Effect of Posture on Target Acquisition with a Trackball and Touch Screen

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Abstract. *Computing devices are becoming more ubiquitous and are increasingly being used in unconventional environments and body postures. For example, more commonly computers are being used while standing up or walking slowly, such as with bank teller machines or hand-held devices. This paper investigates the effect of posture on Fitts' law and cursor position time in user interfaces when using a touch screen or trackball as the input device. Several experiments are described that measure the effect of standing and walking slowly during the interaction. Fitts' law was found to be an effective predictor of movement time across various targets sizes. Standing and walking did not have a significant negative effect on movement time when using a stylus, although a significant increase in error rate was discovered. However, when using a trackball in a standing posture, movement time and error rate both showed a significant increase. Based on these findings, touch screens appear to be more effective input devices for interactive systems that are used in non-sitting postures.*

Keywords. *Fitts' law, human performance modelling, input device evaluation, completion time predictions.*

1. Introduction

Movement Time (*MT*) models allow Human-Computer Interaction (HCI) researchers to understand and predict human aiming performance, such as control selection in a graphical user interface. The most popular model for human aiming is Fitts' law [2]. While the model has been shown to apply to a variety of input devices ([4], [5],[7],[8]), it has not been extended to pointing tasks that require the user to stand or to walk.

Fitts' law expresses a logarithmic relationship between *MT* and the ratio of the distance to the target (*A*), and the width of the target (*W*):

$$MT = a + b\log_2\left(\frac{A}{W} + 1\right) \tag{1}$$

where *a* and *b* are experimentally derived regression coefficients. The form of equation 1 is referred to as the Shannon formulation by MacKenzie [4]. The logarithmic term in equation (1) is commonly referred to as the movement *Index of Difficulty* (*ID*). The target width, *W*, is commonly the smaller of the horizontal or vertical extent of the target for univariate pointing or the width along the approach vector for bivariate pointing, although other values of *W* have been proposed, such as the target's area, the sum of the target's width and height, and the effective width (W_e) adjusted to achieve a uniform 4% error rate ([4]).

The main goal of this study is to examine (a) the interaction between posture, amplitude of movement, and target size on trial completion time and error rate and (b) the conformance with Fitts' law. There is empirical evidence that Fitts' law does not scale to whole body movements and that posture may have a negative effect on its validity [1].

This paper specifically explores the hypothesis that mean movement time and mean error rate increase when using a stylus or a trackball while standing or walking as compared to sitting. The two input devices were selected for investigation because of they are frequently found in ubiquitous computing platforms, such as Internet kiosks, automatic teller machines, and PDAs.

2. Methods

2.1 Participants

Twelve right-handed participants, 9 men and 3 women, were recruited to complete a series of experiments. The participants had a mean age range of 35-40 years and a mean height range of 5”7’-5”9’. All participants had extensive experience using computers and had normal or corrected-to-normal vision with no other physical impairments being reported. The participants received compensation in the form of a gift certificate.

2.2 Apparatus

The experiments comparing sitting and standing postures were conducted on a Gateway M275 Tablet PC (1.4GHz CPU, 512MB RAM) with a 14.1” TFT Touch LCD (1024×768 pixel resolution) running Windows XP Tablet Edition. The screen was at an angle of 80° when the user was sitting down and 55° when standing. A Kensington Turboball (Model 64227) was connected to the computer via USB.

The evaluation of the effects of walking while interacting were carried out on a Fujitsu Stylistic LT hand-held PC (500MHz CPU, 128MB RAM) with an 8.4” TFT Touch LCD (800x600 resolution) running Windows 98.

The trials were presented using the Movement Time Evaluator (MTE) software [6], an open and configurable experimental platform written in Java.

2.3 Experimental Design

Each participant was presented with four blocks of twenty trials each. Each block varied the target size, and within each block movement amplitude and angle to the target were randomly assigned. Each participant saw the same sequence of targets in the same positions. Using the Tablet PC, the participants were instructed to select the targets using stylus and trackball input in sitting and standing postures.

The same group of participants was then asked to select targets with a stylus while standing and walking at a normal pace. For this experiment, the Fujitsu hand-held was employed. The participants cradled the hand-held using a sling underneath the device.

As the targets were positioned at various angles, a circular target shape was selected. This approach avoids a potential hidden effect with a varying target width depending on the approach angle. A circular target presents an equal width from any approach angle.

2.4 Procedure

Before testing, participants were instructed to hit the targets as quickly as possible while minimizing errors. Any click or tap outside the target area was recorded as an error. The participants were allowed to rest 1-2 minutes before each block of 20 trials. An additional 3-5 minute rest period was provided between each posture and input device change. A target acquisition trial consisted of clicking a home region at the center of the screen which started the timing and caused the home region to be hidden. This was followed by clicking the target. Auditory feedback confirmed successful acquisition of the target. Four to eight warm-up trials of randomly chosen target sizes and positions were given for each input device and posture.

