AMCIS Proceedings

AMCIS 2007 Proceedings

Association for Information Systems *Year* 2007

Selecting While Walking: An Investigation of Aiming Performance in a Mobile Work Context

Martin Schedelbauer
Univ. of Mass. Lowell

Jesse Heines
Univ. of Mass. Lowell

Selecting While Walking: An Investigation of Aiming Performance in a Mobile Work Context

Martin Schedlbauer and Jesse Heines
University of Massachusetts
Lowell, MA 01854 (USA)
{mschedlb,heines}@cs.uml.edu

Abstract

Computing devices are becoming more ubiquitous and are increasingly used in environments away from the desktop. For example, computers are more frequently being used while walking, as is the case with hand-held devices, navigation systems and mobile phones. This paper investigates selection accuracy and task completion time when using stylus touch as the input method on hand-held devices. An experiment is described that measures the effect of walking slowly during interactions. Fitts' law was found to be an effective predictor of task completion time. Furthermore, walking did not have a significant negative effect on task completion time, although an increase in error rate and spatial variability of selection endpoints was discovered. Based on these findings, stylus touch is an acceptable input method for interactive systems that are used in non-stationary environments provided that interface layout is designed to compensate for increased errors and reduced selection accuracy.

Keywords

Mobile devices, wearable computers, Fitts' law, human performance modeling, touch screens.

Introduction

Much of the research into human performance modeling has centered on desktop computers and stationary environments. Although the importance of studying mobile computing in its work context has been stressed (Kristoffersen & Ljungberg, 1999; Pascoe, Ryan, Morse, 2000), few studies have been conducted to provide overall performance models for devices that are used while walking. However, there are a few empirical studies such as the experiments by Brewster (2002), Chamberlain and Kalawsky (2004), and Zucco *et al.* (2005, 2006) that have been conducted for wearable computers. Nevertheless, there are insufficient experimental results that can guide the design of user interfaces for mobile computers, such as personal digital assistants (PDA) and navigation systems. User interface designers need statistical evidence that desktop-oriented human performance models and design heuristics are applicable in a mobile work context.

Interactions with computing devices, including mobile ones, typically involve target selection, swiping, scrolling and drag/drop. It is therefore essential that performance models for such tasks be empirically validated in a mobile environment. This paper focuses on one of the most common tasks: target selection, which is the basic operation used to activate user interface controls, such as buttons, menus, and on-screen simulated keyboards.

This study assesses task completion time and accuracy for stylus touch in a mobile work context and compares them to those in a stationary context. It also derives a performance model for predicting cursor positioning in a mobile context. A previous study by Chamberlain and Kalawsky (2004) compared the performance of stylus and off-table mouse (hand-held trackball) input when used for target selection on a wearable computer. Zucco *et al.* carried out experiments that compared the relative usability of several input devices (hand-held trackball, gyroscopic mouse, touchpad, and Twiddler mouse) for selection and drag-and-drop tasks when used with wearable computers while walking. In this paper, these studies are extended by providing a more detailed evaluation of selection accuracy and deriving an empirically validated predictive model for selection time using stylus touch.

Background

One of the earliest and most broadly applied performance models for human aiming is Fitts' Law (Fitts, 1954; MacKenzie, 1995). In his groundbreaking work, Fitts discovered a logarithmic relationship between spatial accuracy and duration of rapid limb movements for pointing. The mathematical quantification of speed versus accuracy has established itself as a cornerstone technique for evaluating human-computer interfaces and predicting human aiming performance.

Fitts' Law offers a predictive model for estimating the time it takes to point at a particular element on the screen, based on the size of and distance to the target. The model is well established and has been empirically validated for a variety of pointing tasks and input devices (MacKenzie & Soukareff, 2003).

Fitts' Law models movement time (*MT*) as the tradeoff between speed and accuracy characterized by the ratio of the distance to the target (*A*) and the width of the target (*W*):

$$MT = a + bID \tag{1}$$

where *ID* is the *Index of Difficulty* of the movement, defined as

$$ID = \log_2\left(\frac{A}{W} + 1\right) \tag{2}$$

The constants *a* and *b* are experimentally derived regression coefficients. Equation (2) presents the formulation of *ID* proposed by MacKenzie (1995), which is the generally accepted form (ISO 2000; Zhai, 2004; Soukoreff & MacKenzie, 2004).

