An Application of Ballistic Movement Models for Comparing Ageing Differences while Interacting with a Touchscreen

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ABSTRACT

To make sure innovative touchscreen techniques can benefit well the elderly population, this study utilized ballistic movement models to evaluate the differences of movement speed and accuracy between elder and young adults while interacting with a t ouchscreen. Six elder and six young participants conducted ballistic movements on a touchscreen monitor. The measured data of movement time and endpoint error were utilized to test the ballistic movement models. Our results showed that ballistic movement models fitted well young participants' data. However, elder participants performed movements with a co nservative manner; their movement time and variable errors did not increase with increased movement distance as much as that of young participants'. Future research will focus on enhancing experimental designs to obtain solid conclusions so that the results could help developing touchscreen design guidelines.

Keywords: ageing, ballistic movements, ballistic movement models, aiming movement, touchscreens, interactive displays

1 INTRODUCTION

Touchscreen displays are quickly become an important interactive device for a variety of electronic products, such as information kiosks, global positioning systems, MP3 players, smart phones, and tablet computers. By attaching touchscreens to electronic devices, users can directly interact with what is displayed on screens with their fingers, rather than indirectly with additional input devices. Because of zero displacement between input and output, control and feedback, and hand action and eye gaze, touchscreens have been considered as the most intuitive way for human computer interaction.

To enhance touchscreen usability, as traditional input devices, researchers study user's task performance while using touchscreen devices. Common hand-control movements for interacting with touchscreens include click, drag, drop, multi-finger zoom in and zoon out. All of these movements begin by a pointing movement, such as pointing the finger to a certain location on the touchscreen surface. The time of pointing movement influences user's motivation and satisfaction with touchscreen devices. Hence, studying pointing movements is one of effective ways to evaluate and improve touchscreen devices.

1.1 Age-associated Changes and Relevant Impacts of Touchscreen Devcie Usage

Because the world's population is ageing dramatically, device designers and developers pay more and more attention to the elderly population. Compared to young adults, the elderly's physical, cognitive, and sensory abilities are relatively diminished (Craik and Salthouse 2000). The elderly have a variety of age-associated changes, such as reduced muscle strength (Ranganathan *et al.* 2001, Carmeli *et al.* 2003), reduced range of motion (Carmeli *et al.* 2003, Gajdosik *et al.* 2009), reduced manual dexterity (Carmeli *et al.* 2003, Hourcade and Berkel 2008) and greater difficulty of executing hand-control movements (Shiffman 1992, Maki and Mcllroy 2006). These changes could generate obstacles while executing target acquisition task (e.g., selecting an icon or a menu item). Hence, to produce elder-friendly products, understanding of these changes and developing compensatory strategies are imperative.

Several studies showed that the elderly have greater difficulty executing pointing movements on touchscreen devices. For example, Fezzani *et al.* (2010) tested ageing differences while performing numerous sequences of serial pointing movements with a stylus on a digitizer tablet and found that elder participants performed movements with a longer duration. Hourcade and Berkel (2008) also evaluated ageing differences when using pens to interact with handheld computers and concluded that elder participants achieved lower accuracy rates. Furthermore, Moffatt and McGrenere (2007) compared ageing effects on pen-based target acquisition on a tablet computer and found that elder participants required longer movement time and achieved lower movement accuracy.

1.2 Fitts' Law as a Common Method

To compare ageing differences, Fitts' law (Fitts 1954) has been the most common method. As shown in Equation 1, Fitts' law describes the speed-accuracy tradeoff relationship while performing target acquisition tasks in which a user uses a stylus or finger to quickly reach a target by moving certain distance.

$$MT = a + b \times \log_2 \frac{2A}{W} \tag{1}$$

where MT is movement time; a and b are experimentally determined variables; the logarithmic term is called "index of difficulty"; A is movement amplitude; W is target width.