2.5 Data Analysis

Time measurements were taken at a resolution of 16ms. Amplitudes were calculated using the Pythagorean distance between the starting point and the end point of the movement. The recorded movement time was not adjusted to remove reaction time so that the trial completion time more accurately reflects the total interaction time [9].

The initial statistical analysis, including calculation of the Pearson moment correlation, linear regression, discovery of outliers, and trackball motion analysis was carried out in MTE. Further statistical analysis was done in R [3].

3. Experimental Results

The collected data contained a few outliers which were removed from the data set after viewing Cook’s distance plot for *MT*. The removed outliers represented less than 0.5% of the collected data. A trial in which *MT* was greater than three times the standard deviation was considered to be an outlier. The cause was predominantly user input error which invalidated the measurement. The results from one subject were removed from the analysis of the data set comparing sitting versus standing posture on the Tablet PC. *A posteriori*, it was discovered that the subject was incorrectly presented with differently positioned target regions than the other subjects.

3.1 Effect of Posture on Stylus

A simple-effects analysis was done via two one-way ANOVAs of *MT* by posture and error rate by posture. Although Figure 1 shows a slight increase in *MT* when standing, the increase was not found to be statistically significant [$F(1,1740) = 0.95$, $p > 0.1$]. On the other hand, the mean error rate while sitting was 7.5% (*sd*=0.298), compared to an error rate of 12.9% (*sd*=0.495) while standing, an increase of 72%. The increase in the error rate was found to be significant [$F(1,1740) = 7.911$, $p < 0.005$].

The error rate while sitting is slightly higher than the expected error rate of 4% reported by MacKenzie [4]. An error rate of 4% is considered to be normal. As expected, larger targets have a lower error rate. A two-way ANOVA showed a significant interaction between error rate, target size, and posture [$F(1,1738) = 12.84$, $p < 0.001$).

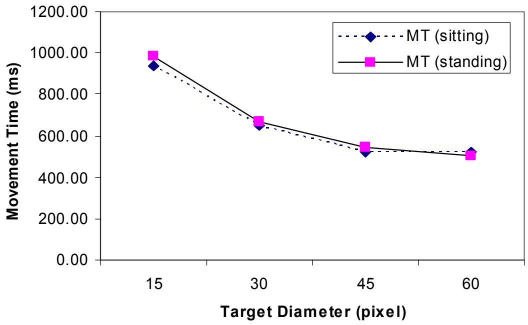

Figure 1. Mean MTs for each posture by target diameter when using stylus touch.

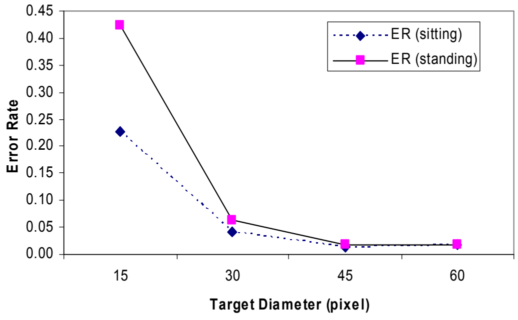

Figure 2. Mean error rates for each posture by target diameter when using stylus touch.

3.2 Effect of Posture on Trackball

Figure 3 illustrates the increase of *MT* when standing and using a trackball. The increase in *MT* is less pronounced as the target diameter increases. A similar trend is apparent for the error rate as shown in Figure 4. The mean error rate while standing was 7.5% (*sd*=0.301) compared to an error rate of 4.2% (*sd*=0.220) while sitting, an increase of 79%. The error rate while sitting is consistent with those reported by MacKenzie [4] and Thompson *et al.* [7].

Once again, a simple-effects analysis was performed via two one-way ANOVAs of *MT* by posture and error rate by posture. There was a small but significant increase in *MT* while standing [$F(1,918) = 8.83$, $p < 0.005$]. The mean movement time increased slightly from 1211ms when sitting to 1270ms when standing. In addition, the increase in the error rate when standing was shown to be significant [$F(1,918) = 7.75$, $p < 0.006$)].

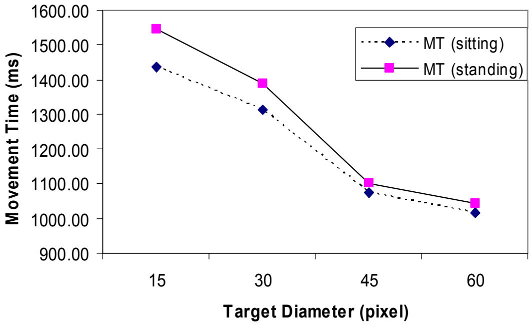

Figure 3. Mean MTs for each posture by target diameter when using a trackball.

