

IDEA: Index of Difficulty for Eye tracking Applications

An Analysis Model for Target Selection Tasks

Mohsen Parisay¹, Charalambos Poullis¹, Marta Kersten-Oertel^{1,2}

¹Department of Computer Science, Concordia University, Montreal, Canada

²PERFORM Center, Montreal, Canada

m-parisa@encs.concordia.ca, charalambos@poullis.org, marta@ap-lab.ca

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Abstract: Fitts' law is a prediction model to measure the difficulty level of target selection for pointing devices. However, emerging devices and interaction techniques require more flexible parameters to adopt the original Fitts' law to new circumstances and case scenarios. We propose *Index of Difficulty for Eye tracking Applications* (IDEA) which integrates Fitts' law with users' feedback from the NASA TLX to measure the difficulty of target selection. The COVID-19 pandemic has shown the necessity of contact-free interactions on public and shared devices, thus in this work, we aim to propose a model for evaluating contact-free interaction techniques, which can accurately measure the difficulty of eye tracking applications and can be adapted to children, users with disabilities, and elderly without requiring the acquisition of physiological sensory data. We tested the IDEA model using data from a three-part user study with 33 participants that compared two eye tracking selection techniques, dwell-time, and a multi-modal eye tracking technique using voice commands.

1 Introduction

In this paper we introduce IDEA: Index of Difficulty for Eye tracking Applications, an integrated prediction model of task workload and performance of target selection tasks. The IDEA model combines the effective contact-free target selection of eye tracking with direct feedback of user's experience obtained from the NASA TLX scores. The IDEA model calculates a prediction index value based on objective technical specifications such as the target's size and distance, and subjective measures from the NASA TLX questionnaire obtained from user studies. To demonstrate the efficacy of IDEA, we measured target selection performance with data from three user studies that compared two eye tracking interaction techniques (dwell-time, and selection by voice commands) and showed that our predictions correlate with *throughput* and *movement time* of the Fitts' prediction model.

1.1 Fitts' Law

Paul Morris Fitts introduced a mathematical prediction model to measure the difficulty level of target selection in 1954 (Fitts, 1954). This model, which has been extensively applied in user study interface evaluations (Gori et al., 2017), correlates the required

movement time (MT) to activate a target with a specific size (W), at a certain distance (D). Fitts' Law is formulated as: $MT = a + b \cdot ID$, and $ID = \log_2\left(\frac{2D}{W}\right)$ where ID denotes the index of difficulty, and a and b are empirically defined constant values. In the field of HCI, the Shannon formulation is most commonly used to calculate the index of difficulty, $ID = \log_2\left(1 + \frac{D}{W}\right)$ as described in (MacKenzie, 1989). Fitts' law has been applied effectively in numerous user studies to analyse the performance of selecting specific targets such as buttons (e.g. (Crossman and Goodeve, 1983), (Keele and Posner, 1968)). One of the earliest applications of Fitts' law in HCI was to compare four devices (mouse, joystick, step keys and text keys) for text selection on a monitor (Card et al., 1978). Researchers have also proposed variations to extend the original Fitts' law, for example MacKenzie *et al.* (MacKenzie and Buxton, 1992) extended Fitts' law from a one-dimension to a 2D model for target acquisition tasks to improve the accuracy of the index of difficulty measure for interactive computer systems.

1.2 Cognitive Workload

Cognitive workload refers to the amount of mental effort used to perform a task by a person. The NASA Task Load Index (TLX) questionnaire is a

well-known method to measure subjective workload in user studies (Hart and Staveland, 1988) and has been shown to be an effective tool to measure cognitive workload (Ruiz-Rabelo et al., 2015). The questionnaire includes: physical demand, mental demand, temporal demand, effort, performance, and frustration with the maximum range of 100 points (Group, 1986). Although there is physiological data (e.g. electroencephalogram or EEG) which can be used to measure subjects' workload, these methods although accurate in detecting brain activity require specialized and sometimes cumbersome equipment. In addition, these techniques are intrusive for users and therefore are restricted to controlled environments such as laboratories (Zagermann et al., 2016). Thus in our model, we focus on the NASA TLX.

1.3 Midas Touch Problem

Eye tracking, like many emerging technologies, has its challenges. The Midas touch problem which refers to unintended activation of functions by eye gaze to select a target is one of the major challenges to be considered when dealing with eye tracking applications. According to Jacob (1990), this problem occurs since the eyes are used to look around an object or to scan a scene, often without any intention to activate a command or function. Thus, numerous research has focused on solving the Midas touch problem for gaze-based interactions (e.g. (Pi and Shi, 2017), (Velichkovsky et al., 2014), (Velloso et al., 2016), and (Schenk et al., 2017)).

