Investigation of the angle and age effect using Fitts’ Law for mouse input

Jennifer Bützler, Christopher M. Schlick

Chair and Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, GERMANY

In human-computer interaction Fitts’ Law has proven to be a highly accurate model for predicting movement times of pointing tasks. 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 total fixation time on target object. 93 subjects, separated in three age groups were tested in executing a pointing task with a computer mouse. The results reveal that horizontal and vertical pointing movements result in significantly shorter movement times than diagonal pointing movements. Regarding the total fixation time on target object we found significantly longer fixation times for pointings in upper areas than for pointings in lower areas. Moreover, movement time as well as total fixation time on target object was significantly higher with increasing age.

Practitioner Summary: We investigated which angle leads to lowest movement times when carrying out goal directed pointing movements with a computer mouse. For different age groups horizontal and vertical pointing movements were beneficial as they led to lower movement times than diagonal pointing movements.

Keywords: age-differences, Fitts’ Law, human computer interaction, pointing movements

1. Introduction

Effective, efficient and satisfying human-computer interaction is strongly influenced by the use of input devices. Age-related changes in visuo-motor abilities as reduced muscle strength, reduced range of motion and greater difficulty executing fine movements (Birren and Fisher 1995; Vercruysse 1997) can lead to an age-related decrease in performance when using information input. This effect is most prominent for conventional information input as a computer mouse (Jochems 2010). To evaluate different input devices Fitts’ Law (Fitts 1954; MacKenzie and Buxton 1992) provides a highly satisfactory model. Furthermore it allows the determination of ‘optimal’ target sizes and target positions to improve speed and accuracy of the information input which is beneficial for productivity. Fitts’ Law states that the movement time (MT) is linearly dependent on the index of difficulty (ID) of a pointing task. The ID is defined as the dyadic logarithm of the quotient of amplitude of the movement (A) and horizontal target width (Wh):

\[ MT = a + b \cdot ID \]

\[ ID = \log_2 \left( \frac{A}{Wh} + 1 \right) \]  

Fitts’ original study only considered one-dimensional movements, however in human computer interaction one has to deal with two-dimensional movements and bivariate targets. Several refinements integrating the angle effect and different target width models can be found in literature considering different input devices (MacKenzie and Buxton 1992; Whisenand and Emurian 1999; Iwase and Murata 2002). However, these models are based on studies in that movement angle and target width were varied at the same time. This can lead to the problem that the effect of the angle might be influenced by the target width and vice versa. Therefore we investigated bivariate pointing movements on large touchscreens in a previous study (Bützler et al. 2012). We were able to derive an age-differentiated refined model based on three empirical studies. Nevertheless, this study could not answer the question if the detected angle effect also holds for mouse input. Therefore, this paper describes a study in which we investigated the angle and age effect using a computer mouse.
2. Literature Review

A goal directed pointing movement can be divided into three phases: movement preparation, initial impulse and error correction phase (Abrams et al. 1990). Within the first phase, mental planning of the movement occurs that contains the visual detection of the target object as well as the activation of motor programs. The subsequent initial impulse phase covers a rapid, typically ballistic movement in that the end effector is moved towards the target object. This phase is characterized by covering the major distance between start and target object. In this phase visual control processes only possess a minor role whereas the subsequent error correction phase highly depends on visual control. As Fitts’ Law describes the movement time, it describes the time which is needed for the second and third phase.

In Fitts’ original study the angle between start and target object was 0° (movements to the right) or 180° (movements to the left) and the target size Wn was determined by the horizontal target width. When applying Fitts’ Law as a predictive model for two-dimensional pointing movements, one has to adapt two factors: The influence of the motion angle and the definition of the target width.