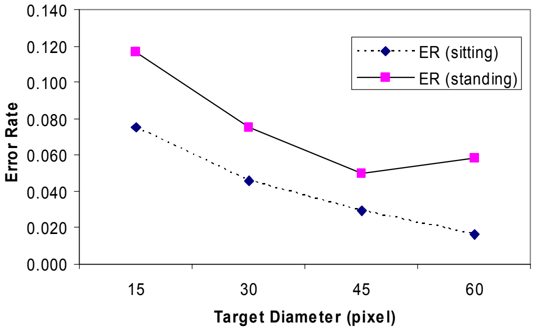

Figure 4. Mean error rates for each posture by target diameter when using a trackball.

3.3 Effect of Walking

Performing selection tasks while walking allows for the analysis of two factors that might affect movement time: (a) carrying out a second manual task (walking) while selecting and (b) selecting in a non-stationary environment which might exert influence on muscle groups, thus affecting conformance to Fitts' law.

Surprisingly, the difference between *MT* when standing still versus walking was found to not be statistically significant [$F(1,719) = 0.012$, $p > 0.05$].

However, the mean error rate while standing still was 7.9% (*sd*=0.512) compared to 17.5% (*sd*=0.715) while walking. The difference in the error rate was found to be significant via a one-way ANOVA [$F(1,1431) = 14.16$, $p < 0.001$]. Figure 4 illustrates the error rates for the four different target sizes. Additionally, a two-way ANOVA showed an interaction between error rate, posture, and target size [$F(3,1431) = 5.62$, $p < 0.001$).

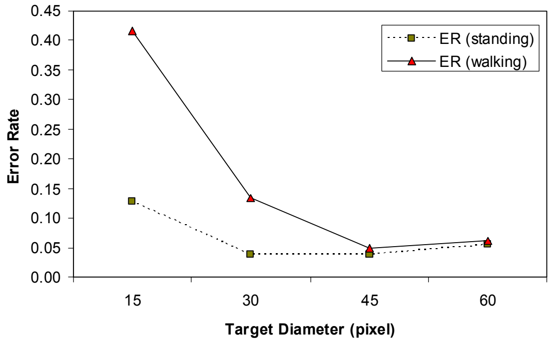

Figure 5. Mean error rates by target diameter when walking versus standing while using stylus touch input on a hand-held device.

A noteworthy observation was that all participants noticeably slowed their walking speed when selecting the 15 pixel target, indicating that the secondary task of walking was neglected as focus shifted to the primary task of selecting the target.

3.4 Conformance to Fitts' Law

The correlation coefficients shown in Table 1 between *MT* and *ID* were calculated using the nominal target width as well as the effective target width W_e. Effective width is defined as

$$W_e = 4.133 \times \sigma \quad (2)$$

where σ is the standard deviation of the actual target selection points from the mean ([4]). Furthermore, the analysis was carried out using the raw data, although many of the results published in the literature have used average *MT* over a range of *ID* values ([4],[5],[7]). The resulting *ID* when using effective width in equation (1) is called the effective index of difficulty (ID_e).

Even though the movement time shows an increase for the standing and walking postures, the Shannon formulation of Fitts' law [4] remains a robust predictor of movement time. Correlation analysis between *MT* and *ID* resulted in *R* values from 0.44 to 0.57 ($p < 0.001$) for the raw data and $R > 0.89$ when using mean *MT* over twenty *ID* ranges. This is consistent with what has been reported by other researchers ([5],[7]). Using the raw data instead of regressing on the mean provides more meaningful insight into the data and more accurately reflects the shape of the data. Wisenand and Emurian [8] also report correlation coefficients in the range of 0.45 to 0.55 when using raw data.

Table 1. Fit of Fitts' law by posture for stylus touch and trackball. The correlation coefficients shown were calculated using the nominal *ID* (R) as well as the effective *ID* (R_e).

	Input Method			
Posture	*Stylus Touch*		*Trackball*	
	R	R_e	*R*	R_e
Sitting (Tablet PC)	0.57	0.52	0.50	0.49
Standing (Tablet PC)	0.54	0.49	0.56	0.55
Standing (Hand-Held)	0.44	0.44	--	--
Walking (Hand-Held)	0.56	0.52	--	--

Linear regression of *MT* with *ID* yielded significant models for all postures and input methods ($p < 0.001$.) The resulting regression coefficients are shown in Table 2. The intercept for the touch screen is markedly lower than those for the trackball. The intercept for trackball movements is larger but has an order of magnitude consistent with those reported by Thompson *et al.* for cursor positioning with a mouse [7]. Averaging the coefficients, we propose the following equation for predicted movement time when using stylus touch input:

$$MT = 106 + 176(ID) \quad (3)$$

For trackball input, the following equation results from the regression calculation:

$$MT = 507 + 237(ID) \quad (4)$$

While the intercept and slope values are overall consistent across input device and posture, the regression intercept *a* for standing posture with the Fujitsu hand-held differs substantially from the other intercepts. We attribute this difference to the poor viewing angle of the device, which caused a glare from the overhead lights in the laboratory. The glare may have required the participants to look longer at the beginning of each trial to locate the target region. The additional overhead before the movement commenced is consistent with the higher intercept value, similar to the non-information aspects of pointing suggested by Zhai [9]. The glare was not present during the walking trials. However, the presence of motion and the manual task of walking would result in a higher intercept representing the non-informational factor present in the overhead of pointing while in a dual-task situation.

