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A Breakdown of the Psychomotor Components of Input Device Usage

by Jeremy Slocum

Summary: This study investigates the breakdown of the psychomotor components of three different input devices, the mouse, trackball, and RollerMouse™ using the Stochastic Optimized Submovement Model. Primary movement time (PMT), Total Movement Time (TMT), Primary Movement Distance (PMD), and Total Movement Distance (TMD) were examined for each device. Results showed that psychomotor variables related to the primary phase of movement help to pinpoint how performance efficiency is affected by a particular device. For example, the relationship between % PMD and efficiency suggests that a device that affords users an initial accurate movement decreases the need for more or longer corrective submovements, thus reducing movement time.

INTRODUCTION

Fitts' law (Fitts, 1954) was first applied to compare computer input devices by Card et al., (1978) and since has become the standard method to identify performance differences between those devices. By using Fitts' law an index of performance (IP) can be derived by dividing the index of difficulty of a target at a set distance and width by the movement time (MT) to acquire the target (IP = ID/MT). ID is defined as a function of the ratio of target distance (D) and width (W) of a target. A doubling of target distance while keeping target size constant increases the ID by 1. However, ID remains constant if the target distance and width are both doubled. A regression analysis using ID to predict movement time reveals that ID accounts for at least 80% of the variance associated with MT and reveals that as ID increases MT increases linearly.

Fitts' IP is a valuable statistic for comparing the efficiency of input devices; however it is purely descriptive and does not explain performance differences. This disadvantage does not allow experimenters to understand the underlying causes of the differences. Psychomotor models have been developed as an alternative explanation to the logarithmic speed/accuracy trade-off between target characteristics and MT. Psychomotor models can be used to derive psychomotor variables that may identify differences between devices. This article focuses on using the Stochastic Optimized Submovement psychomotor model to develop new variables that not only identify differences between devices but inherently offer some explanation for the differences.

THE STOCHASTIC OPTIMIZED SUBMOVEMENT (SOS) MODEL

In a classic paper, Woodworth (1899) proposed that rapid aiming movements consisted of two phases: an initial movement (primary) and feedback control (secondary). The initial movement is believed to be a ballistic movement that transports the limb rapidly to the target. The feedback phase corrects spatial error from the initial movement using sensory feedback to obtain the target. The idea of two-phase movement is a basic component of many psychomotor models, including the SOS model.

The SOS model is based on the hypothesis that submovement duration is optimized to compensate for noise in the motor system. According to the model, the primary movement is a preprogrammed ballistic movement aimed at the center of the target. If the primary movement results in contact with the target then the movement is terminated. This is unlikely to occur due to noise in the motor system. Noise prevents users from producing the exact same movement (spatially and temporally) for a constant target, resulting in failure of the primary movement to be successful in acquiring the target and thus requiring a secondary movement guided by visual feedback. Higher velocity primary movements are more variable because the magnitude of neuromuscular noise increases with movement velocity and thus are more likely to be inaccurate (Meyer, Smith, Kornblum, Abrams, & Wright, 1990).

The SOS model identifies psychomotor variables that are important to understanding the efficiency of movements. Efficient cursor control movements should maximize the time and distance traveled in the primary phase and minimize the time and distance traveled in the secondary phase. In addition the primary movement should be completed as fast as possible without limiting accuracy. By examining psychomotor variables such as the percentage of time and distance spent in the primary movement (%PMT & %PMD), and peak velocity (PV), a more detailed analysis of performance can be achieved.

The purpose of the current study was to determine if variables derived from the SOS psychomotor model can be used to identify performance differences between input devices. Specifically the variables are associated with the primary movement phase. This was done by further exploring data collected for an experiment comparing the performance of the standard mouse, the trackball and the RollerMouse™ (Slocum, Bohan, & Chaparro, 2003). The RollerMouse™ and trackball elicited similar performance across most conditions, while the mouse elicited better performance across all conditions. For this study the devices were compared using Fitts' IP as well as the psychomotor variables of %PMT, %PMD, and PV. The validity of using these variables to evaluate the efficiency of a device was tested using a regression to predict IP.

METHOD

Participants

Twelve college students (8 females, 4 males) were offered partial course credit for their participation in this study. All participants were right handed and ranged in age from 17 to 26 years (Mean = 22.16). Participants reported daily use of the computer and averaged 11 years experience with the standard mouse. Fifty percent of the participants reported using a trackball 1 to 3 times, while the rest reported that they had never used a trackball. No participants reported using a RollerMouse™.

