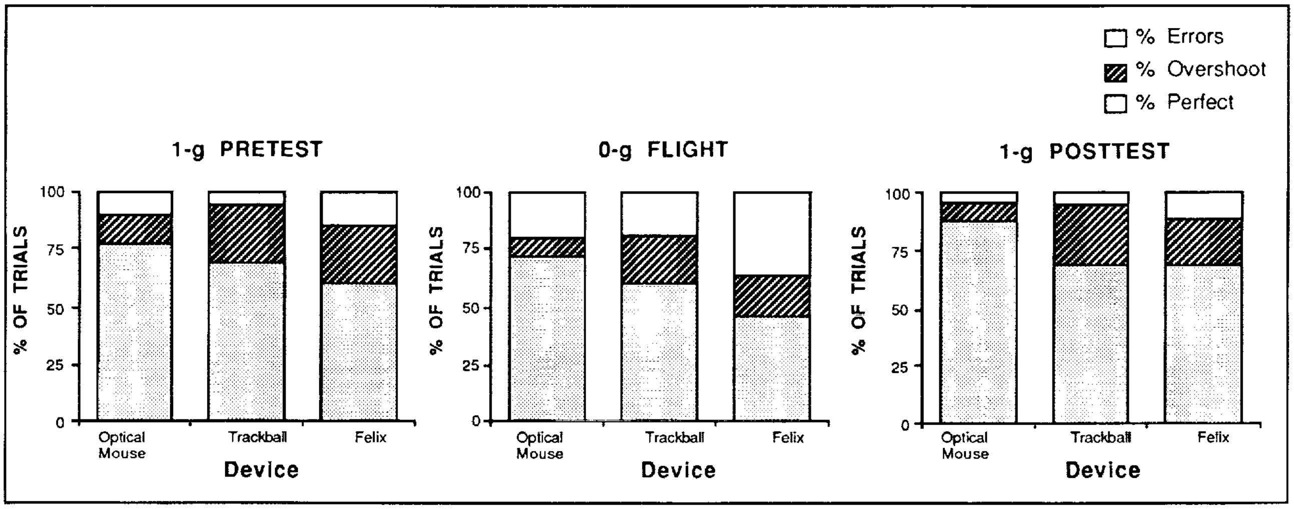

Figure 3. Error distribution across test conditions for Experiment 1

collapsed across devices, were 8.7% slower in 0-g than the average of the 1-g trials. While there was not a significant effect for device used, in both the pointing and dragging portions of the tasks for pretest, flight, and posttest conditions, the optical mouse was fastest (see Figure 2).

The error data presented in Figure 3 shows the percentage of trials where the subject's selection resulted in an (1) Error: the subject made errors resulting in an incorrect selection, (2) Overshoot: subject moved the cursor from the leftmost character of the underlined area (+/-.5 character) beyond the end of the underlined area, but then moved back to the end of the underlined area (+/-.5 character) before releasing the mouse button, and (3) Perfect selection: where the subject made a perfect selection (+/-.5 character) at each end of the underlined area. More errors occurred in flight than in pre- or posttest. The greater percentage of overshoots with the trackball and the Felix™ may contribute to the somewhat longer pointing and dragging times.

STS-29 DTO

The cursor control device evaluation flew as a part of an engineering evaluation of a portable computer to be used as a Payload General Support Computer (PGSC) aboard the shuttle.

Subjects

The participants were the astronauts on the STS-29 Shuttle crew. Each was familiarized with the task before flight but was otherwise unfamiliar with the mouse or trackball.

Apparatus

The evaluation was performed using a GRiD 1536™ Personal Computer with a 10 in. diagonal blue LCD screen. The cursor control devices evaluated were the MSC Technologies™ optical mouse with reflective pad and a PC-TRAC™ trackball. Velcro was fastened to the back of the reflective pad and trackball so that they could be affixed to the cabin wall or the crewmember's pant leg (thigh).

Procedure

The crew was instructed on how to set up the computer and cursor control devices. The evaluation consisted of subjective comments on a questionnaire after attempting specific point, click and drag movements on displays from existing software for the Shuttle Flight Data File. The questionnaire asked the crew to describe: (1) their body position while using the device, (2) ease of use for each of the devices with the point, click and drag movements, and (3) suggestions for modifications to the devices.

Results & Discussion

In all test cases the crewmembers were free floating while using the devices.

The mouse was given a rating of 1 on a scale of 10, were 10 indicates an excellent device. It was considered very difficult to use aboard the shuttle without a specially designed work surface. The crew described it as "requiring three hands" to operate. The trackball was rated a 7 on the same 10 point scale. It was used as a restraint by the crew in that they could keep themselves from floating away while using the device by holding on to the device itself. This method of use suggests that the input or click buttons, located on the top face of the device with the ball, should be located above rather than below the ball. This allows for the user to grasp the trackball with the thumb and ring finger while using the index and middle fingers to manipulate the ball and buttons.