2.1 The target width in bivariate pointing tasks

In a bivariate pointing task with a computer mouse, MacKenzie and Buxton (1992) investigated different target width parameters. They investigated three different approach angles, 0° (movement to the right), 45° (diagonal movements) and 90° (vertical movements) in order to define the target size of rectangular target objects. Five target width models were compared in the study: The horizontal target width (Wn), target height plus target width (Wn+w), object area (Wn+w), target width in the direction of motion W' and a model which considers the shortest length of the sides, the Wmin model. The best fit between model and data was found for the Wmin model (R²=0.950), followed by the W' model which determines the target width in the direction of motion (R²=0.933). Although MacKenzie and Buxton (1992) found better fitting for Wmin, the parameter W' was established in the ISO standard 9241-9. Nonetheless, the Wmin model is the de facto standard in most experimental and practical studies. A later study by Accot and Zhai (2003) investigated Fitts’ Law in a pointing task with a motion angle of 0° (movements to the right) and 180° (movements to the left) with rectangular target objects of different side lengths ratios. The results show a complex interaction of target width and target height. The authors suggest a model integrating the horizontal target width and the vertical target height and were able to validate their model with a high coefficient of determination of R²=0.994.

2.2 The angle in bivariate pointing tasks

The second purpose of the study by MacKenzie and Buxton (1992) was to investigate the angle effect. As mentioned before, rectangular target objects were arranged at different angles between start and target objects (0°, 45°, 90°). The results regarding the motion angle showed that movement time was lowest when start and target object were arranged horizontally (0°). Whisenand and Emurian (1999) conducted a study in that the angle between start and target object was varied in eight steps 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°, whereas 0° defines movements to the right and 180° movements to the left. The pointing task was executed with a computer mouse. In accordance with MacKenzie and Buxton (1992) the results showed that movement time was lowest for start and target objects that were arranged on a horizontal line (0°, 180°). Iwase and Murata (2002, 2005) examined movement times using either a computer mouse or a touch panel. In a pointing task, circular target objects were arranged in the same eight angles as in Whisenand and Emurian (1999) (α=0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). For touch panels they found a periodical sinusoidal relationship between movement time and motion angle, whereas no angle effect was found for the pointing task with the mouse. Appert et al. (2008) investigated seven angles in a pointing task with a mouse (α=0°, 30°, 60°, 90°, 120°, 150°, 180°; for a better understanding and a consistent definition of the angle, the angle γ which was used in the original study was transferred to α: γ=90°-α). The highest movement times were found for an angle α of 90°, the lowest movement times occurred for an angle α of 0° and 180°. A model was derived from the observation and expanded by the angle. Yang and Xu (2010) compared different variants of Fitts’ Law with regard to their goodness of fit. The Wmin model yielded a coefficient of determination of R²=0.924. The model of Accot and Zhai (2003) reaches a R²=0.923 and the model which was expanded by the angle α by Appert et al. (2008) a R²=0.916. The target width in the direction of
movement ($W'$) was not investigated. Yang and Xu developed an own „Augmented Regular Configuration Model“, which fits the data best ($R^2=0.955$).

### 2.2 Previous work of the authors

As initially mentioned, these models are based on studies in that movement angle and target width were varied at the same time. For example MacKenzie and Buxton (1992) presented rectangular target objects at different motion angles to obtain a variation of the target width in the direction of motion $W'$. However, the variation of the target width and the angle within one experiment can lead to the problem that the effects of the target width might be influenced by the angle and vice versa. Whisenand and Emurian (1999), Appert et al. (2008) and Yang and Xu (2010) used rectangular target objects in their studies and arranged them at different angles. Therefore, the angle effects found in their studies possibly are confounded by the target width in the direction of motion that also varied for different angles. Furthermore, the often insufficient validation of the model has to be criticized. In most studies one data set is used for both, the derivation and the validation of a model. This procedure of testing the model against itself however is tautological (circular reasoning) and necessarily results in a high coefficient of determination.

