Fitts' Law in Bivariate Pointing on Large Touch Screens: Age-Differentiated Analysis of Motion Angle Effects on Movement Times and Error Rates

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Abstract. Fitts' Law is a famous and highly satisfactory model to predict movement times in ergonomic studies. The original Fitts' Law only considers one-dimensional movements. In the field of human-computer interaction however one has to deal with at least two dimensions. Due to inconsistency in previous research concerning the integration of the motion angle into the Fitts' formulation, we investigated the influence of this factor on movement times and errors systematically. 30 subjects, separated in two age groups (younger: 21-36 years, elderly: 58-77 years) were tested in executing a pointing task on a large touch screen. The results reveal that the motion angle has a sinusoidal effect on the movement time for both age groups. Subsequently Fitts' Law was refined by an additional summand which is an explicit sine function of the motion angle. Based on our findings we give practical recommendations where to arrange information elements on large touch screens.

Keywords: Fitts' Law, Motion Angle, Bivariate Pointing, Movement Times.

1 Introduction

Although Fitts' Law is a strong model to predict movement times the role of the motion angle in two-dimensional pointing tasks is still unclear. In this study we investigated the angle-effect regarding movement time and error rate in detail. Based on the results a refined model of Fitts' Law was built and evaluated. Besides theoretical implications the results provide practical recommendations for the spatial arrangement of information elements on large touch screens.

Large touch screens provide a promising alternative to classical computer workstations in application areas where one has to display and manipulate complex information at once (plant design, project management, architecture, etc.). With touch screens the way people interact with computers has changed as the separation between information input and output is repealed. Research has shown that this interaction-technique can be beneficial for many user-groups, particularly for the elderly [10, 11, 13, 14, 15]. To display complex information and to enable natural input the touch screen technology has developed to large scaled multitouch screens. The effectiveness and efficiency of information input however depends highly on the ergonomic design of the user-interface. When transferring software originally designed for classical desktop

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computers to large touch screens one has to consider that the regular button size used in many software systems is optimized for mouse input and that movements of the hand-arm-system are error prone when buttons are located in the upper parts of the touch screen. Crucial questions are where to display menus, buttons or icons on large touch screens, and which size these elements should have in order to enhance pointing performance. To determine ergonomically “optimal” target sizes and target positions Fitts' Law provides a highly satisfactory model. Fitts' Law states that the movement time (*MT*) is linearly dependent on the index of difficulty (*ID*) of a pointing task. The *ID* of a movement is defined as the dyadic logarithm of the quotient of amplitude of the movement (*A*) and target width (*W*):

$$MT = a + b \cdot \log_2 (2*A/W) . \quad (1)$$

Fitts' original study only considered one-dimensional movements; however on large touch screens one has to deal with two-dimensional movements. To adopt Fitts' Law to bivariate pointing one has to consider two potential influencing factors: the definition of the target width and the motion angle between the starting position and the target object. In the present study we focus on the motion angle.

A literature analysis showed that in 1954 Fitts already found an angle effect concerning the error rate. He mentioned that pointings to the left side (180°) are more accurate than pointings to the right (0°) [8]. Two decades later, when adopting Fitts' Law to human computer interaction, Card et al. (1978) analyzed performance in text selection regarding different angles (0°-360°, in 45° increments) using a mouse, a joystick, step keys and text keys. They found that the motion angle has a significant effect for every investigated input device except for the mouse. For the joystick for example the movement time is slightly higher (3 % of the mean movement time) when the target is approached diagonally [2]. In 1991 Boritz et al. investigated the approach angle for different pieces of pie menus (0°-360°, in 45° increments) and the time to move the mouse cursor to the target. They found that the movement time is higher for 270° than for 0° [1]. MacKenzie et al. (1992) compared motion angles of 0°, 45° and 90° in bivariate pointing tasks using standard mouse input. In accordance to Card et al. they found that movement time is higher when the motion angle was 45° than when it was 0° or 90° [12]. Whisenand & Emurian (1999) examined the effect of the motion angle (0°-360°, in 45° increments) on the movement time and accuracy in a discrete drag-drop and point-select task with squared and circular target objects using a computer mouse. They found the highest movement times for 90° and 270°. The lowest movement times were found for 180° and 0° [16]. Iwase & Murata (2002, 2005) examined the effect of motion angles (0°-360°, in 45° increments) in more detail. In their study with elderly subjects using either a touch panel or a mouse for input, they found differences in movement times for motion angles of 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° degrees. For touch panels they found a periodical sinusoidal relationship between movement time and angle defined by the following function [9, 13]:

$$MT = \alpha \cdot d - \beta \cdot \log_2 s + \gamma \cdot \sin 2\theta + \delta \cdot \sin \theta + c \ . \qquad (2)$$