2 Related Work

Both Fitts' law and the NASA TLX are popular tools for user studies. Felton *et al.* applied these tools to study mental workload during brain-computer interactions (Felton et al., 2012). Kim *et al.* applied Fitts' law in a driving safety simulation to analyze the usability of touch-key sizes (Kim et al., 2014). Hansen *et al.* made use of Fitts' law to analyze the performance of gaze and head tracking for point and selection tasks when using head-mounted displays (HMDs) (Hansen et al., 2018). In addition, Fitts' law was applied to reduce dwell-time for gaze-based selection techniques by considering the estimated target acquisition time and the actual eye movement time (Isomoto et al., 2018). Researchers have investigated the relation between eye blinks and mental workload among surgeons (Zheng et al., 2012), finding that shorter blink duration and frequency indicate an increase of mental workload (Zheng et al., 2012).

Borghini *et al.* studied brain activity and heart rate of car drivers and also found shorter blink rates correlate with mental workload (Borghini et al., 2012). Lanthier *et al.* studied the correlation between fixations and eye fatigue during visual search tasks and found that fixation duration increases with fatigue (Lanthier et al., 2013). Abdulin *et al.* showed that the distance drift of fixation points in response to a stimuli can reveal physical eye fatigue (Abdulin and Komogortsev, 2015) and calculated this using the fixation qualitative score (FQIS) (Komogortsev et al., 2010). Another study looked at developing a metric based on fixation points and the NASA TLX to determine the possibility of eye fatigue in gaze-based interactions (Parisay et al., 2020). There are also approaches to measure eye fatigue based on saccades, however, analysis of saccades requires expensive eye trackers, and these approaches are not applicable on budget-friendly devices (Abdulin and Komogortsev, 2015), such as the one used in our study.

Building on previous work, we propose a non-invasive approach which can be applied on any remote eye trackers without the need of raw data analysis of the specific eye tracking sensors. We apply eye tracking for target selection from a safe distance and assess the difficulty levels including subjects' ratings independent from device abilities or tracking techniques. The primary purposes of IDEA are (1) to compare different eye tracking applications, and (2) to enable adaptation of eye tracking applications on different user groups such as children, users with disabilities, and the elderly. Furthermore, IDEA has the potential to be applied for eye fatigue assessment, and stress level measures based on target selection tasks. To the best of our knowledge, there are no models that integrate the index of difficulty of the Fitts' law (ID) and the NASA TLX scores for eye tracking applications without the need of technical parameters such as *blink rates, fixation duration time, average number of fixations, and saccade duration.*

3 Index of Difficulty (IDEA)

Users' perceived rating is one of the most valuable sources of data in any user study and the NASA TLX questionnaire is a valid tool for this purpose. On the other hand, Fitts' law can reflect the difficulty and performance of target selection tasks based on test specifications. Therefore, we integrated users' feedback into the Fitts' law model to result in a combined value reflecting both technical and experimental aspects of target selection tasks for eye tracking applications. In addition, the entire workload of a task

(subjective rating) can be modulated by a selection ratio parameter (selection distance divided by screen diameter) which is determined based on test conditions, users' ability to select targets, and interaction techniques. The purpose of modulating the technical factor with the experimental factor is to combine the importance of both into a single index value. In other words, the multiplication combines both, technical aspects which are bound to case scenarios, with subjective understanding of the actual functions. This results in a single value for comparison. Thus, the IDEA analysis model is a novel simple-to-calculate compound model for eye tracking techniques based on the Fitts' law (Fitts, 1954) and the NASA TLX questionnaire (Group, 1986) to measure the difficulty of target selection tasks. IDEA is device-independent and can be applied on any eye tracker, and depends on the following parameters:

- All scores from the NASA TLX questionnaire: *physical demand* (PD), *mental demand* (MD), *temporal demand* (TD), *effort* (E), *performance* (P), and *frustration* (F).
- Diameter of screen (D): represents the longest distance on screen $D = \sqrt{x^2 + y^2}$ where x and y represent screen width and height.
- Selection ratio (S): represents the difficulty of target selection (distance to target) in regards to the screen diameter (see Figure 1).
- DISTANCES: the set of target distances from each other.
- WIDTHS: the set of target sizes (widths).

