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Published in:
Proceedings of the Workshop on Communication by Gaze Interaction

Link to article, DOI:
10.1145/3206343.3206344

Publication date:
2018

Document Version
Peer reviewed version

Link back to DTU Orbit

Citation (APA):
A Fitts’ Law Study of Click and Dwell Interaction by Gaze, Head and Mouse with a Head-Mounted Display

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ABSTRACT
Gaze and head tracking, or pointing, in head-mounted displays enables new input modalities for point-select tasks. We conducted a Fitts’ law experiment with 41 subjects comparing head pointing and gaze pointing using a 300 ms dwell (n = 22) or click (n = 19) activation, with mouse input providing a baseline for both conditions. Gaze and head pointing were equally fast but slower than the mouse; dwell activation was faster than click activation. Throughput was highest for the mouse (3.24 bits/s), followed by head pointing (2.47 bits/s) and gaze pointing (2.13 bits/s). Dwell activation was faster than click activation. The effective target width for gaze (∼ 94 pixels; about 3°) was larger than for head and mouse (∼ 72 pixels; about 2.5°). Subjective feedback rated the physical workload less for gaze pointing than head pointing.

CCS CONCEPTS
• Human-centered computing → Pointing devices;

KEYWORDS
Fitts’ law; ISO 9241-9; gaze interaction; head interaction; dwell activation; head mounted displays.

ACM Reference format:
https://doi.org/10.1145/3206343.3206344

1 INTRODUCTION
Several developers of eye-wear digital devices, including FaceBook, Google and Apple, have recently acquired companies specialising in gaze tracking, with the result that gaze and head tracking are now both integrated in commodity headsets for virtual reality (VR). There are mainly two reasons for this: (1) substantial processing-power in headsets may be saved using gaze-contingent rendering where the full image is only shown at the current fixation point [Murphy and Duchowski 2001; Reingold et al. 2003], and (2) gaze may serve as a hands-free pointer for effortless interaction with head-mounted displays (HMD) [Jalaliniya et al. 2015]. Dwell selection has become the preferred selection method for “eyes only” input. This eliminates the need for a hand controller, reducing cost and complexity of the systems. However, if dwell selection is less efficient than click selection, then a physical trigger may be required. People with motor disabilities could use an HMD for interaction when a remote tracking setup is not possible, for instance while lying in bed or sitting in a car. If HMDs become a successful product with head- and gaze-tracking, they may offer a low-cost alternative to high-end gaze communication systems.

This paper aims to inform designers of eye-wear applications what to expect from the gaze- and head-interaction options appearing in HMDs. There are number of questions we address. Is dwell selection a viable alternative to click selection? How large should targets be for accurate selection? How fast is target activation? Is it better to use head interaction instead of gaze interaction? Do people experience physical or mental strain with these new pointing methods? The main limitation is that our study only addresses interaction where the pointer symbol (i.e., cursor) is visible at all times, thereby allowing the user to compensate for inaccuracies in gaze tracking through additional head movements. The study is also not addressing interaction in VR since we are using the original “flat” (i.e., 2D) version of the Fitts’ law test. Finally, we only use one type of headset.

2 PRIOR WORK
Ware et al., presented one of the first evaluations of gaze input in 1987 [Ware and Mikaelian 1987]. Gaze was used for pointing, with selection using either dwell, a physical button, or a software (on-screen) button. Zhang and MacKenzie were the first to conduct a Fitts’ law evaluation of gaze input according to the ISO 9241-9 standard for evaluating the performance and comfort of non-keyboard computer devices [Zhang and MacKenzie 2007]. Based on two target widths and two amplitudes, the index of difficulties (IDs) varied from 1.9 bits to 2.5 bits.

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COGAIN ’18, June 14–17, 2018, Warsaw, Poland
© 2018 Association for Computing Machinery.
ACM ISBN 978-1-4503-5790-6/18/06...$15.00
https://doi.org/10.1145/3206343.3206344

1https://www.iso.org/standard/38896.html [last accessed - June 8, 2018]
eye tracking system runs at 120 Hz. Although the manufacturer indicates that tracking accuracy is less than 1 degree of visual angle, in two recent experiments [Rajanna and Hansen 2018], we found the FOVE headset mean accuracy to be around 4 degrees of visual angle. The headset weighs 520 grams and has IR-based position tracking plus IMU-based orientation tracking. A Logitech corded mouse M500 was used for the manual input.

Software to run the experiment was a Unity implementation of the 2D Fitts’ law software developed by MacKenzie, known as FittsTaskTwo3. The Unity version4 includes the same features and display as the original; that is, with spherical targets presented on a flat 2D-plane, cf. Figure 1. Based on the findings [Majaranta et al. 2009] a dwell time setting of 300 ms was chosen for the dwell condition.

3 METHOD

3.1 Participants

Forty-one participants were recruited on a voluntary basis among visitors at a VR technology exhibition. The mean age was 29 years, (SD = 9.7 years); 31 male, 10 female. A majority (77%) were Danish citizens. Most (91%) had tried HMDs several times before, and 9% only one time before. A few (16%) had previously tried gaze interaction. Vision was normal (uncorrected) for 28 participants, while eight used glasses (which they took off), and five used contact lenses during the experiment.