The crew also suggested the incorporation of a toggle mode for selection. This would allow the user to click at the beginning of the text to be selected, thus triggering a selection mode, then move the ball and click at the end to complete the selection. Currently the drag mode of selection requires the user to hold down the selection button while using the ball to move the cursor to the end of the selection area. Holding down a button while moving the ball can be difficult, even in 1-g, depending on the relative locations of the button and ball.

KC-135 EXPERIMENT 2

Procedure

This experiment compared the use of the toggle selection mode suggested by the STS-29 crew with the typical Macintosh drag selection mode. The trackball and the optical mouse were used in each mode.

Two subjects practiced with each device in each selection mode to steady state performance prior to pretest data collection. Pretest and posttest data collection sessions were held for four days. Each day each subject completed eight blocks of trials (i.e., two blocks with each device in each selection mode).

Four flight sessions were planned but one was lost due to computer problems. The design allowed for each subject to perform two blocks of trials using each device in one selection mode per flight. On day two each subject would use the selection mode they had not used the day before. Similarly, on day three they switched modes again. Because during the last day no data was collected, each device x mode condition was performed twice by one subject and only once by the other. A General Linear Model (GLM) statistical analysis showed the subject effect was not significant.

Results & Discussion

Contrary to the expectation that the toggle selection mode would provide faster performance, the drag mode proved to be significantly faster as collapsed across all other testing conditions ($p < 0.05$). Selection times were not significantly different, though the mouse was consistently faster in both drag and toggle modes than the trackball (see Figure 4).

CONCLUSION

Direct manipulation performance is somewhat slower and more error prone in microgravity than in 1-g, even with sufficient restraint mechanisms. Longer selections, greater than 5 cm, are most affected by microgravity. Fifteen-inch diagonal displays have been baselined for use aboard Space Station Freedom. This current data shows that either the interface must be designed to minimize large selections or cursor controllers must be further researched to improve performance and accuracy.

The mouse has consistently provided for faster text selection than the trackball or post-mouse. The European Space Agency (ESA) has also independently arrived at this same conclusion (Gale, 1989). However, the mouse requires greater real estate for operation (i.e., the footprint of the control device) and requires more elaborate restraint than does the trackball. However, by increasing the gain (the control/display ratio) the footprint of the mouse can be substantially reduced. The trackball allows for one-handed use and serves as its own restraint for the resolution of input forces in microgravity. More research needs to be conducted which considers modifications to the trackball to improve its performance. Incorporation of the toggle mode of selection was such an attempt. One-g research is planned to evaluate the placement of selection buttons on the trackball.

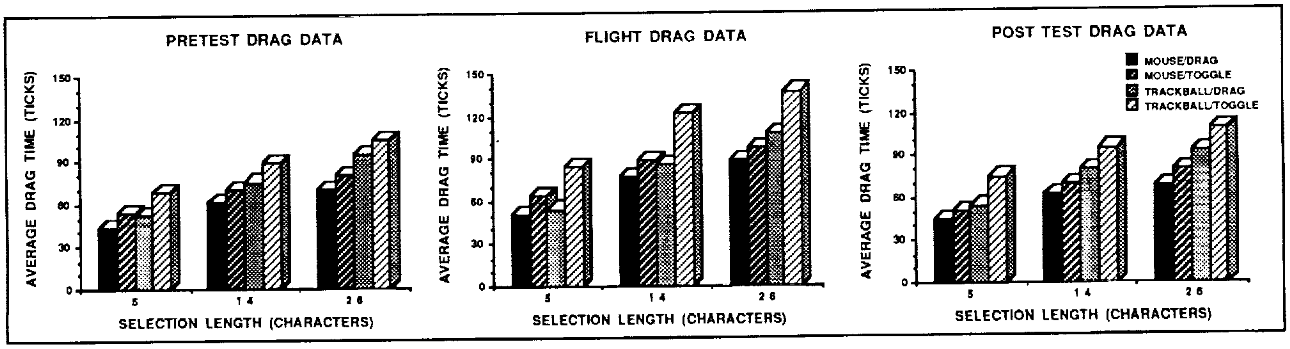

Figure 4. Drag times by selection length and device for Experiment 2

A DTO planned to fly aboard STS-41 in October 1990 will compare the 1.3 in. trackball built into a Macintosh portable with a new version of the Felix™. The new Felix™ is expected to be less sensitive than the original Felix™ used in Experiment 1.

A KC-135 flight planned for November 1990, will evaluate various restraint mechanisms for use with each of the two cursor control devices McDonnell Douglas Space Systems Company (MDSSC) has tentatively baselined for the space station workstation. These devices are a standard type trackball as well as a 1.5 in. joystick mounted thumb-ball/trackball. These designs will be further refined and evaluated aboard a DTO planned for May 1991.

Variations of the control/display ratio, variable gain designs, as well as double-click speeds will be further researched to define appropriate ranges for use in 0-g. Such controls will be user selectable aboard the space station for whatever device is chosen. Practice to steady state performance in 0-g is unfortunately impossible until the station is in place. It would be difficult and unwise to absolutely predefine these settings for all users.

ACKNOWLEDGEMENTS

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