Therefore, our previous work has focused on examining the factors target width and motion angle in two separate studies for two-dimensional pointing movements on large scaled touchscreens and validating the resulting model in a third empirical experiment. In the first study (Vetter 2010) the two most common target width definitions $W_{min}$ and $W'$ were analysed empirically. $W'$ was varied systematically, whereas $W_{min}$ was kept constant. Based on the results of the study, the $W_{min}$ model was rejected. Furthermore, significant effects of the target height perpendicular to the direction of motion ($H'$) were found. The best empirical fit was found for a model taking into account the target width in the direction of motion ($W'$) and the target height perpendicular to the direction of motion ($H'$).

In the second study (Vetter et al. 2011) we focused on examining the effect of the motion angle. The angle $\alpha$ between start and target object was varied systematically in $10^\circ$ steps between $0^\circ$ (movements to the right) and $180^\circ$ (movements to the left) for two amplitudes (200 mm, 400 mm). To eliminate confounding influences of the target width, circular target objects were used. The results support Murata’s and Iwase’s findings (2005), namely that for touch input movement time follows a sinus-shaped curve depending on the angle (Eq. 2). This model yields a high fitting with the experimental data, resulting in a $R^2$ of 0.984.

$$MT = a + b \log_2 \left( \frac{\alpha}{W'} + 1 \right) + c \sin(2a). \quad (2)$$

The results from the studies were examined and validated in a third study (Bützler et al. 2012). Within this experiment the refined model was compared to existing models regarding their predictive validity. It was found that the refined model explains variability in movement time better than the other models with a high coefficient of determination $R^2=0.937$.

One question which emerged by these results was if the detected angle effect is input specific or also holds for other input devices. As research has not shown consistent findings regarding the angle effect for mouse input, this question was investigated systematically in this study.

### 3. Method

To answer the question how the motion angle influences movement times when using a computer mouse for information input, a pointing task with circular target objects was carried out. The data was analyzed with respect to age of the participants in order to gather additional information about age related changes in pointing speed. Furthermore eye tracking data was evaluated to gain insides to visual-cognitive processes.

A full-factorial design with 2 within-subject factors was used, investigating the ID as the first factor in 4 levels and the motion angle as the second factor in 8 levels ($0^\circ$, $45^\circ$, $90^\circ$, $135^\circ$, $180^\circ$, $225^\circ$, $270^\circ$, $315^\circ$), whereas $0^\circ$ denoted pointing movements to the right continuing anti-clockwise. Combinations of two amplitudes (11 cm; 5.5 cm) and target widths (3 cm; 1 cm) let to IDs of 1.50, 2.22, 2.70 and 3.58. Furthermore, the sample was divided into three age groups which served as in-between subject factor. Dependent variables were the movement time and total fixation time on target object in order to gain additional insides to visual-cognitive processes before the movement phase starts. Therefore, the total
fixation time on target object gives additional information which is relevant for the practical situation of information input.

93 right-handed subjects between 25 and 68 years participated in the empirical study. Furthermore, the sample was divided into three age groups with 31 persons each (young: 25-39 years, medium: 40-54 years, old: 55-68 years). The medium age within the youngest group was 29.10 years (SD=3.19), 46.74 years (SD=4.21) in the medium group and 62.10 years (SD=3.81) in the oldest age group.

The pointing task was carried out at a 17-inch-TFT-monitor (1280 x 1024 pixel) using a computer mouse as information input. Eye movements were measured during the task using a Tobii T120 Eye Tracking system. A chinrest was used that allowed a central eye position to the monitor and reduced head movement of the participant while solving the task. The viewing distance was set to 500 mm and the illumination was kept constant at 300 lx. The subjects were seated in front of the monitor and were asked to position their head on the chin rest. 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 move the cursor of the mouse from the circular start position (Ø = 3 cm) located in the center of the screen to the target object and choose it with a mouse click. It was not necessary to move the whole upper body to move the mouse from start to target object. Every participant pointed each condition resulting from 8 angles and 4 IDs three times. The objects were shown in a randomized order. In between each pointing task a fixation cross was shown at the position of the starting object, which needed to be fixated for 0.5 seconds before the next target object was presented. Movement time and total fixation time on target object were logged for each condition. Whereas the movement time was only recorded between releasing the start object and clicking the target object, the total fixation time on target object was logged starting with the presentation of start- and target-object and ending with the mouse click on the target object. In conclusion, the total fixation time on the target object was analyzed for the complete three phases of a goal directed movement while the movement time is only a measure for the initial impulse and error correction phase.