The conditions and range of each of the parameters are given by:

1. $\forall a \in \{PD, MD, TD, E, P, F\} : a \in \mathbb{Z} \wedge 1 \leq a \leq 100$
All NASA TLX scores are integers in the range of 1 to 100.
2. $D \in \mathbb{Z} \wedge D > 0$
Diameter of screen is an integer value greater than 0 in pixels.
3. $r \in \mathbb{R} \wedge 0 \leq r \leq D$
The distance to target (r) is a real number between 0 and screen diameter in pixels (see Figure 1a).
4. $S = \frac{r+1}{D} \wedge S \in \mathbb{R} \wedge S > 0$
Selection ratio (S) is the ratio of distance to target (r) over diameter of the screen (D). The constant value of 1 added to the equation to avoid the 0 case for distance to target (see Figure 1b).
5. $DISTANCES = \{d \mid d \in \mathbb{R} \wedge d > 0\}$
DISTANCES is the set of real numbers containing distances of targets from each other greater than 0.

6. $WIDTHS = \{w \mid w \in \mathbb{R} \wedge w > 0\}$

WIDTHS is the set of real numbers containing widths (sizes) of targets greater than 0.

7. $m = |WIDTHS| \wedge m \geq 1$

m is the count of members in the WIDTHS set greater than or equal to 1.

8. $n = |DISTANCES| \wedge n \geq 1$

n is the count of members in the DISTANCES set greater than or equal to 1.

9. $Technical\ Factor \in \mathbb{R} \wedge Technical\ Factor > 0$

The technical factor (Equation 1) is the sum of all distances ($d \in DISTANCES$) doubled and divided by the width values ($w \in WIDTHS$) derived from the Fitts' law (Fitts, 1954). This results in a real number greater than 0 which resembles the index of difficulty of the Fitts' law $ID = \log_2 \frac{2D}{W}$. The technical factor represents the *precondition of target properties* (distances and widths).

$$Technical\ Factor = \sum_{i=1}^n \sum_{j=1}^m \frac{2d_i}{w_j} \quad (1)$$

10. $R \in \mathbb{R} \wedge 1 \leq R \leq 100$

The subjective rating (R) is the mean of all TLX scores which is a real number between 1 and 100 shown in Equation 2.

$$R = \frac{PD + MD + TD + E + P + F}{6} \quad (2)$$

11. $Experimental\ Factor \in \mathbb{R} \wedge Experimental\ Factor > 1$

The experimental factor (Equation 3) is defined as the product of the calculated selection ratio (S) depicted in Figure 1, and the subjective rating (R) which results in a real number greater than 1.

$$Experimental\ Factor = S \times R \quad (3)$$

12. $IDEA \in \mathbb{R} \wedge IDEA > 1$

The proposed index of difficulty for eye tracking applications (IDEA) is calculated by multiplying (a) the technical factor, and (b) the experimental factor offset by a constant value of 2 which results in a real number greater than 1 (Equation 4). We offset both technical and experimental factors by the constant value of 2 in case these factors are close to zero, therefore the calculated IDEA value starts from 1.x. Figure 2 shows the 3D visualization of IDEA and its factors.

$$IDEA = \log_2 \left(\underbrace{\left(\sum_{i=1}^n \sum_{j=1}^m \frac{2d_i}{w_j} \right)}_{Tec.\ Fac.} \times \underbrace{(S \times R)}_{Exp.\ Fac.} + 2 \right) \quad (4)$$

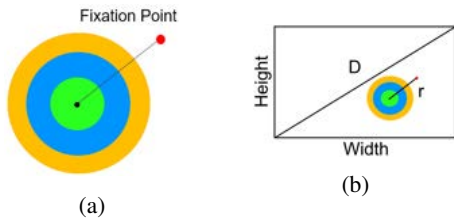


Figure 1: (a) overview of the dart-test to measure Euclidean distance, and (b) the concept of selection ratio regarding diameter of screen (D) and the selection distance (r).

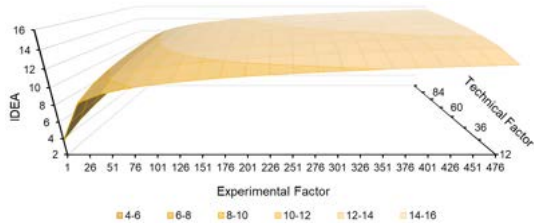


Figure 2: 3D illustration of the IDEA model.

4 Methodology

We conducted a three-part repeated measures user study to evaluate the efficacy of our proposed model with 33 participants (20 male, from 22 to 35 years old, $mean = 26.06$). Subjects were asked to navigate and select highlighted targets (see Figure 4) under two gaze-based interaction techniques: (1) dwell-time with 500 ms threshold, and (2) eye tracking using voice commands. Prior to running the experiments, participants were informed about the objectives of the user study, trained on each of the interaction techniques, and filled out a pre-test questionnaire. Before running the tests, the built-in eye tracking software was used to calibrate eye positions for each participant. The order of interaction techniques was randomly selected for each participant. Overall, the user studies took 8 minutes on average for a participant to finish. At the end of the two experiments measuring the Fitts' law parameters (Figure 4) participants were asked to fill out a post-test questionnaire consisting of the NASA TLX questionnaire.