In which α, β, γ, δ and c are the multiple regression coefficients, d is the distance, s is the target size and θ is the angle between start- and target object. Du et al. (2007) also report a sin-curve pattern in their investigation of pointing tasks on a board [5].

As there is inconsistency in previous research in how to include the factor motion angle to Fitts' Law the aim of this study is to investigate the influence of this factor on movement time and errors systematically.

2 Method

The study included a pointing task with target objects varying their position on the screen to answer the question how the motion angle influences movement times and error rates. The data was analyzed with respect to the age of the participants in order to gather information about age related changes in pointing performance.

2.1 Subjects

Altogether, a sample of 30 right-handed subjects was tested in the experiment. They were paid volunteers aged from 21 to 77 years. The subjects were divided by age into two groups with 15 persons each. The age of the younger group (9 male, 6 female) ranged from 21 to 36 years (M = 29.39, SD = 4.52); the age of the older group (8 male, 7 female) from 58 to 77 years (M = 67.82, SD = 5.47).

2.2 Apparatus

The hardware used to register the pointing movements was the so termed “DiamondTouch” screen developed by Circletwelve Inc. [3]. The DiamondTouch screen is basically a tabletop device (projection area 865 mm x 649 mm, 4:3 ratio) with a touch-sensitive surface of 1070 mm in diagonal. The images are projected from top. Through capacitive coupling between a transmitter array located in the touch surface and separate receivers the subjects sit on, the attached computer can distinguish multiple touch inputs. The physical setup of the system consists of the DiamondTouch screen connected to a PC via USB cable, and a video projector (1600 x 1200 pixel) mounted above the tabletop and aimed down onto the touch surface.

2.3 Procedure

The pointing task was carried out with the DiamondTouch screen lying on a table with a height of 755 mm. The subjects were seated on a chair in front of the DiamondTouch screen. The investigator demonstrated and supervised a sample target block to familiarize the subject with the task and the test environment. The subjects were instructed to point as quickly and as accurately as possible. In the experimental task the participants had to point with the right index finger from the start position (Ø = 20 mm) located in the centre of the table to a target object (Ø = 40 mm). The

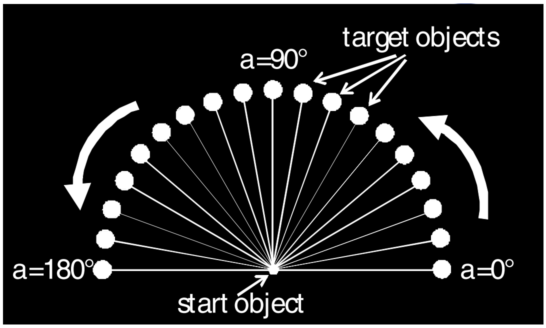

Fig. 1. Sketch of the experimental setup. Exemplarily shown for a starting position at 0°.

size of the start position was chosen according to the 95th percentile of index finger width for men [4]. Each subject completed eight blocks. A block consisted of 38 pointings in that the position of the target object varied from 0° (pointings to the right side) to 180° (pointings to the left side) in 10° increments and back from 180° to 0° in 10° increments. The subjects started alternately with pointings where the target was located at 0° or 180°. This setting was first executed with an amplitude of 400 mm, followed by an amplitude of 200 mm (Figure 1).

2.4 Data Analysis

Movement time data and errors were aggregated into a mean movement time in milliseconds and a mean error rate in percent (in decimals) for each participant. The significance level for each analysis was p=0.05. The statistical software package SPSS Version 17.0 was used to compute the descriptive and inferential statistics.

