

How should trackball directional movement intuitively relate to an end effector?

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Three strategies for the trackball control of an end effector on a laparoscopic graspers tool were tested to see which strategy was most intuitive to the user. The three strategies (UURR, UDRL, UDRR) were tested on four different orientations of the hand: horizontal holding the tool as an extension of the arm while rolling the trackball with the thumb, horizontal holding the tool as an extension of the arm and forearm pronated 90 degrees while rolling with the thumb, horizontal with tool 90° to arm using the thumb, and horizontal with tool 90° to arm using the index finger to roll the ball. Twenty-four subjects, each randomly chosen to test one of the three movement strategies, performed two trials sets per hand orientation, the first to test for intuition and the second to test for the effect of training. The outcome of the trials was a number of correct and incorrect movements of the trackball to control the end effector which was simulated on a computer screen. The results were analyzed using a general linear model test on repeated measures to determine the effects of strategy and hand orientation. Analyses showed that intuitively, subjects were significantly better when the end effector moved as the trackball did (UURR). The analyses of the learned trials showed that subjects did equally well with all three strategies. From these results, it was determined that the trackball control of the forceps will be manipulated using the UURR strategy.

Introduction

Laparoscopic surgery is a relatively new field in the medical profession and because of this, there has not been a lot of work done to design optimal tools and procedures. Tools that laparoscopic surgeons are currently using are not only difficult to use, they may actually be doing harm to the highly trained physician. Berguer, et al. (1999) reported an alarming 8% to 12% incidence of frequent pain or numbness in the neck or upper extremities after laparoscopic operations from self-reports by surgeons. There is a strong desire from within the surgical community to improve the design of laparoscopic tools available. The redesign should add comfort and function to the tool.

An important function that many laparoscopic tools are missing is an actuating tip. Physicians report that the degrees of freedom at the graspers can cause excessive awkward arm motion (Van Veelen, et al. 2001). A well-designed actuating tip will add degrees of freedom to the end effector allowing for more precise manipulation of the tool which will benefit the surgeon by decreasing the number of awkward arm motions and possibly decreasing surgery time. An actuating tip will also benefit the patient by possibly decreasing the number of medical errors which harm the patient.

The number of studies relating to tools and procedures for laparoscopic surgery are slowly

increasing. Matern and Waller (1999) are testing two new handle designs, (Berguer et al. 1997) compared surgeons' posture in open surgery vs. laparoscopic surgery and (Van Veelen et al. 2001b) looked at design criteria for laparoscopic tool handles. As more work is done and more tools are redesigned, actuating tips will be an integral part of laparoscopic tools and the manipulation of those tips will be critical to the comfort and ease of use of the tool.

In the midst of designing a new laparoscopic graspers tool, a decision had to be made in regards to how to design the manipulation of the graspers using a trackball, the desired controller. There was disagreement on what the most intuitive strategy for trackball control would be. There are four directional strategies for how the trackball can control the end effector. The first is similar to the use of a computer mouse with movement of the trackball upwards causing the end effector to move upwards and movement right causing right end effector movement. The second is similar to the pivot control of a solid rod. Movement of the rod up makes the end effector move down and movement to the right equals movement of the rod left. The third strategy is similar to a flight simulator. Movement of the trackball upward would cause downward end effector movement and trackball movement right would cause right end effector

movement. The fourth would be movement of the trackball up would move the end effector up, but movement to the right would move the end effector left. There is no situation where this strategy seems intuitive, so it was excluded from the study.

Wayman (1993) performed a similar test, but tested only for preference between “forward for up” and “back for up” using a joystick. Wayman found that intuitively more users expected the “forward for up” configuration, but after training, there was no statistical difference between the two configurations when performing a task.

No past studies were found that completely answered this question, so an independent study had to be performed. In this study both intuitiveness and learning ability is of interest. The goal is for use of the laparoscopic tool to be intuitive to most users and easily learned by the rest.

Expected outcome

The selected manipulation strategy for trackball to forceps control was expected to make a difference in intuitive end effector positioning. The second set of trials was expected to show a smaller magnitude of difference because of the effect of minimal training during the first trial. The hand orientation was not expected to make a difference in the outcome.

Method

Apparatus

A trackball mouse (Fellowes Micro Trac) was used as the input device. An extended handle was made from clay and attached to the mouse to more closely mimic the intended laparoscopic surgical grasper handle shape. The output was the direction of movement of a stylized laparoscopic graspers (end effector) on a computer screen. The testing program was programmed with three different trackball input strategies. The first strategy was the intuitive strategy for mouse and trackball users: when the marble is moved up, the end effector moves up, when moved right, it moves right and vice versa (UURR). The second strategy was intuitive to a flight simulator: the end effector moves down when the marble is moved upward, but when the marble is moved to the right, the end effector moves to the right (UDRR). The third strategy was the opposite of the first scenario and intuitive to controlling a rod with a pivot point: when the marble is moved up, the end effector moves downward and when the marble is moved to the right, the end effector moves left (UDRL). The end effector was simulated on a computer screen as a shaft with a graspers tip. The subject was instructed to move the end effector, by manipulation of the trackball, to a target on the screen. The program recorded the trackball movement direction as toward the target

(correct) or away from the target (incorrect). Accuracy was not particularly important, so a rather large area was provided for error. Any movement within ± 45 of the absolute accurate was considered correct.