4.1 Interaction Techniques

We applied two eye tracking techniques (single and multi-modal interactions) to evaluate the efficacy of our proposed model. We ran the mentioned interaction techniques on an Intel i7 PC with the 64-bit Windows operating system. Figure 3 illustrates the test setting and overview of the interaction techniques.

4.1.1 Dwell-time

The dwell-time method can select a target only by eye gaze fixations after a predefined threshold is reached. We defined the target selection threshold to 500 milliseconds which is in the typically accepted range of 300-1100 milliseconds (Špakov and Miniotas, 2004), and has been shown to be the best-suited threshold for the dwell-time method (MacKenzie, 2012), (Špakov and Miniotas, 2004). In other words, when a subject focuses for 0.5 seconds on a target it gets selected, and any gaze movement from the target boundaries prior to that threshold causes the restart of target selection process.

4.1.2 Eye Tracking with Voice recognition

The voice recognition method operates in two phases, (1) pointing phase using the eye tracker, and (2) selection phase using voice commands. Figure 3b illustrates the overview of these phases. The process of voice recognition was developed using the built-in Windows 10 speech recognition functionalities provided in the Microsoft .NET framework. We developed a C# application to capture user's activation command 'select' to activate a left mouse click.

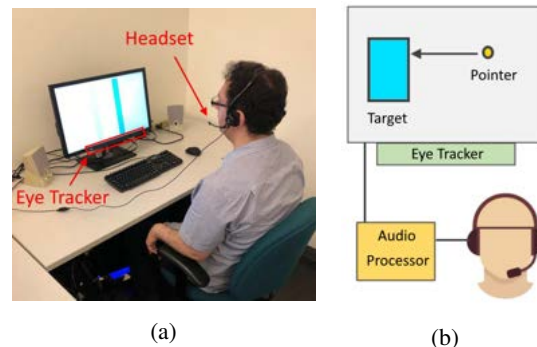


Figure 3: (a) test setting and equipment, and (b) system overview and workflow of both interaction techniques.

4.2 Interaction Modules

Eye Tracking: We used the Tobii 4C eye tracker to capture the mouse pointer position to enable users to interact with the system with their gaze. Moreover, we employed the Tobii SDK to obtain users' gaze locations (2D coordinates) on the screen and synchronize the mouse pointer to these coordinates in pixel. The eye tracking module for both interaction techniques was developed in C++ and integrated into the Tobii SDK as a new plug-in. The samples were recorded at a distance of 60 cm (24 in) from the eye tracker with a sampling rate of 90 Hz on a 24 inch

screen with the resolution of 1920×1080 pixels. The dwell-time technique relies solely on the eye tracking module.

Voice Processing: We used a headset microphone (Logitech H370) to capture the user’s voice commands in the presence of an artificial ambient noise around 50 dB played by stereo speakers (Figure 3a) to simulate a typical working office. The voice recognition module received the commands in real-time to be activated by the keyword ‘select’ to trigger a left mouse click.

4.3 Hypotheses

Based on the previous literature, which has demonstrated the effectiveness of Fitts’ law (Crossman and Goodeve, 1983), (Keele and Posner, 1968), (Card et al., 1978), and (MacKenzie and Buxton, 1992) and the NASA TLX questionnaire (Hart and Staveland, 1988), (Hart, 2006), and (Ruiz-Rabelo et al., 2015), we propose a compound simple-to-calculate mathematical model to measure the difficulty level of eye tracking applications independent from device type and technical capabilities during user studies. This model enables analysis of eye tracking applications based on user groups and their abilities to interact with an eye tracking device or interaction technique. Specifically, we hypothesize that:

1. When IDEA is higher on average for an interaction technique, the calculated *throughput* based on the Fitts’ law will be lower, and vice versa.
2. When IDEA is higher on average for an interaction technique, the calculated *movement time* based on the Fitts’ law will be higher as well, and vice versa.
3. When IDEA is higher on average for an interaction technique, the registered *error rates* will be higher as well, and vice versa.