Fitts' law (1954) is a useful method to measure age differences while using touchscreen devices, but the results obtained by this method do not give us adequate information to know why elder people execute movements with a longer duration. Specifically, Fitts' law allows researchers to obtain the result of pointing movement time that is an overall performance of movement speed, movement accuracy and sensory ability. Therefore, by applying Fitts' law as methodology, one has difficulty clarifying the extent to which speed, accuracy, and sensory individually contribute to long-duration movements. To develop effective techniques for helping elder users of touchscreen devices, it is necessary to understand the factors that cause the differences between the elderly and young adults in more detail.

1.3 Ballistic Movement Models as a Potential Method

To evaluate the performances of movement speed and accuracy individually, Lin and Drury (2011) suggested a method of using ballistic movement models. Lin et al. (2009) proposed a general model that stated that an aiming movement described by Fitts' law is consisted of several subsequent ballistic movements. The understanding of ballistic movements can predict the performance of Fitts-type aiming movements. To understand how one performs ballistic movements, Lin and Drury (2011) verified two models, originally proposed by Hoffmann and Gan (Hoffmann 1981, Gan and Hoffmann 1988) and Howarth et al. (Howarth *et al.* 1971), to predict ballistic movement time and endpoint variability. As shown in Equation 2, the ballistic movement time ($t_{ballistic}$) is linearly related to the square root of ballistic movement distance ($\sqrt{d_u}$).

$$t_{ballistic} = e + f\sqrt{d_u} \tag{2}$$

where e and f are experimentally determined constants. Furthermore, Equation 3 shown as below shows that the endpoint variability of a ballistic movement is linearly related to the square of ballistic movement distance (${d_u}^2$).

$$\sigma^2 = g + h \times {d_u}^2 \tag{3}$$

where g and h are experimentally determined constants. These two ballistic movement models was validated with the hand-control movements performed on a drawing table and were further validated for the hand-control movements performed in a true three-dimensional environment (Lin and Ho 2011).

1.4 Research Objective

This research aimed at testing ballistic movement models for comparing ageing differences of movement speed and endpoint variability while interacting with a touchscreen. Compared to Fitts' tapping movements, ballistic movements are relatively essential to describe one's capability of movement control. The speed-accuracy tradeoff relationship described by Fitts' law is a combination resulted from the properties of ballistic movement time and ballistic movement variability. To enhance the usability of touchscreen designs, ballistic movements could be a more representative experimental task to measure.

2 METHOD

2.1 Participants and Apparatus

Six colleague students and six health elder adults participated in this study. These colleague students, aged from 23 to 27 years, were familiar with the use of computers. The elder adults, aged from 62 to 79 years, were all healthy and had a regular exercise habit in the morning. Both sexes were equally distributed in these two groups. All of them were right-handed with normal or corrected-to-normal vision.