The *throughput* (*TP*) of an input device is a measure of its efficiency and is calculated as the ratio of the mean *ID* and the mean *MT* (Soukoreff & MacKenzie, 2004), although the alternative form of *1/b* has been proposed as well (Zhai, 2004). The former is the basis for establishing input device efficiency according to ISO 9421 Part 9 (ISO 2000; Soukoreff & MacKenzie, 2004; Douglas, Kirkpatrick, & MacKenzie, 1999). Throughput is measured in bits per second (*bps*). ISO 9241-9 recommends that between-study comparisons of input device evaluation results should be based on throughput rather than movement time.

MacKenzie (1995) proposes an adjustment of the width used in Fitts model calculations that more accurately reflects what subjects actually do rather than what they were asked to do. More precisely, some subjects will select targets more quickly but make more errors, while other subjects might select with more care and therefore make fewer errors but take longer. He proposes an *effective width* (W_e) that is based on the distribution of the hits and a normalized error rate of 4.1%. W_e is calculated as follows:

$$W_e = 4.133\sigma \tag{3}$$

where σ is the standard deviation of the selection end points from the mean. ISO 9241 endorses the use of the effective width rather than nominal width in the evaluation of input devices. Substituting W_e for W in Equation (2) results in an *Effective Index of Difficulty* (ID_e).

Methods

Subjects were asked to stand and then walk slowly at their normal pace while carrying out standard Fitts tasks. The intent of this experiment was to determine if movement of the body has an impact on target selection performance. In addition, walking represents a concurrent manual task which might have a negative effect on the speed and accuracy of target acquisition.

Hypotheses

The experiment sought to determine the validity of the following *null* hypotheses:

H1: The completion time of selection tasks using a stylus is not significantly different when walking compared to standing.

H2: The targeting accuracy of a stylus is not significantly different when walking compared to standing.

H3: Fitts' Law is not a reliable predictor of completion time when selecting using a stylus while walking.

Subjects

The experiment was carried out by 12 volunteer participants (9 men, 3 women) with the following characteristics: right-handed users, normal or corrected-to-normal vision, and no physical impairments. The age for the subjects ranged from 22 to 60 years. All reported having many years of computer use experience. The participants received compensation in the form of a gift certificate.

Apparatus

The equipment used for the experiments was a Fujitsu Stylistic LT hand-held PC (500MHz CPU, 128MB RAM) with an 8.4" (168×128*mm*) Color TFT Touch LCD (800×600 pixel resolution) running Windows 98. See Figure 1 for an illustration of the testing apparatus. The trials were configured and presented using the author's *Movement Time Evaluator* (MTE) research workbench (Schedlbauer, 2007; Schedlbauer *et al.*, 2005)[1].

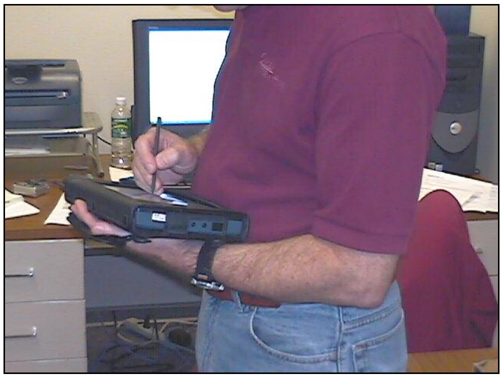

Figure 1. Subject cradling the Fujitsu hand-held using a sling underneath the device while performing rapid aiming tasks first in a standing and then in a walking posture.

Experimental Design

The experiment varied target distance, target size, and angle of approach as independent within-subject variables. The dependent variables were the Index of Difficulty (*ID*), the mean Movement Time (*MT*), and the error rate (*ER*). The same series of experiments with the exact same target sizes, positions, and approach angles were repeated with stylus control while standing still and then while walking at a normal pace. Each subject was randomly presented with 20 targets each at four sizes (3, 6, 10, and 13 *mm*) for a total of 80 trials per subject.

In keeping with the recommendations of Soukoreff and MacKenzie, the experiment varied the selection difficulty by testing a broad range of *ID* values (*min* = 1, *max* = 5, *mean* = 2.5), *i.e.*, targets placed at different distances and having different widths.

Procedure

Participants were instructed to hit randomly appearing circular targets while standing and then walking at their normal speed on a predefined indoor track. There were no other distractions during the experiment. The track was straight and did not contain any obstructions. Distance to the target (amplitude) and approach angle were randomized across four different circular targets sizes (3, 6, 10, and 13 *mm* in diameter). Because the targets were positioned at various angles, a circular target

---

[1] Open source software available under GNU Public License from `http://www.cs.uml.edu/~mschedlb/mte`.

shape was used in all experiments. This approach avoids a potential confounding effect with a varying target width depending on the approach angle. A circular target presents an equal width from all approach angles.