Procedure

Participants were asked to perform a discrete point-and-click task that represents the type of action typically performed using pointing devices. The task required the participant to click the left button on each device to bring up a target on the screen. Once the target appeared, the participant was asked to move the cursor into the target as quickly and accurately as possible. When the trial was completed the participant was required to click the left button again to bring up the next target. The order of devices was counterbalanced to control for any order effects. Target angle, amplitude, and width were randomized within each block of trials. The experiment took about one hour to complete, with each participant completing 144 practice trials (2 trials per each device x distance x size x angle) and 720 experimental trials (10 trials per each device x distance x size x angle) for a total of 864 trials.

Materials

The devices used in this experiment were a Logitech® MX™ Optical Mouse (traditional mouse), a Logitech Marble® Mouse Optical Trackball, and the RollerMouse™ Station by Contour Design. The RollerMouse™ by Contour Design is a novel alternative pointing device that rests below the spacebar on the keyboard and consists of a rolling bar cursor control and three selection buttons. Cursor movements follow the rolling (up-down) and sliding (left-right) actions of the bar (see Figure 1). The centrally-located cursor control bar was designed to reduce repetitive reaching typical of standard mouse usage.

Figure 1. The RollerMouse™ by Contour Design

Stimulus presentation was controlled by custom software developed for controlling stimulus presentation and data collection. The software sampled the X and Y location of mouse at 125 Hz. The data from this sampling was smoothed by eliminating 20% of the longest and shortest intervals and determining the velocity by the Pythagorean distance of the dx and dy values. This allowed the specific spatial and temporal characteristics of a single movement to be calculated.

Experimental Design

The study utilized a within-participants design, with device (standard mouse, trackball and RollerMouse™) as the independent variable. Dependent variables (DVs) included IP, errors (any click made outside the target), %PMT, %PMD, and PV.

Each dependent variable was determined by extracting certain points of interest for each movement:

Total movement time (TMT) was defined as the time from when velocity first reaches 8% of the maximum velocity until the last point at which velocity was 2% of the last peak velocity.

Primary movement time (PMT) was defined as the time from which velocity reaches 8% of the maximum until the first acceleration after the point of peak velocity.

Primary movement distance (PMD) was determined by distance traveled until the point after PV that velocity levels out and began to increase.

Total movement distance (TMD) was determined from distance traveled from when velocity first reached 8% of the maximum velocity until the last point at which velocity was 2% of the last peak velocity.

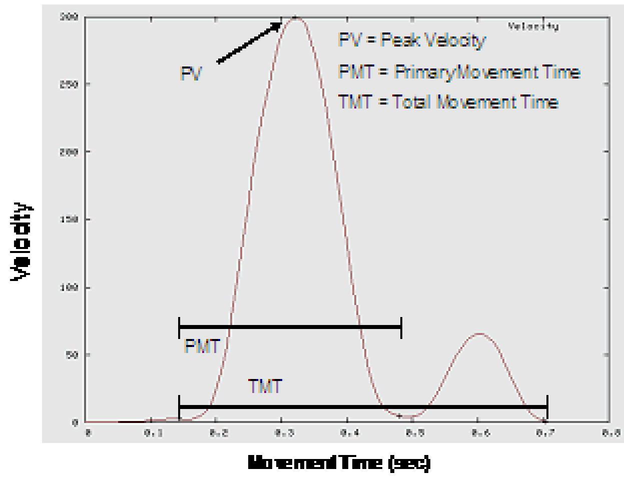

Figure 2. Velocity profile showing kinematic variables

RESULTS

IP

Mean IPs were as follows: 4.66 bits/sec for the mouse, 3.54 bits/sec for the trackball, and 3.15 bits/sec for the RollerMouse™. The main effect for device was significant [$F(2,22) = 69.138$, $p < .01$; $?^2 = .863$]. Tukey's HSD test showed that the IP's were significantly different from each other.