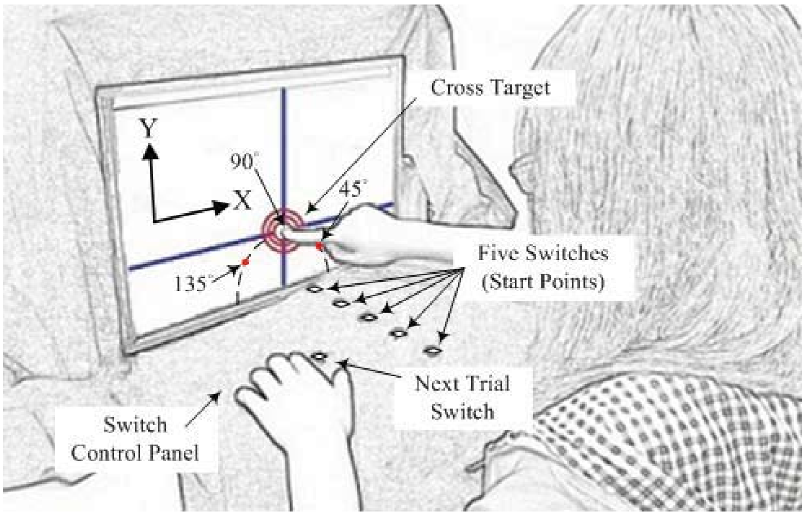

Figure 1 Executions of ballistic movement on a modified touchscreen

Experimental apparatus included a personal computer, a 19” modified LED monitor, and a switch control panel. The computer was used to run Visual Basic 2010 using a self-developed program that both displayed the experimental tasks and measured task performance. The LED monitor was attached with a touch panel on which participants could perform ballistic movements by using their pointing fingers. The monitor was modified to a condition where its backlight could be turned on and off rapidly by the program to make movements ballistically. As shown in Figure 1, on the center of switch control panel, five push switches were mounted linearly toward the monitor to generate five start points. The intervals between the centers of these switches were 50 mm, providing five different distances (50, 100, 150, 200, and 250 mm) between the touch panel and these switches. An additional switch, called the “Next Trial Switch”, was mounted on the left side of the control plane that was used to continue the next trial.

2.2 Experimental Setting and Procedures

The experiments were conducted in a darkened room in which the modified LED monitor was the only illumination source. As shown in Figure 1, the participant sat on a chair in a distance about 500 mm from the LED monitor while performing experimental tasks. To perform experimental tasks, participants executed ballistic movements from one of the five push switches to the center of a cross target showed on the monitor. To start tasks, the participants first used their pointing fingers to press down a switch indicated by the program and then moved quickly toward the cross target displayed right after the switch was pressed. Once the pointing finger were moved away the switch, the backlight of the monitor immediately turned off and the movement time started to record. When the finger touched the screen, the backlight turned on and the information about the cross target and the endpoint of that movement were recorded and displayed on the screen. By clicking the “Next Trial Switch”, participants could continue on the next trial.

2.3 Experimental Variables

Independent variables were different age group of participant (Age Group) and movement distance (Distance). To make sure that executing movements were not obstructed by any switches and to eliminate learned kinesthetic feedback, cross targets were programmed to appear at three different locations on a virtual circle (radius = 57 mm) at the angles of 45°, 90° and 135°, respectively. The virtual extension line of five push switches hit the center of the circle. Hence, five values of ballistic movement distance (d_u) tested in this study were 76, 115, 160, 208, and 256 mm. Every experimental combination was replicated 8 times, resulting in a total 120 trials (3 angles × 5 distances × 8 replications). All the trials were randomly conducted by each participant, taking about 20 to 30 minutes to finish. Each participant performed two formal measurements in different days. There was a one-hour practice and ten minutes practice before the first and the second formal measurements, respectively.

Three dependent variables were ballistic movement time, horizontal endpoint error (X error), and vertical endpoint error (Y error). As shown in Figure 1, X error was measured in the horizontal direction and Y error was measured in the vertical direction of the monitor.

3 RESULTS

3.1 Ballistic Movement Duration

Analysis of variance was performed on the movement time, using a mixed model with Distance and Age Group as fixed effects and Participant as a random effect nested within Age Group. The results showed significant the main effect of Distance ($F_{4,40} = 32.11$, $p < 0.001$), implying that the increase of ballistic movement distance resulted in increased ballistic movement time. However, the main effect of Age Group was not significant ($F_{1,10} = 1.22$, $p > 0.05$).