The tasks were carried out using stylus touch only due to the capabilities of the testing apparatus. Before testing, participants were instructed to hit the targets as quickly as possible while minimizing errors. Upon successfully selecting a home region at the center of the screen, the home region was hidden, and the timing began. Successfully selecting the target region caused the target to disappear, auditory feedback to be heard, the next target to appear and the home region to reappear. Any tap outside the target area was ignored, but was recorded as an error and an error sound was generated. The touch screen used in the experiment used a *land-on* selection strategy, which means that the tap was recorded as soon as the stylus touched the screen.

Time measurements were taken at a resolution of 10*ms*, which is the smallest granularity supported by the Sun JVM on Microsoft Windows XP (Green, 2007). 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 measured time more accurately reflects the total interaction time (Zhai, 2004).

To reduce the effect of learning, a series of warm-up trials was administered before each experiment. The participants were allowed to rest before each block.

Results

Soukoreff and MacKenzie (2004) state that obvious outliers, which they define as being farther than three standard deviations from the mean, should be removed from the calculation of *ID*. They attribute the presence of outliers to 'misfires' where a subject accidentally double-clicks a target or pauses during the movement. The outlying values recorded in this experiment do not fall into one of these two categories because double-clicking is not possible with the land-on strategy for stylus touch and no hesitation during selection was observed. As an overall performance model was sought, all movement trials were included in the calculation. There were no trials with exceedingly high trial completion time that could be attributed to a hardware malfunction or that clearly violated the experiment assumptions.

Time

Surprisingly, the difference between the values of *MT* when standing still (*mean* = 618*ms*, *sd* = 344) versus walking (*mean* = 619*ms*, *sd* = 340) was not significant [$F(1,1918) = 0.006$, $p = 0.935$]. A simple effects analysis showed that target width was not a significant factor. The combined mean movement time and the mean movement times for each target size by posture are shown in Figure 2.

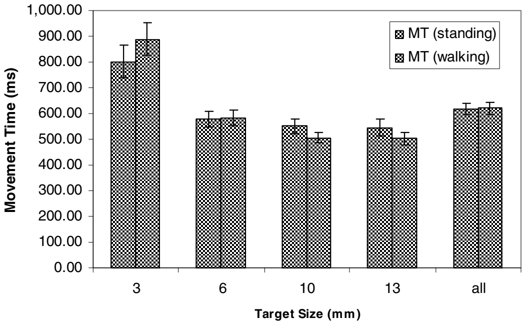

Figure 2. Mean movement (target selection) time by width and posture. Shown with 95% confidence interval.

Accuracy

The accuracy of an input method can be assessed by two measures: error rate and spatial dispersion. The error rate is the average number of selections outside the target area for some number of trials, and spatial dispersion is the standard deviation of the distances of the selection end points from the mean. That is, the greater the distances between the end points, the less accurate the selection.

The mean error rate while standing still was 8.1% (*sd* = 0.472) compared to 19.6% (*sd* = 0.740) while walking. This difference in error rates was found to be significant via a one-way ANOVA with posture as the sole factor [$F(1,1918) = 16.645$, $p < 0.0001$]. Figure 3 illustrates the error rates for the four different target sizes. Additionally, a two-way ANOVA shows an interaction between error rate and posture and target size as factors [$p < 0.001$]. Interestingly, only the error rates for the two smaller targets sizes (3*mm* and 6*mm*) were significantly different for the two postures as shown by *post-hoc* paired *t*-tests with Bonferroni corrections [$t(239) = 3.37$, $p < 0.0001$ and $t(239) = 2.89$, $p = 0.004$].

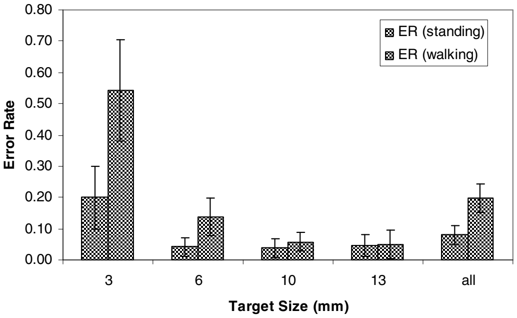

Figure 3. Mean error rates by target size and posture for stylus input with 95% confidence interval. The error rate shows an increase while walking, particularly for the smaller target sizes.