3 Results

3.1 Descriptive Analysis

Movement Times. In Figure 2 the mean movement time data of the 200 mm condition is depicted depending on the angle (0°-180°). In fact, the movement time of both age groups clearly varies over the angle in a periodical pattern similar to the sin-curve. In both age groups the lowest movement time was found for an angle of 30° (young: 284 ms; old: 312 ms), the highest movement time was found for an angle of 140° (young: 357 ms; old: 361 ms). As obvious, the movement time of the older age group lays approximately 21 ms above the movement time of their younger counterparts.

The time data for the 400 mm condition (see Figure 3) follow the same sin-shaped pattern for both age-groups. In the younger age group, the lowest movement time was found for an angle of 40° (411 ms), in the older age group the fastest pointing occurred at a 20° angle (437 ms). The highest movement time occurred at a 160° and 180° angle respectively for the younger (484 ms) and the older age group (520 ms). Again, the movement time of the older age group is approximately 30 ms higher.

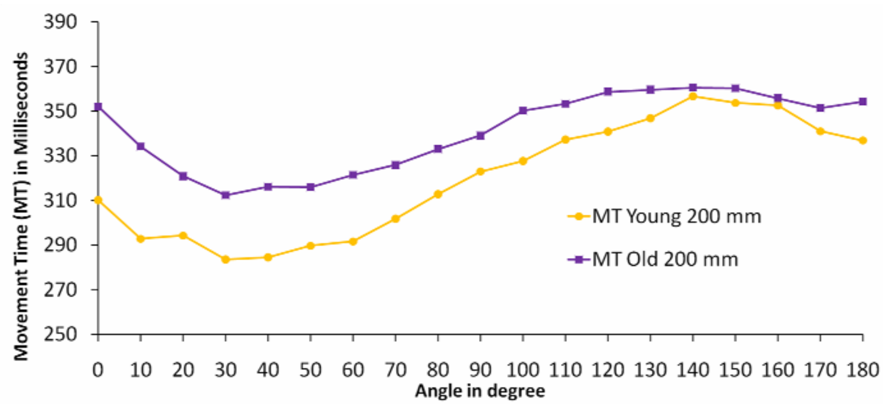

Fig. 2. Movement time data of the 200 mm condition for both age groups

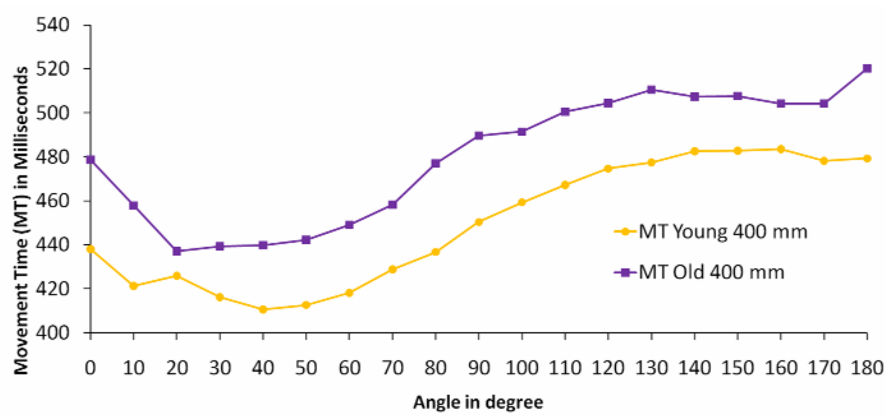

Fig. 3. Movement time data of the 400 mm condition for both age groups

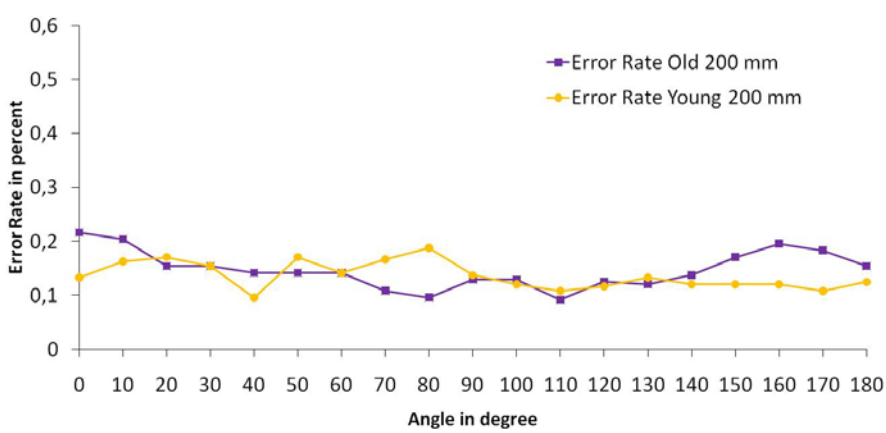

Fig. 4. Error rate data of the 200 mm condition for both age groups

Error Rates. For the 200 mm condition Figure 4 depicts the mean error rate in percent (in decimals) for each angle and both age groups (please note that the number of pointings per angle is 16). For both age groups the angle has low impact on the error rate. The mean error rate varies rather unsystematically around 0.14.