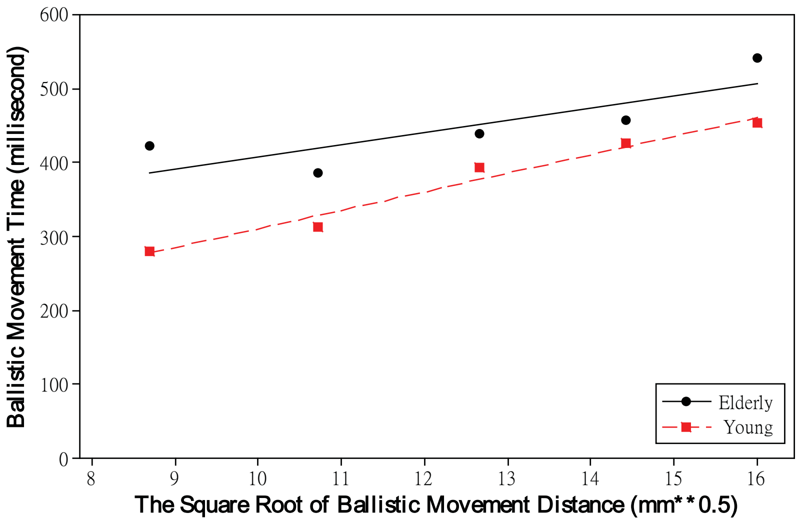

Figure 2 Relationship between ballistic movement time and the square root of distance

Because the significant main effect of Distance was found, the application of Equation 2 was tested. The means of ballistic movement time ($t_{balllitic}$) were calculated for elder and young participants respectively and were then regressed on to the square root of ballistic movement distance ($\sqrt{d_u}$). As shown in Figure 2, the model fitted young participants' data better than elder participants. Equation 2 accounted for 96.4% variance of the overall young participants' data. However, the model did not predict well the overall elder participants' data ($p > 0.05$). Although the main effect of Age Group was not significant, there was a small trend for young participants to have shorter movement time compared to elder participants.

3.2 Ballistic Movement Accuracy

Endpoint errors are consisted of constant error and variable error. To analyze whether Distance and Age Group had significant effects on the two types of errors, eight replications of each experimental combination were calculated as the constant error and the variable error (measured by variance). Since the constant errors were small (less than 2 mm), only the results of variable error were discussed in this article.

Analysis of variance, as movement time, was performed on X- and Y-variable errors using a mixed model with Distance and Age Group as fixed effects and Participant as a random effect nested within Age Group. The results only showed significant main effect of Distance on Y-variable error ($F_{4,40} = 7.59, p < 0.001$), indicating that the increase of ballistic movement distance resulted in increased Y-variable error.

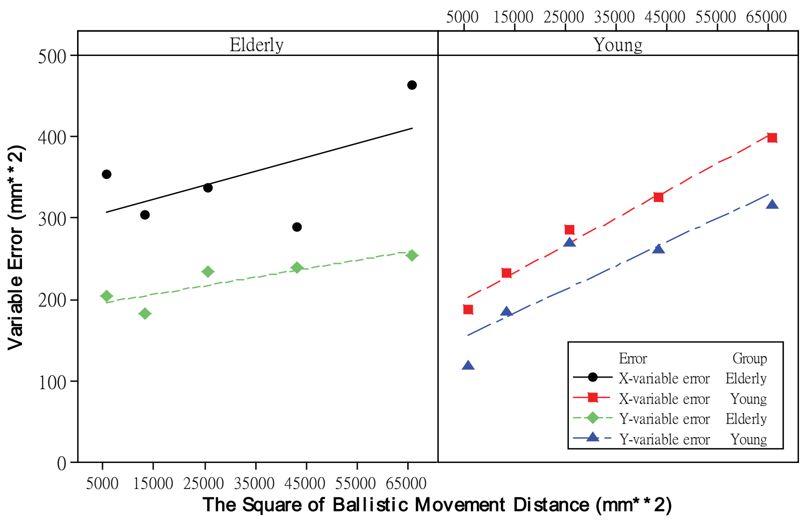

Figure 3 Relationships between two types of variable errors and the square of distance for elder adults and young adults

Although the main effect of Distance had no statistically significant effect on X-variable error and the main effect of Age Group had no significant effect on both types of variable errors, Equation 3 was tested for two groups' both axes of errors. The two error variances, calculated from the raw data for each movement distance, were regressed on to $d_u{}^2$. The results showed that Equation 3 was only applicable for young participants' data ($p < 0.05$), in which the model accounted for 97.4 % variance of X-variable error and 74.0 % variance of Y-variable error. As shown in Figure 3, two groups of participants committed smaller Y-variable error compared to X-variable error. Furthermore, there was a trend for young participants to have smaller variable errors compared to elder participants.