The increased error rate while walking suggests a more pronounced spatial variability of the selection end points. Therefore, an analysis of the standard deviations of the selection end points among the different postures was conducted. When walking the standard deviations for each selection trial differ significantly as shown by a one-way repeated-measures ANOVA [$F(1,159) = 42.83$, $p < 0.0001$] indicating a more widely dispersed set of selection end points. This wider spread, as illustrated in Figure 4 showing the selection end points for a subset of targets, was consistent with the higher error rate observed during the walking experiments.

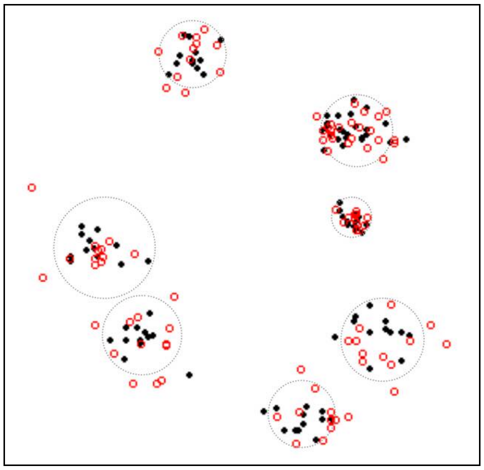

Figure 4. Illustration (not to scale) of the spread of selection end points for stylus touch input (shown with target outlines). The open circles represent selection end points while walking whereas the filled circles indicate selection end points while standing. The selection end points obtained while walking are less closely clustered compared to the selection end points while standing.

Fitts Model

Fitts' law remained a robust predictor of movement time. Linear correlation analysis between *MT* and *ID* results in $R^2 = 0.89$ ($p < 0.001$) when using mean *MT* values over twenty ID_e ranges for the walking posture, and $R^2 = 0.85$ ($p < 0.001$) when using averaged *MT* values for the standing posture.

There is considerable debate over whether to use the raw data values in the correlation calculations or averaged *MT* values over fixed ID_e ranges (Thompson *et al.*, 2004; Soukoreff and MacKenzie, 2004). From a statistical perspective, the use of the raw data models the shape of the data more accurately and the correlation results are more meaningful. However, a few far outliers can affect correlation results markedly. Using averaged values attenuates the effect of outliers by bringing them closer to the mean, but this may have the unintended consequence of hiding the effect of certain factors, such as the higher selection time of very small targets. Therefore, threshold values that markedly affect performance may not be detectable. On the other hand, most published studies on Fitts' Law report correlations based on average *MT* over a fixed range of ID_e values, so the publication of the correlations obtained from the averaged data allows for more meaningful comparisons with prior results. Consequently, the correlation and regression results presented in this paper are based on averaged *MT* values.

Linear regression results in the following Fitts' models for stylus selection, where MT_s is the model for standing and MT_w is the model for walking (movement or target selection time is estimated in milliseconds):

$$MT_s = 19 + 212ID_e \tag{4}$$

$$MT_w = 35 + 221ID_e \tag{5}$$

Throughput – calculated as the inverse of the regression slope – characterizes the overall efficiency of a pointing device. The values are 4.9*bps* when standing and 4.5*bps* when walking, an overall decrease in efficiency of about 0.4*bps* or 8.2%. For comparison, the throughput of a mouse device used in a stationary desktop setting is about 4.5 *bps* (MacKenzie, 1995).

The higher value of the slope for MT_w indicates that movement time increases more rapidly with the effective Index of Difficulty (ID_e) when walking compared to standing. In other words, carrying out two tasks concurrently – walking and selecting – amplifies the effect of higher *ID*s.

Discussion

The time of target selection was not significantly different when walking, which leads to an acceptance of the first *null* hypothesis (*H1*: *The completion time of selection tasks using a stylus is not significantly different when walking compared to standing*). This is in contrast to the findings by Chamberlain and Kawalsky who observed an increase in target selection time when walking. However, their experiment required subjects to walk a more challenging course containing obstacles that they had to avoid. The more complex walking task likely forced subjects to neglect the aiming task in favor of avoiding collisions with the obstacles. A similar effect occurred in the present study: all participants noticeably slowed their walking speed when selecting the 3*mm* target, indicating that the primary task of walking was neglected as focus shifted to the secondary task of making a difficult selection. This is consistent with the observations by Hoffmann and Lim (1997) that suggest that the scheduling of two tasks causes interference and often one task is temporarily neglected in favor of the other. It also means that humans may neglect a primary task and focus on the completion of the secondary task if that task is difficult. Consequently, this possible neglect of the primary task may lead to unsafe situations when, for example, driving is neglected while working with an in-vehicle navigation system, a PDA, or dialing a mobile phone.