3.2 Apparatus

A headset from FOVE with built-in gaze tracking was used.2 The headset has a resolution of 2560 × 1440 px, renders at a maximum of 70 fps, and has a field of view of 100 degrees. The binocular gaze tracking in the gaze-pointing mode.

The participants were asked to sign a consent form and were given a short explanation of the Fitts’ law experiment. When seated, the HMD was put on and adjusted for comfort. Then the participants were randomly assigned to do either dwell or click selections. None of the participants did both. Their hand grasped the mouse, which was required for click activation condition. In the dwell condition, the participants only used the mouse for pointing; the mouse button was not used.

Both selection condition groups were exposed to all three pointing methods: gaze pointing, head pointing, and mouse pointing, alternating the order between participants. For each pointing method,

Footnotes:

1available at http://www.yorku.ca/mack/FittsLawSoftware/ [last accessed: June 8, 2018]
2available at https://github.com/GazeIT-DTU/FittsLawUnity [last accessed: June 8, 2018]
When this target was selected, a target at the opposite side would be highlighted one-by-one in the same order for all levels, starting with the bottom position (6 o’clock). When this target was selected, a target at the opposite side would be highlighted (approximately 12 o’clock), then when activated a target between 6 and 7 o’clock was highlighted and so on, moving clockwise. The first target at 6 o’clock is not included in the data analysis in order to minimize the impact from initial reaction time. The pointer (i.e., cursor) was visible at all times, presented as a yellow dot. For mouse input, the pointer was the mouse position on screen. For eye tracking, this was the gaze position as defined by the intersection of the two gaze vectors from the centre of both eyes on the target plane. For head tracking, the pointer was the central point of the headset projected directly forward.

Failing to activate 20% of the targets in a 21-target sequence triggered a repeat of that sequence. Sequences were separated, allowing participants a short rest break as desired. Additionally, they had time to rest for a couple of minutes when preparing for the next pointing method. Also during this break, they were given three short Likert-scale (10-point) questions: “How mentally demanding was this task?” “How physically demanding was the task?” and “How comfortable do you feel right now?” Before testing the eye tracking method, participants performed the standard FOVE gaze calibration procedure, and the experimenter visually confirmed that gaze tracking was stable; if not, re-calibration was done. Completing the full experiment took approximately 20 minutes for each participant.

### 3.4 Design

The experiment was a $3 \times 2 \times 2 \times 2$ design with the following independent variables and levels:

- Pointing method (gaze, head, mouse)
- Selection method (click, dwell)
- Amplitude (160 pixels, 260 pixels)
- Width (50 pixels, 100 pixels)

Pointing method and selection method were the primary independent variables. Amplitude and width were included to ensure the conditions covered a range of task difficulties.

We used a mixed design with pointing method assigned within-subjects and selection method assigned between-subjects. For selection method, there were 19 participants in the click group and 22 participants in the dwell group. For pointing method, the levels were assigned in different orders to offset learning effects.

The dependent variables were time to activate, throughput, and effective target width, calculated according to the standard procedures for ISO 9241-9. For click selection, we also logged the errors (selections with the pointer outside the target). Errors were not possible with dwell selection.

For click activation, there were 228 trial sequences (19 Participants $\times$ 3 Pointing Methods $\times$ 2 Amplitudes $\times$ 2 Widths). For dwell, there were 264 trial sequences (22 $\times$ 3 $\times$ 2 $\times$ 2). For each sequence, 21 trials were performed.

Trials with an activation time greater than two SDs from the mean were deemed outliers and removed. Using this criterion, 120 of 5124 trials (2.3%) were removed for click activation and 129 of 5712 trials (also 2.3%) were removed for dwell activation.

### 4 RESULTS AND DISCUSSION

We performed a two-factor mixed model ANOVA with replication on the dependent variables. The results are shown in Table 1. The effect of pointing method was statistically significant for all the three dependent variables. The effect of selection method was statistically significant for time to activate and effective target width. No interaction effects were found. The results for each dependent variable are shown in Figure 2 (Time To Activate), Figure 3 (Throughput), and Figure 4 (Effective Target Width).