Predicting IP

To determine if the variables can accurately predict IP, partial correlations between IP and the variables measured were performed. As seen in Table 1, only %PMD and PV are significantly related to IP, indicating that as %PMD and PV increased IP increased, while as %PMT changed it had no significant effect on IP. %PMD and PV were found to be negatively related. This suggests that as PV increases the accuracy of the primary phase decreases, resulting in a speed accuracy tradeoff. To verify that %PMD and PV independently predict IP, a forward multiple regression was completed with %PMD entered first followed by PV. Both variables made significant contributions to the prediction of IP with %PMD explaining 19.7% of the variance and PV explains 44.3% of the variance. Combined they explained 64% of the variance of IP. The resulting prediction equation was significant [$F(2,69) = 61.448$, $p < .01$, $R = .800$, $R2 = .640$].

Table 1. Adjusted Partial Correlation Between Kinematic Measures, *** = p < .001

	1	2	3	4
1. IP	-			
2. Percentage of MT in Primary Phase (% PMT)	-0.204	-		

3. Percentage of MD in Primary Phase (%PMD)	.701***	.660***	-	
4. Peak Velocity (PV)	.683***	.032	-0.511***	-

Using %PMD and PV to Compare the Devices

The mean %PMD and PV for each device is shown in Table 2. To determine the validity of using %PMD and PV to discriminate between devices, a within-subjects ANOVA was completed to compare between devices for %PMD and PV.

A significant effect for %PMD was found [F (2, 22) 85.013 =, p < .01; ?2 = .919], showing that the mean %PMD for the mouse was higher than the other two devices (p <.01) and the mean %PMD of the RollerMouse™ was significantly greater (p < .01) than the trackball.

A significant effect for PV was found [F(2,22) = 55.641, p < .01; ?2 = .835]. The mean PV of the trackball was significantly greater (p. < .01) than the mean for the other two devices and the mean PV for the mouse was significantly greater than for the RollerMouse™ (p. < .01). These results show that %PMD and PV were effective in discriminating between devices.

Table 2. Mean %PMD and PV for Each Device

	%PMD	PV
Mouse	88.616	92.969
Trackball	70.280	114.126
RollerMouse	77.126	78.122

DISCUSSION

The purpose of the study was to evaluate the use of psychomotor variables derived from the SOS model of movement as a means of comparing the performance of input devices. Specifically, psychomotor variables associated with the primary phase of a movement were used. The results showed that %PMD and PV can be used to evaluate the performance of input devices.

The relationship between %PMD and efficiency suggest that a device that affords users an initial accurate movement decreases the need for more or longer corrective submovements, and thus reducing movement time. This finding supports Phillips & Triggs (2000) suggestion that error in the initial cursor direction may explain performance differences.

The relationship between efficiency and PV indicates that devices that afford faster movement allow users to move with greater efficiency. However, the negative correlation between PV and %PMD indicates a "speed accuracy trade-off". Devices that allow faster primary movement results in a less accurate primary movement and lead to a greater distance travels in secondary movement phase. The most efficient devices are less constrained by the "speed accuracy/tradeoff" allowing users to move at a higher optimal velocity, without increasing the chance of error. This is consistent with the SOS model prediction that movements are made to optimize performance by limiting the effect of motor noise and suggest input devices should be designed to limit the effect of noise in the interaction between the user and the input device.

Performance differences can be understood in terms of how users operate the devices. The mouse (if given enough space) allows the user to make one fluid movement to a target, similar to what would be made in a direct pointing task. With the trackball users accelerate the ball with a quick flick of the index finger to move toward the target and then roll the ball with the fingers for more precise movements (MacKenzie et al., 2001). The trackball strategy leads to higher velocity, but a reduced accuracy of the primary phase due to a lack of control while the ball is being "flicked". Although the RollerMouse™ functions similar to the trackball, the %PMD and PV show that participants used the devices very differently. The RollerMouse™ had a greater %PMD than the trackball, yet because subjects moved more slowly, they performed less efficiently. In addition, the RollerMouse™ has a wider operating area when compared to the trackball. This allowed subjects to make more fluid movements using a strategy where they slid or rolled the bar without taking their hand off the device. This different strategy does not allow users to move as fast, but it increases the accuracy of the primary movement, although decreased speed ultimately makes it less efficient.

This study has shown that psychomotor variables related to the primary phase of movement are useful additions to the evaluation of input devices. These analyses help pinpoint how performance efficiency is affected by a particular device. These results give input device developers information that can allow them to maximize the performance of their devices.

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