4.4 User Study

The user study described above was used to analyze the mentioned eye tracking interaction techniques to evaluate the proposed IDEA model, according to well-established academic standards. We measured four parameters in our 3 part study: (1) distance to target, (2) throughput, (3) movement time, and (4) error rates. We developed a dart-like application (Figure 1a) to measure distance to target and used the application developed by Wobbrock *et al.* (Wobbrock et al., 2011) called the *FittsStudy* version 4.2.7 which includes two widths (96, 128), and three distances (256, 384, 512) pixels to record the rest of the measures.

4.4.1 Dart test

The stimulus consisted of three circles, green from 0 to 30 pixels, blue from 30 to 60 pixels, and red from 60 to 90 pixels in radius as illustrated in Figure 1a. Any selection outside of the dart colored circles is recorded as the fixed maximum range of 90 pixels for that selection. The purpose of this experiment was to measure the Euclidean distance to target to be applied in Equation 3 by calculating the fraction of distance (r) over diameter of screen (D) as shown earlier ($S = \frac{r+1}{D}$). Subjects were asked to select, as accurately as possible, the center of a dart target using both interaction methods. Since eye tracking has different accuracy in different regions of a screen (Feit et al., 2017), we calculated an average of five trials for each interaction techniques where the stimulus moved to different areas around the center of screen randomly. Each random trial started in two second intervals enabling subjects to change their gaze before recording the distance measures. A countdown timer with intervals of 100 ms was displayed from 5 to 0 to show the remaining time to subjects.

4.4.2 Ribbon-shaped test

The stimulus contains two vertical bars to be selected (clicked), each at a time shown in Figure 4a. The variation of distances and widths are chosen randomly by the *FittsStudy* (Wobbrock et al., 2011) application and the order of each interaction method for each participant were also chosen randomly.

4.4.3 Circle-shaped test

This test is the same as the ribbon-shaped test with circular-shaped targets illustrated in Figure 4b. This experiment measures two variations for throughput, (1) uni-variate endpoint deviation (SD_x) through one axis, and (2) bi-variate endpoint deviation ($SD_{x,y}$) through both axes which results in a better Fitts’ law model (Wobbrock et al., 2011). The stimulus contains equally-sized circles with different distances and widths to be selected (clicked), each at a time shown in Figure 4b. The variation of distances and widths are chosen randomly by the *FittsStudy* (Wobbrock et al., 2011) application and the order of each interaction method for each participant was also chosen randomly.

4.4.4 Workflow and parameters

The user study was conducted on a screen with the resolution of 1920×1080 pixels which results in a *diameter* (D) of 2203 pixels (rounded up). *Distances*



Figure 4: The *FittsStudy* application (Wobbrock et al., 2011). (a) Ribbon-shaped, and (b) Circle-shaped targets.

of 256, 384, and 512 pixels between targets were used with a target *width* of 96 and 128 pixels. The *distance to target* (r) for both interaction techniques was measured by the dart test application (Figure 1) based on the Euclidean distance in pixels. Lastly, the selection ratio was calculated by measured distance to target over the screen diameter ($S = \frac{r+1}{D}$). The constant value of 1 is added to the measured distance for selecting the target exactly in the middle which results in a distance to target of 0.

5 Results

The results of our experiments were analyzed using paired-sample t-tests with the JASP¹ software. Figure 5b shows the NASA TLX scores and the calculated average workload based on Equation 2 for both interaction techniques from the post-test questionnaire.

As per Equation 1, the technical factor, which is 42, was the same for both interaction techniques as it depends on distances and widths which were constant in our user study. This is the case in our experiments as both interaction techniques were evaluated on the same device with the same screen resolution and the same target distances and widths. However, the technical factor can be different for varying case scenarios. A paired-sample t-test was applied to check the effectiveness of the interaction technique on the experimental factor based on Equation 3 with ($t(32)=2.86, p < .05$). A significant difference was found between dwell-time ($M = 0.48, SE = 0.06$) and voice recognition ($M = 0.65, SE = 0.06$). Specifically, dwell-time had a lower experimental factor than the voice recognition technique. This suggests that the multiplication of users' selection ratio on screen (S) and their rating scores (R) is significantly lower for the dwell-time method than the voice recognition technique.

A paired-sample t-test was applied to check the effectiveness of interaction technique on the index of difficulty based on the Equation 4 shown in Figure 5a and Table 1. A significant difference

($t(32)=3.19, p < .05$) was found between dwell-time ($M = 4.17, SE = 0.15$) and voice recognition ($M = 4.66, SE = 0.15$). This suggests that the dwell-time method has a significantly lower IDEA value than the voice recognition technique. Dwell-time can thus be considered an easier eye tracking technique for our subjects comparing to the voice recognition.