The investigation of the 400 mm condition results in a similar error pattern for both age groups. The highest error rate is found in both age groups between 0° and 20° degree with a mean error rate around 0.38 for the younger and a mean rate around 0.55 for the elderly. By trend, the error rate decreases in the range of 20° (young=0.43 /old=0.53) up to 110° degree (young and old=0.09), reaching minimum values at 130° (young=0.05) and at 120° (old=0.08).

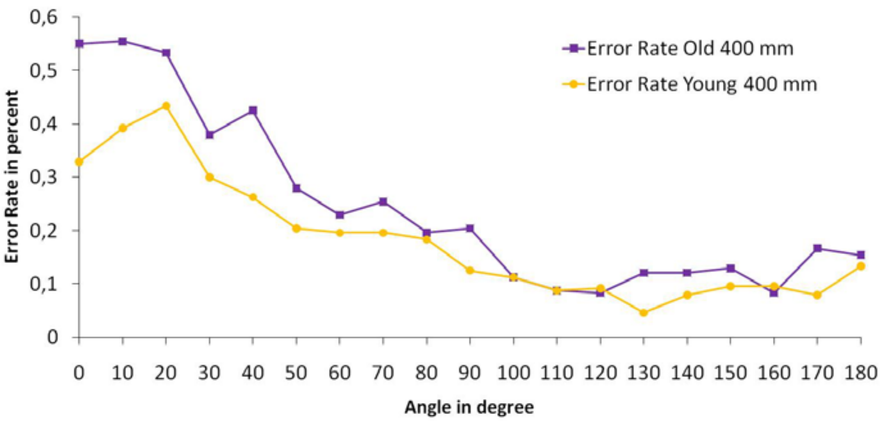

Fig. 5. Error rate data of the 400 mm condition for both age groups

3.2 Analysis of Variance (ANOVA)

Regarding the assumptions of inferential statistics, it must be noted that the KS-Test indicated significant deviations from normal distribution for at least some of the movement time (19 of 76) and error rate data (40 of 76). However, the overall pattern of the data is bell-shaped and ANOVA provides a robust measure when the sample size is equal across the groups [7]. Mauchly test indicated that the assumption of sphericity had been violated; degrees of freedom were thus corrected using Greenhouse-Geisser estimates of sphericity. Additionally, the variable ω^2 for repeated measures was calculated to quantify the strength of significant effects [5, 7].

Movement Time. The mean movement time for each angle was analyzed with ANOVA. For the 200 mm condition a significant main effect of movement time was found relating to the angle ($F_{(9.83,652.25)}=17.42$, $p=0.000$) and a medium effect size of $\omega^2=0.33$ within subjects was calculated. An additional significant effect was found for age group ($F_{(1,66)}=45.19$, $p=0.000$) and a large effect size of $\omega^2=0.60$ between subjects occurred. In addition the interaction between angle and age group is significant ($F_{(9.83,652.25)}=9.25$, $p=0.000$, $\omega^2=0.19$). Thus, angle had different effects on movement time depending on the participant's age group.