The accuracy of selection is significantly less when walking as evidenced by a doubling of the mean error rate and an increase in the variability of the selection end points. Consequently, the second *null* hypothesis has to be rejected (*H2*: *The targeting accuracy of a stylus is not significantly different when walking compared to standing*). Interestingly, Chamberlain and Kawalsky did not find a significant increase in the error rate when selecting with a stylus while walking. However, in their experiment they noted an increase in the task completion time which suggests that subjects slowed their aiming speed and increased their accuracy. This observation matches Fitts' Law which defines a tradeoff between speed and accuracy. In fact, they noticed a very slight decrease in errors which they attribute to subjects being more focused on the aiming task when walking. Nonetheless, there is a definite interaction between selection performance and walking: one task has to subrogate to the other, which confirms the observations by Hoffmann and Lim regarding task interference in dual-task situations.

Moreover, aiming while walking leads to a higher spatial variability of selection end points. The broader deviation from the mean implies that the error rate can be expected to increase as targets get smaller. Furthermore, the analysis showed that motion has a significant effect on error rate as demonstrated by the increase in the deviation of the selection end points from the mean. Once again, this results in an expected increase in the error rate for small targets. Such an increase may lead to the user becoming frustrated and losing situational awareness. As was observed during the experiments involving aiming while walking, subjects noticeably slowed their walking speed when attempting to select the smallest target size. This observation suggests that subjects neglect the primary task to focus on selecting small targets accurately. As noted earlier, such a focus on the secondary task in a dual-task situation can lead to unsafe conditions since the subject may ignore warning signs that the primary task is being neglected too long.

The error rates are only significantly higher for the two smallest target sizes. In fact, for the two larger sizes, the differences between postures are not significant and the error rate reaches a level of around 4% which is comparable to mouse input on a stationary desktop (MacKenzie, 1995).

A strong correlation ($R^2 = 0.89$) exists between the measured movement time (MT) and the calculated index of difficulty (ID_e). Therefore, the third *null* hypothesis must also be rejected (*H3*: *Fitts Law is not a reliable predictor of completion time when selecting using a stylus while walking*). The effective throughput of stylus input is better when standing and comparable to the pointing efficiency of a mouse even when walking.

Conclusion

The findings of the study are summarized in Table 1. Overall, Fitts' Law was found to be a robust predictor of movement time. The correlation was surprisingly strong for the data collected from the walking trials, suggesting that variations in the production of human limb movements are accounted for by Fitts' model. However, even though Fitts' Law applies, it does not account for the increased number of selection errors while walking or standing. Nevertheless, user interface designers of mobile systems can rely on Fitts' Law for predicting cursor positioning times using stylus touch as the input method. It is important to note that subjects did adjust their walking speed to accommodate the selection task. If subjects had not been allowed to slow down or the walking task had been more complex, it is conceivable that selection performance might have been reduced while walking.

Table 1. Summary of performance differences by posture for stylus selection.

	Standing	Walking
Mean Selection Time (MT)	0.62*s*	0.62*s*
Mean Error Rate (ER)	8.1%	19.6%
Correlation ($MT \sim ID_e$)	0.85	0.89
Fitts' Model	$19+212 ID_e$	$35+221\ ID_e$
Throughput (TP)	4.9*bps*	4.5*bps*

Extrapolating from the error rate observations for each target size, a minimum target diameter of 10*mm* is recommended for systems used in a mobile work context, although a smaller size of 6*mm* might be acceptable for systems used in a stationary environment. Based on the two different minimum target sizes, designers of mobile devices should allow for zooming and personalization of user interface element size. Alternatively, if screen space is limited, appropriate error correction facilities must be provided and destructive actions should not be placed close to commonly selected tasks. Furthermore, the spacing of user interface controls should be increased in mobile settings as much as screen space allows. Of course, such guidelines are applicable in general, but are essential for mobile interfaces.

In conclusion, stylus touch is an acceptable and effective method of input for mobile devices.