	Dwell-Time	Voice Recog.
Distance	35.30	29.27
Selection ratio	0.016	0.014
Tech. factor	42	42
Exp. factor	0.48	0.65
IDEA	4.17	4.66

Table 1: Summary of IDEA calculations.

Dart Test: Paired-sample t-tests were performed to study the effect of interaction type on (1) distance to target, and (2) selection ratio. A significant difference ($t(32)=2.88, p < .05$) was found between dwell-time ($M = 35.30 \text{ pixels}, SE = 2.11 \text{ pixels}$) and voice recognition ($M = 29.27 \text{ pixels}, SE = 2.07 \text{ pixels}$) on distance to target (r) depicted in Figure 6a. This shows that the voice recognition technique has a higher target selection accuracy (lower distance to target) than the dwell-time method. This is likely the case because this method splits the pointing (eye tracking) and selecting (voice command) into different modalities.

A paired-sample t-test was also applied to check the effectiveness of interaction technique on selection ratio (S) depicted in Figure 6b. A significant difference ($t(32)=2.88, p < .05$) was found between dwell-time ($M = 0.016 \text{ pixels}, SE = 9.620e - 4 \text{ pixels}$) and voice recognition ($M = 0.014 \text{ pixels}, SE = 9.409e - 4 \text{ pixels}$). This means that users are more accurate to select targets using the voice recognition technique than the dwell-time.

Ribbon-shaped Test: Paired-sample t-tests were performed to study the effect of interaction type on (1) throughput, (2) movement time, and (3) error rate. There was a significant difference ($t(32)=5.96, p < .001$) of throughput for dwell-time ($M = 3.30 \text{ bits/sec}, SE = 0.36 \text{ bits/sec}$) and voice recognition ($M = 1.16 \text{ bits/sec}, SE = 0.09 \text{ bits/sec}$) as seen in Figure 6c. This confirms our hypothesis that a lower IDEA value for an interaction technique reflects a higher throughput.

A paired-sample t-test was applied to check the effectiveness of interaction technique on movement time depicted in Figure 6d. A significant difference ($t(32)=15.13, p < .001$) was found between dwell-time ($M = 0.60 \text{ sec}, SE = 0.01 \text{ sec}$) and voice recognition ($M = 2.01 \text{ sec}, SE = 0.08 \text{ sec}$). This confirms

¹<https://jasp-stats.org/>

our hypothesis that a lower IDEA value for an interaction technique reflects a lower movement time.

A paired-sample t-test was applied to check the effectiveness of interaction technique on error rate depicted in Figure 6e. A significant difference ($t(32)=4.84, p < .001$) was found between dwell-time ($M = 0.28 \text{ errors}, SE = 0.03 \text{ errors}$) and voice recognition ($M = 0.11 \text{ errors}, SE = 0.02 \text{ errors}$). This rejects our hypothesis that an interaction technique with a lower IDEA value should cause lower error rate. The cause of errors in eye tracking applications as explained above are mostly due to the Midas touch problem (Jacob, 1990). Thus as the dwell-time method relies on eye tracking solely, and selection is done based on fixation time there were higher error rates in this method than in the multi-modal voice method where selection is done based on a voice command.

Circle-shaped Test: Paired-sample t-tests were performed to study the effect of interaction type on (1) throughput with two variations, (2) movement time, and (3) error rate. For univariate throughput (illustrated in Figure 7a) there was a significant difference ($t(32)=7.98, p < .001$) between dwell-time ($M = 3.91 \text{ bits/sec}, SE = 0.31 \text{ bits/sec}$) and voice recognition ($M = 1.48 \text{ bits/sec}, SE = 0.09 \text{ bits/sec}$). This confirms our hypothesis that an interaction technique with a lower IDEA value should reach higher throughput.

A paired-sample t-test was applied to check the effectiveness of interaction technique on bivariate throughput illustrated in Figure 7b. A significant difference ($t(32)=7.19, p < .001$) was found between dwell-time ($M = 2.51 \text{ bits/sec}, SE = 0.22 \text{ bits/sec}$) and voice recognition ($M = 1.01 \text{ bits/sec}, SE = 0.06 \text{ bits/sec}$). This confirms our hypothesis that an interaction technique with a lower IDEA value should reach higher throughput.

A paired-sample t-test was applied to check the effectiveness of interaction technique on movement time illustrated in Figure 7c. A significant difference ($t(32)=11.31, p < .001$) was found between dwell-time ($M = 0.64 \text{ sec}, SE = 0.02 \text{ sec}$) and voice recognition ($M = 2.12 \text{ sec}, SE = 0.13 \text{ sec}$). This confirms our hypothesis that an interaction technique with a lower IDEA value should reach a lower movement time.