For the 400 mm condition significant effects of angle ($F_{(8.92,267.68)}$=26.59, p=0.000), age group ($F_{(1,30)}$=14.90, p=0.001) and a significant interaction effect of angle and age group ($F_{(9.83,652.25)}$=4.82, p=0.000) were found. Here the effect size of the angle is larger with ω^2=0.45. Age has a medium effect size of ω^2=0.32 within subjects. The interaction effect of angle and age group is low with ω^2=0.11.

Error Rate. Regarding the error rate for the 200 mm condition, the results of the ANOVA do not show any significant effects or interactions of within or between-subject factors. In the 400 mm condition a significant effect of angle was found ($F_{(6.99,194.84)}$=33.47, p=0.000) and a large effect size of ω^2=0.52 within subjects was calculated.

3.3 Building of a Refined Model

In accordance to our findings a nonlinear sinusoidal model on the basis of movement time, motion angle, amplitude and target width was build in order to refine Fitts' Law. Therefore the ID formulation is expanded by an additive sinusoidal term:

$$MT = a + b \cdot ID + c \cdot \sin(2\alpha) \ . \tag{3}$$

The results of performance modeling are listed in table 1 for both age groups.

Table 1. Parameters and coefficients of determination of the refined model

Age group	*a*	*b*	*c*	R^2
Young	-111.58	129.83	-35.70	.984
Old	-121.83	139.25	-30.25	.981

In Figure 6 the empirical and modeled movement time data are depicted for the two distances and both age groups.

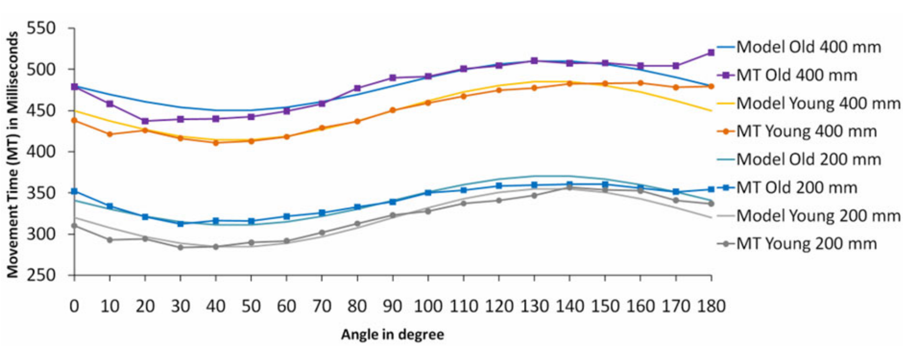

Fig. 6. Empirical and modeled movement time data

This manifest model yields a high fitting with the experimental data, resulting in a R^2 of 0.984 for the younger age group and a R^2 of 0.981 for the older age group.

4 Discussion

The results unambiguously show that there is a significant influence of the factor motion angle in bivariate pointing tasks. The movement time data varies in a clear sinusoidal pattern across the angles investigated. This sin pattern is evident at both amplitudes – 200 mm and 400 mm – and for both age groups. Regarding the age of the participants, the mean movement times of the older age group are significantly higher than the movement times of the younger age group. Depending on the age group and the amplitude we found the lowest movement times for motion angles between 20° and 40° and the highest movement times for motion angles between 140° and 180°. Regarding the error rate, the results differ for the two amplitudes. For the 400 mm amplitude a significant angle effect was found for both age groups. The error rate decreases in the range of 0° up to 90° and then keeps a minimum for both age groups. For the 200 mm amplitude we found no significant angle effect; the mean error rate is nearly constant over the angle.

The sinusoidal pattern of movement times depending on the angle is in accordance with findings of Iwase & Murata [9, 13] and Du [5]. Moreover we found this effect to be evident for 10° angular steps, at two different amplitudes and for a wide range of age. The appeal of Fitts' Law lies in its simplicity and the remarkably good fitting. By adding a term representing the sinusoidal curve to Fitts' original formulation, the effect of the motion angle can be modeled easily.