Time and fixation data of correct pointings was aggregated over the three repetitions for each condition and analyzed by factorial analyses of variance with repeated measures (ANOVA). The age group of the participants served as a between-group factor and the level of significance was set to $\alpha = 0.05$. Post-hoc tests were performed using Bonferroni correction.

4. Results

4.1 Movement Time

The ANOVA showed a significant effect of the factor ID on the movement time ($F_{(3,349;\,211,419)}=657.861$; $p<0.001$). As expected due to Fitts’ Law, movement time was higher with increasing ID ($p<0.001$ for all direct comparisons; Figure 1 left). Furthermore, a significant effect of the age-group was found ($F_{(2;\,90)}=34.158$; $p<0.001$). Participants of the older age group needed significantly longer to execute the movements than participants of the younger ($p<0.001$) and middle-aged group ($p=0.022$). Furthermore middle-aged participants were slower than younger subjects ($p<0.001$). The results are shown in Figure 1 right. Moreover, a significant ordinal interaction between ID and age group was found ($F_{(4,696;\,211,419)}=4.999$; $p<0.001$).

Regarding the angle, we also found a significant main effect on the movement time ($F_{(7;\,630)}=11.125$; $p<0.001$). Horizontal and vertical pointing movements led to lower movement times than diagonal movements (Figure 2 left). Pointing movements to the right (0°) were significantly faster than movements in an angle of 315° ($p=0.012$). For an angle of 90° movement times were faster than for 45° ($p<0.001$), 135° ($p<0.001$), 225° ($p=0.001$) and 315° ($p<0.001$). Horizontal pointing movements to the left (180°) showed the lowest movement times and were significantly shorter than for 45° ($p<0.001$), 135° ($p<0.001$), 225° ($p<0.001$) and 315° ($p<0.001$). For an angle of 270° movement times were significantly faster than for 315° ($p=0.018$). Descriptively this effect was more prominent for higher IDs (Figure 2 right).
In addition a regression analysis was conducted which results are shown in Figure 3. The effect of the ID is pronounced stronger with increasing age as can be seen by the higher slopes of the lines with increasing age.

Figure 1. Movement time depending on ID (left) and age group (right)

Figure 2. Movement time depending on angle for all IDs (left) and differentiated by ID (right)

Figure 3. Movement time depending on the index of difficulty and age
4.2 Total fixation time on target object

Regarding the total fixation time on target object, a significant effect of the factor ID was found ($F(2.363; 210.289) = 147.728; p<0.001$). The target object was fixated longer with increasing ID but we did not find a linear dependency between total fixation time on target object and ID (Figure 4 left). In fact, a gap can be detected between ID 2.22 and 2.70. The IDs 1.50 and 2.22 resulted from the two amplitudes in combination with the large target width (3 cm), whereas the IDs 2.70 and 3.58 were a combination of the two amplitudes and the small target width (1 cm). The post hoc tests underline this as they showed significant differences between the small IDs (1.50, 2.22) and the large IDs (2.70, 3.58) ($p<0.001$ each comparison). Moreover, the difference between ID 1.50 and 2.22 was statistically significant ($p=0.007$) but the difference between 2.70 and 3.58 was not. This leads to the conclusion, that small target objects are fixated longer than large ones and that the target width effects the total fixation time on target object stronger than the amplitude.