Table 2. Linear regression coefficients of MT versus ID by posture for Equation (1).

Posture	Input Method			
	Stylus		*Trackball*	
	a	*b*	*a*	*b*
Sitting (Tablet PC)	81	185	538	218
Standing (Tablet PC)	62	193	477	256
Standing (Hand-Held)	206	140	--	--
Walking (Hand-Held)	77	188	--	--
Average Values	106	176	507	237

3.5 Spread of Movement End Points

Since effective width is based on the spread of the movement end points, we conducted a comparison of the standard deviations among the different postures and input methods. The end point spread did not differ significantly for either stylus or trackball input when comparing sitting versus standing postures.

When walking, however, the standard deviations for each selection trial did differ significantly [$F(1,79) = 12.19$, $p < 0.001$) indicating a more widely dispersed set of selection end points when walking. This wider spread, as illustrated in Figure 6, is consistent with the much higher error rate we observed during the walking experiments.

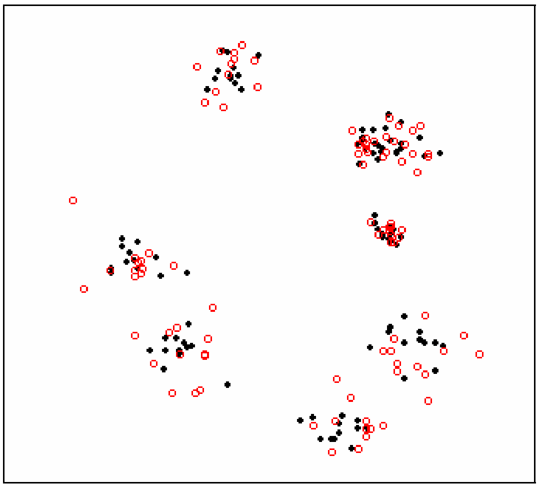

Figure 6. Illustration of the spread of selection end points for stylus touch input. The open circles represent selection end points while walking whereas the filled circles indicate selection end points while standing.

4. Discussion

Using either device (Tablet PC and Fujitsu hand-held), the mean movement time did not show a significant increase when standing and using stylus input. However, when using a trackball as the input device, the mean movement time was larger when standing. Comparing the two input methods, we recorded an increase of 588ms for the average movement time when using a trackball standing up compared to stylus input. The differences were amplified at smaller target sizes.

The error rates, however, showed a more pronounced increase when comparing sitting and standing postures regardless of input method. In all three experiments, the error rate about doubled when standing.

We found it interesting that the mean error rate while standing was about the same for all three experiments. In particular, the mean error rate while standing and using the Fujitsu hand-held was close to the observed error rate for the experiment using the Tablet PC while standing, even though there was a marked difference in screen size (8.4” versus 14.1”) and resolution (800x600 versus 1024x768). This appears to imply that error rates while standing are generally at least twice the commonly accepted error rate of around 4%.

Moreover, the error rate for the small target size was 12% for the Fujitsu hand-held compared to 23% for the Tablet PC. The difference can be attributed to the way in which the interaction occurred. The Tablet PC was used standing upright with the computer supported in an angled bracket similar to a kiosk setup. On the other hand, the Fujitsu was being cradled in one hand and held close to the body, thus attenuating any noise in the arm movement.

Overall, Fitts' law was found to be a robust predictor of movement time. Surprisingly, correlation was strongest for the data collected from the walking trials, suggesting that natural noise in the production of limb movements is accounted for by Fitts' model. However, the regression intercept for touch input is markedly lower than the intercept for trackball input as well as being lower than the intercept reported in the literature for mouse input [7]. This difference is likely attributable to a lower overhead in the commencement of the movement for touch screen interactions. As a result, touch input appears to be a more efficient input method.

5. Conclusion

The increase in the mean target selection time, along with the doubled error rate when standing means that user interface designers must adjust their task completion time models for applications that are intended to be used when standing. Since the mean selection and error rate differences are far less pronounced for larger target sizes, such user interfaces should employ large controls that are spaced apart further than usual to minimize selection errors and reduce overall task completion time. Finally, touch based input was found to be more efficient and requiring less time overall.

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