With the account of errors it is also possible to give practical recommendations for the field of interface and software design concerning the spatial arrangement of buttons or menus on large touch screens. Certainly, the question where to display information elements in order to enhance effectiveness and efficiency of information input depends on the task characteristics and the importance of either speed or accuracy. If the objective is to point a button in preferably short time, it should be located in the right part of the screen (20°-40°) though a higher error rate has to be accepted. In contrary if the accuracy is most important it depends on the amplitude. For an amplitude of 400 mm we recommend a motion angle of 90° as the lowest error rates occur between 90° and 180° and coevally (in this interval) the movement time is lowest for 90°. Whereas for a smaller amplitude (200 mm) an angle between 20°-40° should be preferred as the error rate remains nearly constant.

The focus of the present study was to identify the influence of the factor angle on the movement time and to refine Fitts' Law by this factor. This was done systematically by varying the factor angle in 10° steps between 0° and 180°. The amplitude was varied in two steps; the target width was kept constant. Since just two amplitudes and one target width were investigated, it is only possible to generalize the results to a limited extent. Certainly, there is need to validate the refined model in a more applied setting using a larger ID range by investigating a broader range of amplitude and target width combinations.

In this study we could show that the motion angle clearly affects the user performance in bivariate pointing tasks and that the refined model leads to a significant better movement time prediction than Fitts' original law. In order to design software for large touch screens we therefore recommend using the refined model.

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References

1. Boritz, J., Booth, K.S., Cowan, W.B.: Fitts' law studies of directional mouse movement. In: Proceedings of Graphics Interface, pp. 216–223. Canadian Information Processing Society, Toronto (1991)
2. Card, S.K., English, W.K., Burr, B.J.: Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. Ergonomics 21, 601–623 (1978)
3. Dietz, P., Leigh, D.: Diamondtouch: a multi-user touch technology. In: Proceedings of the ACM Symposium on User Interface Software and Technology, New York, pp. 219–226 (2001)
4. DIN 33402-2: Ergonomie Körpermaße des Menschen Teil 2: Werte, Deutsche Fassung EN ISO 33402-2 (2005) (in German)
5. Du, J., Shi, H., Yuan, X.-g.: Modeling of human's pointing movement on the effect of target position. In: Duffy, V.G. (ed.) HCII 2007 and DHM 2007. LNCS, vol. 4561, pp. 48–55. Springer, Heidelberg (2007)
6. Field, A., Hole, G.: How to Design and Report Experiments. Sage Publications, Thousand Oaks (2007)
7. Field, A.: Discovering Statistics Using SPSS. Sage Publications, Thousand Oaks (2009)
8. Fitts, P.M.: The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology 47, 381–391 (1954)
9. Iwase, H., Murata, A.: Empirical study on improvement of usability for touch-panel for elderly - comparison of usability between touch-panel and mouse. In: IEEE International Conference on Systems, Man, and Cybernetics, pp. 252–257 (2002)
10. Jochems, N.: Altersdifferenzierte Gestaltung der Mensch-Rechner-Interaktion am Beispiel von Projektmanagementaufgaben. Dissertation RWTH Aachen, Shaker, Aachen (2010) (in German)
11. Luczak, H., Schlick, C., Jochems, N., Vetter, S., Kausch, B.: Touch Screens for the Elderly: Some Models and Methods, Prototypical Development and Experimental Evaluation of Human-Computer Interaction Concepts for the Elderly. In: Haftor, D., Mirijamdotter, A. (eds.) Information and Communication Technologies, Society and Human Beings: Theory and Framework, ch. 11, pp. 116–135. IGI Global, Hershey (2010)
12. MacKenzie, I.S., Buxton, W.: Extending Fitts' law to two-dimensional tasks. In: Proceedings of the ACM Conference on Human Factors in Computing Systems - CHI 1992, pp. 219–226. ACM, New York (1992)
13. Murata, A., Iwase, H.: Usability of touch-panel interfaces for older adults. Human Factors 47, 766–776 (2005)
14. Pak, R., McLaughlin, A.C., Lin, C.C., Rogers, W.A., Fisk, A.D.: An age-related comparison of a touch screen and a novel input device. In: Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting, pp. 189–192. Santa Monica, CA (2002)
15. Rau, P.P., Hsu, J.: Interaction devices and web design for novice older users. Educational Gerontology 31(1), 19–40 (2005)
16. Whisenand, T.G., Emurian, H.H.: Analysis of cursor movements with a mouse. Computers in Human Behavior 15, 85–103 (1999)