Subjects

Twenty-four subjects (12 males and 12 females) were tested in the experiment. They were separated into three groups of eight subjects. Each group had four males and four females and performed the tasks with one of the three strategies. The subjects were further divided so that one female and one male started the intuition trials in each of the four directions: up, down, left and right. All assignments of strategy and initial hand orientation were random.

The age of the subjects (25-35 years of age) was selected to match the approximate age of the incoming laparoscopic surgeon. Subjects having substantial experience with flight simulators or first-person shooting games were excluded since they had a bias toward UDRR. Computer trackball users were also excluded since they had a bias toward UURR.

Procedure

After informed consent was obtained, the subject was instructed to hold the trackball in a randomly assigned hand orientation. Tests were performed on four orientations of the hand. (See Fig. 1) The first orientation had the subject hold the tool with trackball horizontally as an extension of the subject's arm and the subject used the thumb to manipulate the trackball. The second orientation also had the subject hold the tool with trackball horizontally as an extension of the subject's arm, but pronated the forearm so that the trackball was on the side, the subject's forearm pronated and the subject used the thumb to manipulate the trackball. The third orientation had the subject hold the tool horizontally, but at a 90° angle from the outstretched arm and the subject used the thumb to manipulate the trackball. The fourth orientation also had the subject hold the tool horizontally at a 90° angle, but the subject used the index finger to manipulate the trackball.

One of the strategies was randomly selected and the subject was instructed to move the end effector in the direction of the target which was programmed for their trial to be up, down, left or right initially. The computer program recognized the direction the trackball moved and coded this data as correct or incorrect. The subject was not told which manipulation strategy the trackball was programmed for, so the first up-down movement and the first right-left movement were true tests for intuition.

The first four directional trials served as training for the subject to identify for him/herself the manipulation strategy of the trackball. After the