A paired-sample t-test was applied to check the effectiveness of interaction technique on error rate illustrated in Figure 7d. A significant difference ($t(32)=2.26, p < .05$) was found between dwell-time ($M = 0.23 \text{ errors}, SE = 0.03 \text{ errors}$) and voice recognition ($M = 0.13 \text{ errors}, SE = 0.02 \text{ errors}$). This rejects our hypothesis that an interaction technique with a lower IDEA value should have a lower error rate. As

described above, the cause of errors in eye tracking applications are mostly due to the Midas touch problem and thus the single mode method which requires gaze for both pointer movement and selection is more error prone.

6 Discussion

The results reflect the efficacy of our two-factor model to measure the performance of eye tracking applications independently of device type. We showed that our model can predict the difficulty of eye tracking applications solely based on Fitts' law and the NASA TLX scores. Further, we showed our model correlates with the standard measures (throughput and movement time) described by Fitts' law. The global pandemic of COVID-19 showed the importance of computer interactions from a safe distance without physical contact. Eye tracking applications, specifically the dwell-time method, are suitable candidates to enable safe interactions on shared and public devices for selection tasks. Therefore, our proposed model can be applied in pilot studies to measure the usability and performance of selection techniques to address different user groups such as children, users with disabilities, or elderly based on the experimental factor which reflects (a) subjective ratings (NASA TLX scores), and (b) perceived difficulty levels of interaction techniques or user groups. Although we only studied voice recognition as a multi-modal interaction technique, the results of the user studies confirm our first and second hypotheses regarding the correlation between *throughput* and *movement time* calculated by the Fitts' law and the predictions by our proposed model. However, eye tracking applications suffer from the Midas touch problem, and since the dwell-time method relies on eye gaze only, it reached higher error rates than the multi-modal selection technique using voice recognition with separate modalities for point and selection. The analysis of our results emphasizes the potential of our two-factor prediction model on two similar eye tracking interaction techniques. We hope, this experiment leads to more innovations of multi-dimensional compound models for gaze-based interactions.

7 Conclusion and Future Work

In this paper we proposed the Index of Difficulty for Eye Tracking Applications (IDEA) a compound two-factor model to measure the performance and

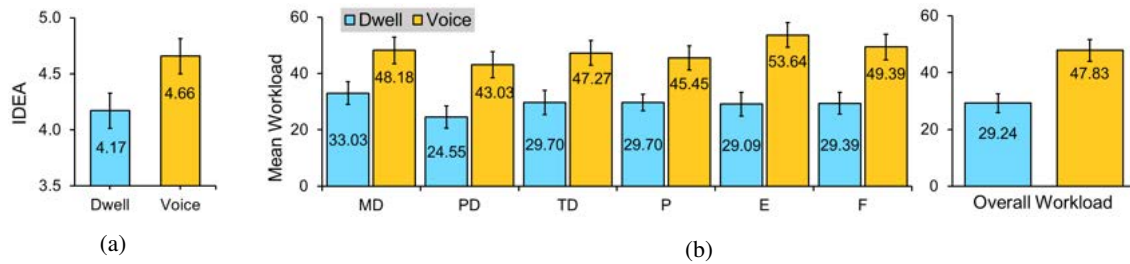


Figure 5: (a) shows index of difficulty for eye tracking applications (IDEA) based on Equation 4 for both interaction techniques ($p < .05$), and (b) illustrates the results of the NASA TLX scores. Error bars represent SE.

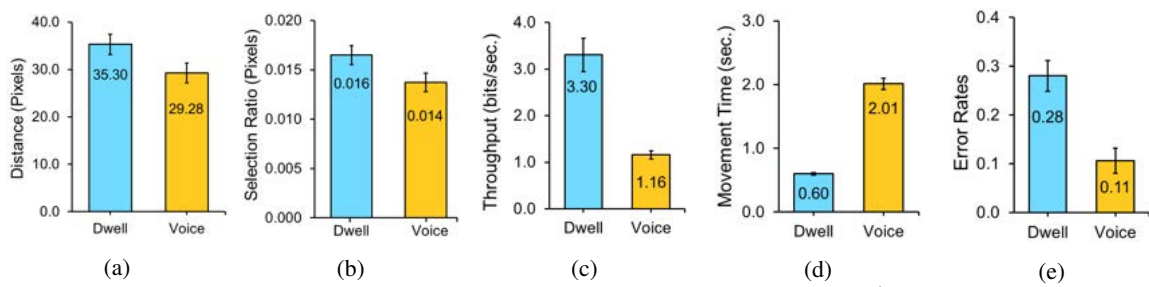


Figure 6: (a) Euclidean distance to target measure (r). (b) Calculated selection ratio ($S = \frac{r+1}{D}$) for both interaction techniques. (c) Throughput (TP), (d) Movement time (MT), and (e) Error rates (ER) for both interaction techniques of the ribbon-shaped test. Error bars represent SE. ($p < .05$ on (a) and (b) measures, $p < .001$ on (c), (d), and (e) measures).