4 DISCUSSION

This preliminary study showed the potential of ballistic movement models for comparing ageing differences while interacting with touchscreens. With a self-modified LED monitor, we successfully measured ballistic movement time and ballistic movement endpoint variability when participants performed ballistic movements on the touchscreen by using their pointing fingers. Although statistically significant differences between the elderly and young adults were not found and two ballistic movement models did not fit well elder participants' data, we revealed the differences of movement speed and accuracy by plotting measured data against certain formats of movement distance. Relevant explanations of statistical issues and the findings related to ageing are discussed below.

There are two potential explanations for no significant difference between two groups of participants. The results of analysis of variance showed that the main effect of Age Group had no significant effect on both movement time and two axes of variable errors. The first explanation of this finding might be the small number of participants. In this study, only 12 participants were recruited and they were nested within two different age groups. While large variance was found among participants, it was difficult to show statistically significant difference between age groups. The second explanation could be that the elder participants recruited in this study were much healthier than normal elder people. As mentioned in the method section, all the elder participants had a regular exercise habit and all of them were healthy without any issues of executing hand-control movement. This might lessen the discrepancy of motor skills between two groups of participants.

Furthermore, two reasons could explain why ballistic movement models did not fit the data well. The results of model validation showed that both ballistic movement time model and ballistic movement variability model fitted well young participants' data, but not elder participants' data. The first potential reason to explain the results could be that the ballistic movements designed in this study were inappropriate. The ballistic movements were not executed in an exactly vertical direction toward the surface of screen, especially for short distance movements. This inappropriate design might impact the predictions of models, especially the ballistic movement variability model. Secondly, the elderly might perform ballistic movement in a different manner. As shown in Figure 2 and Figure 3, the elder participants' data of the movement time and two axes of variable errors were not affected by movement distance too much; they did not increase dramatically with increased movement distance. Several studies (e.g., Chaparro *et al.* 1999, Bakaev 2008, Fezzani *et al.* 2010) that utilized Fitts' law reported similar findings and found that the elderly tend to be more conservative while executing target-acquisition tasks.

Except for the statistical issues, several differences between two groups of participants were found. As just discussed, elder participants tended to be more conservative; the measured data were not significantly affected by movement distance. Compared to young participants, they took relatively a long duration while performing short distance movements (see Figure 2) and they produced relatively high variable errors of short distance movements and low variable errors of long distance movements (see Figure 3).

Suggestions for future research and design suggestions for the elderly were made after this preliminary study. To obtain solid conclusions, the number of participants should be increased and the experimental issue of non-vertical ballistic movement direction should be solved. While ballistic movements were measured, instead of Fitts-type movements, we found detail characteristics between the elderly and young adults. As expected, the elderly performed movements with a slower speed. However, the elderly had relatively high variable errors even in short distance movements. Furthermore, the discrepancy between vertical variable error and horizontal error on a touchscreen was larger for elder participants, compared to young participants. These findings can be utilized to develop design guidelines for touchscreen devices.

5 CONCLUSIONS

This study utilized ballistic movement models to compare the differences of speed and accuracy between the elderly and young adults while interacting with a touchscreen. The results showed that (1) because of few experimental issues, there was no statistically significant difference found between two groups of participants, (2) two ballistic movement models fitted well young participants' data, but not elder participants' data, and (3) elder participants performed movements with a conservative manner that could be utilized to develop touchscreen design guidelines. To provide solid conclusions, few suggestions were made for future research.

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