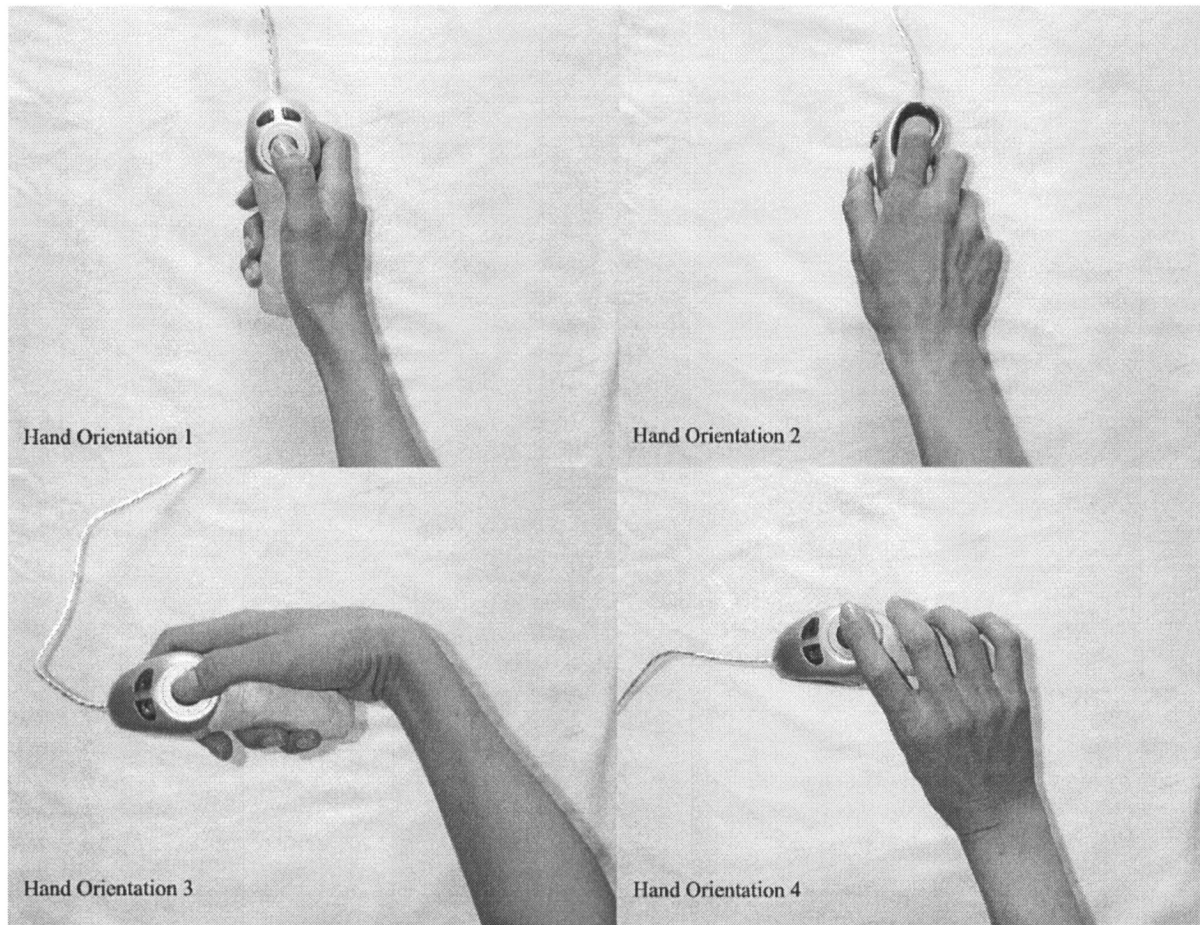


Fig. 1 Four Hand Orientations

intuition trials, it was verbally confirmed that the subject knew which manipulation strategy was being used. The second set of trials followed immediately after the first four directional trials. There were eight directions, randomly presented: up, up-right (mid-way between up and right or at 45 degrees), right, down-right, down, down-left, left and up-left. The result (correct or incorrect) of the trackball movement was recorded for each subject.

Experimental Design

The dependent variable in the experiment was a binomial outcome, correct or incorrect directional movement of the end effector from the trackball. The independent variables were strategy and hand orientation. Strategy was the most important variable for this study. The overall concern was the effect of intuition of the three strategies (UURR vs. UDRR vs. UDRL) on control of the end effector. The hand orientation was important for use of the tool in non-standard hand positions. The four hand orientation scenarios were tested. Trials were divided into two sections: the initial four directions (intuitive) and subsequent (learned) trials (randomly

selected angles -- every 45°). The first direction the target was programmed was blocked on subjects within gender, 2 subjects per beginning direction (1 male and 1 female). Subsequent trials were randomized.

The dependent variable, number of correct trials (frequency), was analyzed using a general linear model test on repeated measures (SPSS Version 11.5) to determine the effects of strategy and hand orientation. The analysis was done with the data on the initial four directions and again for the randomly assigned eight subsequent trials in order to obtain intuitive and learned results, respectively.

Results

Initial Intuition Trials

The results of the general linear model test for the dimension of strategy showed that initially, subjects were significantly ($p = 0.000$) better at the 95% confidence level when the control of the end effector mimicked a trackball mouse (UURR). The intermediate scenario (UDRR) was not significantly different from

the UDRL scenario, but both averaged significantly fewer correct trials than the UURR scenario.

Looking at hand orientation as a single factor, analysis showed that there was no significant difference ($p = 0.208$) between the four hand positions at the 95% confidence level. Using a one-way ANOVA and Tukey's post hoc test to compare means shows that while in hand position 1, strategy 1 (UURR) was significantly better ($p = 0.000$) than strategies 2 and 3. While in hand position 2, strategy 1 was significantly better ($p = 0.005$) than strategy 3, but showed no significant difference from strategy 2. Hand positions 3 and 4 did not produce any significant differences.

Subsequent Learned Trials

The results of the general linear model test for the dimension of strategy showed that during the eight trials immediately after the initial trials, subjects did equally well ($p = 0.389$) with all three strategies since they did not differ significantly at the 95% confidence level.

Looking at hand orientation as a single factor, analysis showed that during the learned portion of the testing, there was a significant difference ($p = 0.006$) between hand positions, hand orientations 1 and 3 being better than 2 and 4. Using a one-way ANOVA and Tukey's post hoc test to compare means shows that there is no significant difference between trackball strategies within each hand orientation.

Discussion

After the initial trials were recorded and the subjects discovered, through trial and error, which strategy the trackball was programmed for, they were able to learn and manipulate the end effector fairly well. There was no statistical difference between the three strategies once each strategy was learned. Because there was no statistical difference between the three learned strategies and since the UURR strategy was found to be the most intuitive, this is the manipulation strategy that will be applied to the laparoscopic forceps tool.

It is hypothesized that the UURR strategy was more intuitive to the subjects because of the population stereotype that forward on any mouse or trackball equals an upward movement, despite the elimination of self-identified trackball users.

We hypothesized that the differences in hand orientations occurred because of confusion based on physical and spatial awareness; the outcome of this being a decrease in effective usage and correctness.

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