Table 1: ANOVA of the Fitts’ evaluation matrix with three dependent variables: time to activate, throughput, and effective target width. The between-subjects factor was selection method and the within-subjects factor was pointing method [Gz-gaze, Hd-head, Ms-Mouse]. Cells highlighted in gray indicate significance at $p < 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Pointing</th>
<th>Selection</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Gz, Hd, Ms]</td>
<td>[click, dwell]</td>
<td></td>
</tr>
<tr>
<td><strong>Time To</strong></td>
<td>$F(2,324) = 135.362$</td>
<td>$F(1,162) = 5.376$</td>
<td>$F(2,324) = 1.83$</td>
</tr>
<tr>
<td>-Activate</td>
<td>$p = 0.000$</td>
<td>$p = 0.022$</td>
<td>$p = 0.162$</td>
</tr>
<tr>
<td><strong>Throughput</strong></td>
<td>$F(2,324) = 125.024$</td>
<td>$F(1,162) = 2.325$</td>
<td>$F(2,324) = 1.031$</td>
</tr>
<tr>
<td>-put</td>
<td>$p = 0.000$</td>
<td>$p = 0.129$</td>
<td>$p = 0.358$</td>
</tr>
<tr>
<td><strong>Eff-Target</strong></td>
<td>$F(2,324) = 31.803$</td>
<td>$F(1,162) = 8.191$</td>
<td>$F(2,324) = 1.292$</td>
</tr>
<tr>
<td>-Width</td>
<td>$p = 0.000$</td>
<td>$p = 0.005$</td>
<td>$p = 0.276$</td>
</tr>
</tbody>
</table>
However, there was no significant difference between head pointing and the mouse \((p > 0.05)\). The error rates were 1.53\% (3.35\%) for gaze pointing, 0.26\% (0.89\%) for head pointing, and 0.06\% (0.24\%) for the mouse.

### Table 2: ANOVA of Fitts’ evaluation matrix with post hoc analysis \([Gz\text{-gaze}, Hd\text{-head}, Ms\text{-Mouse}]\). Cells highlighted in gray indicate significance at \(p < 0.05\).

<table>
<thead>
<tr>
<th>Pointing</th>
<th>Mean</th>
<th>SE</th>
<th>Post hoc Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>TimeTo Activate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gz = 812.190</td>
<td>16.471</td>
<td>(Gz, Hd) (p = 0.053)</td>
<td></td>
</tr>
<tr>
<td>Hd = 849.951</td>
<td>14.432</td>
<td>(Gz, Ms) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Ms = 641.750</td>
<td>9.528</td>
<td>(Hd, Ms) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Throughput</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gz = 2.127</td>
<td>0.068</td>
<td>(Gz, Hd) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Hd = 2.472</td>
<td>0.048</td>
<td>(Gz, Ms) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Ms = 3.239</td>
<td>0.048</td>
<td>(Hd, Ms) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Eff-Target Width</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gz = 93.765</td>
<td>2.733</td>
<td>(Gz, Hd) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Hd = 71.794</td>
<td>2.564</td>
<td>(Gz, Ms) (p = 0.000)</td>
<td></td>
</tr>
<tr>
<td>Ms = 72.420</td>
<td>2.711</td>
<td>(Hd, Ms) (p = 1.000)</td>
<td></td>
</tr>
</tbody>
</table>

The index of difficulty \((ID)\) influenced the three input methods according to Fitts’ law: Higher \(ID\) increases the time to activate. Figure 5 shows that dwell time activation was slightly faster than click activation for all pointing methods and \(ID\)s. We also examined if movement direction had an impact on selection time for both the click and the dwell group. Click performance was very uniform in all directions, except for the very first target which took a bit longer to hit. Dwell activation was consistent in all directions, but showed more variation over target angle than click, cf. Figure 6.

Figure 2: Time To Activate (ms) by pointing method and selection method.

Figure 3: Throughput (bits/s) by pointing method and selection method.

Figure 5: Violin plot, showing the time to activate the targets \((y\text{-axis, ms})\) vs. Fitts’ index of difficulty \((x\text{-axis, bits})\) split according to the selecting method (left: dwell in blue, right: click in green) and grouped according to pointing method (gaze, head, mouse). The violin shows the kernel density estimate of the underlying distribution. The median value is marked with a dashed line, and the quartile ranges are marked with dotted lines.

Following the completion of the experiment, participants rated their experience on physical workload, mental workload, and comfort. Responses were on a 10-point Likert scale. These were analyzed using a Friedman non-parametric test. For post hoc analyses, we used a Wilcoxon signed-rank test, which is the non-parametric equivalent of a matched-pairs \(t\)-test. The results are presented in Table 3. The effect of pointing method was statistically significant for the three subjective responses. There exists a difference in the mental workload between the mouse and the other pointing methods; however, when comparing gaze pointing and head pointing, the mental workload is perceived equally. The physical workload differs significantly among the three pointing methods. Also, the participants experienced the highest physical workload with head pointing and the least with the mouse.

In summary, our study provides the following contributions: 1) dwell activation is faster than click selection, providing a mean target activation for both gaze and head of \(\approx 800\text{ ms}\) (with a \(300\text{ ms}\)
Post hoc Analysis

We emphasize that both the present study and their study are based on one type of headset only (i.e. the FOVE), and may well change with improvements in tracking technology. Also, gaze pointing holds promise by tending to be faster than head pointing (although not significant so) and it is rated less physically demanding than head pointing.

5 CONCLUSIONS

Overall, gaze pointing is less accurate than head pointing and the mouse, and gaze pointing also has a lower throughput than either alternative considered here. Gaze pointing and head pointing are perceived mentally more demanding than mouse pointing. Head pointing is more physically demanding than gaze pointing.

ACKNOWLEDGMENTS

We would like to thank the Bevica Foundation for funding this research. Also, thanks to Martin Thomsen, Atanas Slavov, Dr. Tracy Hammond, and Niels Andreasen for their support and guidance.

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