The age group had as well a significant effect on the total fixation time on target object ($F(2, 89)=6.512; p=0.002$). Participants of the younger age group fixated the target object significantly shorter than participants of the medium (p=0.037) and older age group (p=0.002) (Figure 4 right). In addition, a significant interaction was found between ID and age group ($F(4.726; 210.289)=3.398; p=0.007$). However, more detailed analysis showed that the significant pairwise comparisons for both factors can be interpreted unambitiously.

As expected, the angle had also a significant effect on the total fixation time on target object ($F(4.752; 422.911)=9.483; p<0.001$). The dependency between angle and total fixation time on target object is depicted in Figure 5.

![Figure 4. Total fixation time on target object depending on ID (left) and age group (right)](image)

![Figure 5. Total fixation time on target object depending on angle (left) and visualizing the concrete position (right)](image)
The target object was fixated longest for movements to the upper direction. Targets that were positioned in 45° and 90° were fixated significantly longer than targets positioned in 225° (p=0.011 and p=0.017) and 270° (p<0.001 both). The fixation time on targets positioned in 135° was significantly higher than for 0° (p=0.027), 180° (p=0.031), 225° (p=0.001), 270° (p=0.001) and 315° (p=0.006). Moreover, targets positioned in 180° were fixated significantly longer than targets positioned in 270° (p=0.005). All other direct comparisons were statistically not significant.

Moreover, the analysis showed a significant interaction between angle and ID ($F_{(9.077; 807.812)}=1.976; p=0.039$). As depicted in Figure 6 the interaction is not ordinal and the described angle effect did not show for all IDs. The IDs resulting from the smaller target object (2.70 and 3.58) show a higher variance and a slightly different trend than the main effect. But overall, the tendency to longer fixation times on the target objects in the upper parts than in the lower parts can be noticed.

![Figure 6. Total fixation time on target object depending on angle and differentiated by ID](image)

5. Discussion

The aim of the study was to investigate the angle and age effect on movement time in a typical pointing task when using a computer mouse. According to Fitts’ Law we found a linear relationship between movement time and ID. Furthermore, the age group had a significant effect on the movement time. As expected, movement time increased with the age of the participants. Regarding the angle, we found higher movement times for diagonal pointing movements than for horizontal and vertical ones. These results are partially in line with MacKenzie and Buxton (1992) and Whisenand and Emurian (1999) as they also found lower movement times for horizontally arranged target objects. As expected, the refined model for two-dimensional pointing movements on large scaled touchscreens, which was proposed in Vetter et al. (2011) and validated in Bützler et al. (2012), cannot be transferred to pointing movements with the computer mouse.

In order to gain insights to visual-cognitive processes, the total fixation time on target object was evaluated. The ID had as well a significant effect on this variable, but not in all levels, so that it is assumed that the target width effects the total fixation time on target object and not the amplitude. Smaller targets were fixated longer than larger targets. Regarding the age effect, the total fixation time on target object was higher for older than for younger subjects. This finding is in line with the age-related decline in visuo-motor abilities described in literature (Birren and Fisher 1995; Vercruyssen 1997). Moreover, the angle affected the total fixation time on target object significantly. A dissimilar trend than for the movement time was found. The total fixation time on target object was significantly higher for pointing movements to the upper part than to
the lower part. This result is not surprising as the total fixation time was recorded for all three phases of the pointing movement (Abrams 1990) including the planning phase, whereas the movement time is only a measure for the initial impulse and error correction phase. Combining the results for the movement time and the total fixation time on target object, it can be concluded that pointing movements in an angle of 270° result in a short movement time and at the same time the fixation time on the target object is low. Further analyses need to be carried out to examine the angle effect on the movement time of the planning phase, error rate and the mouse trajectory in order to understand underlying visuo-motor processes better for executing goal directed pointing movements with a computer mouse.

Therefore, future work should focus on investigating time data, visual parameters as well as trajectories separately for each phase of the goal directed pointing movement in order to gain more knowledge in how far the angle effect is due to visual-cognitive or motor processes.

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References