Future Work

The findings presented in this paper provide a basis for conducting more extensive field studies in which the applicability Fitts' Law is evaluated in more complex walking patterns and in the presence of obstacles. Furthermore, the performance in terms of time and accuracy of stylus input should be compared to finger touch. Another extension of the work focuses on testing stylus and finger touch input in other non-stationary environments, such as in-vehicle and maritime use.

ACKNOWLEDGMENTS

The authors wish to thank the students and faculty members of the UMass Lowell Computer Science Department that participated in the study. Also, the contributions of Dr. Robert Pastel of Michigan Technological University are gratefully acknowledged.

REFERENCES

1. Brewster, S. (2002). Overcoming the lack of screen space on mobile computers, *Personal and Ubiquitous Computing*, 6, 3, 188-205.
2. Chamberlain, A., Kalawasky, R. (2004). A comparative investigation into two pointing systems for use with wearable computers while mobile, In *Proceedings of the Eighth International Symposium on Wearable Computers (ISWC '04)*, Arlington, VA, IEEE Press, 110-117.
3. Douglas, S., Kirkpatrick, A., & MacKenzie, S. (1999). Testing pointing device performance and user assessment with the ISO 9241, Part 9 Standard. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2003)*, ACM Press, New York, NY, 215-220.
4. Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47, 381-391.
5. Green, R. (2007). Online resource at http://mindprod.com/jgloss/time.html.
6. Hoffmann, E., Lim, J. (1997). Concurrent manual-decision tasks. *Ergonomics*, 40, 3, 293-318.
7. ISO (2000). *ISO 92141-9 International standard: Ergonomic requirements for office work with visual display terminals (VDTs) – Part 9: Requirements for non-keyboard input devices*, International Standards Organization.
8. Kristoffersen, S., Ljungberg, F (1999). "Making Place" to make IT work: empirical explorations of HCI for mobile CSCW. In *Proceedings of the International Conference on Supporting Group Work (Group '99)*, Phoenix, AZ, ACM Press, New York, NY, 276-285.
9. MacKenzie, S. (1995). Movement time predictions in human-computer interfaces. In *Readings in Human-Computer Interaction*, 2nd Edition, Morgan Kaufman, Los Altos, CA, 483-493.
10. MacKenzie, S., Soukoreff, R. W. (2003). Card, English, and Burr (1978) – 25 years later. In *Extended Abstracts of the ACM Conference on Human Factors in Computing Systems (CHI 2003)*, ACM Press, New York, NY, 760-761.
11. Pascoe, J., Ryan, N., Morse, D. (2000). Using while moving: HCI issues in fieldwork environments, *ACM Transactions on Computer-Human Interactions*, 7, 3, 417-437.
12. Schedlbauer, M., Pastel, R., Heines, J. (2005). *An extensible and interactive research platform for exploring Fitts' law*, Technical Report 2005-014, Department of Computer Science, University of Massachusetts Lowell.
13. Schedlbauer, M. (2007). An extensible platform for the interactive exploration of Fitts' law and related movement time models. In *Extended Abstracts of the ACM Conference on Human Factors in Computing Systems (CHI 2007)*, ACM Press, New York, NY.
14. Soukoreff, W., MacKenzie, I. S. (2004). Toward a standard for pointing device evaluation, perspectives on 27 years of Fitts' law research in HCI. *International Journal of Human-Computer Studies*, 61, 6, 751-789.
15. Thompson, S., Slocum, J., & Bohan, M. (2004). Gain and angle of approach effects on cursor-positioning time with a mouse in consideration of Fitts' law. In *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*. New Orleans, LA, Human Factors and Ergonomics Society, 823-7.
16. Zhai, S. (2004). Characterizing computer input with Fitts' law parameters – the information and non-information aspects of pointing. *International Journal of Human-Computer Studies*, 61, 6, 791-809.
17. Zucco, J., Thomas, B., Grimmer, K. (2005). Evaluation of three wearable computer pointing devices for selection tasks, In *Proceedings of the Ninth International Symposium on Wearable Computers (ISWC '05)*, Osaka, Japan, October, 2005, IEEE Press, 29-36.
18. Zucco, J., Thomas, B., Grimmer, K. (2006). Evaluation of four wearable computer pointing devices for drag and drop tasks when stationary and walking, In *Proceedings of the Tenth International Symposium on Wearable Computers (ISWC '06)*, Montreux, Switzerland, October, 2006, IEEE Press, 29-36.