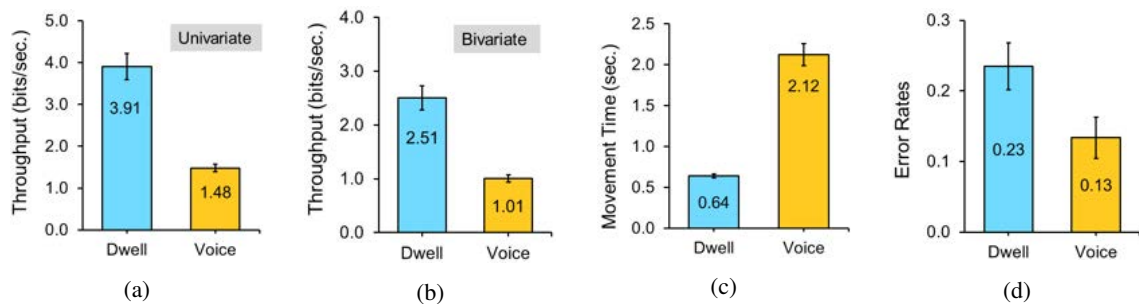


Figure 7: Calculated measures of the circle-shaped test. (a) Univariate throughput (TP) ($p < .001$), (b) Bivariate TP ($p < .001$), (c) Movement time (MT) ($p < .001$), and (d) Error rates for both interaction techniques ($p < .05$). Error bars represent SE.

usability of selection techniques based on calculations of Fitts' law and the results of a NASA TLX questionnaire. As emerging interaction techniques are required to cope with emerging users' demands, the need for more complex models to compare different techniques requires more attention. We present our model to assess the efficacy of eye tracking applications for pilot studies with different user groups such as children, users with disabilities, or elderly. Our configurable model can be applied for case scenarios as well as to discriminate specific interaction techniques. In addition, we presented an in-depth analysis of the dwell-time method based on the Fitts' law measures. Although our model was developed to address eye tracking interactions, it can be applied on any selection technique to measure difficulty levels based on test specifications (target size and distance) and users' subjective ratings. Further, we showed eye tracking techniques can be compared without analysis of technical raw data such as fixation duration time and blink rates. These enable researchers to run pilot studies independently from device type. We predict the transition from conventional interaction techniques, such as keyboard and mouse, to contact-free techniques from a safe distance caused by the latest global outbreak of viral infections, especially for equipment in healthcare sectors, and shared public devices. IDEA enables researchers to run user studies based on video eye tracking techniques via remote webcams to comply with restrictions caused by viral diseases which limit the physical presence of participants in laboratories or attaching sensory equipment to record users' feedback. We plan on applying our proposed model on AR and VR headsets with internal eye trackers to study usability of target selection in our future work.

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REFERENCES

- Abdulin, E. and Komogortsev, O. (2015). User eye fatigue detection via eye movement behavior. In *Proceedings of the 33rd annual ACM conference extended abstracts on human factors in computing systems*, pages 1265–1270. ACM.
- Borghini, G., Vecchiato, G., Toppi, J., Astolfi, L., Maglione, A., Isabella, R., Caltagirone, C., Kong, W., Wei, D., Zhou, Z., et al. (2012). Assessment of mental fatigue during car driving by using high resolution eeg activity and neurophysiologic indices. In *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pages 6442–6445. IEEE.
- Card, S. K., English, W. K., and Burr, B. J. (1978). Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a crt. *Ergonomics*, 21(8):601–613.
- Crossman, E. and Goodeve, P. (1983). Feedback control of hand-movement and fitts' law. *The Quarterly Journal of Experimental Psychology Section A*, 35(2):251–278.
- Feit, A. M., Williams, S., Toledo, A., Paradiso, A., Kulkarni, H., Kane, S., and Morris, M. R. (2017). Toward everyday gaze input: Accuracy and precision of eye tracking and implications for design. In *Proceedings of the 2017 Chi conference on human factors in computing systems*, pages 1118–1130. ACM.
- Felton, E. A., Williams, J. C., Vanderheiden, G. C., and Radwin, R. G. (2012). Mental workload during brain-computer interface training. *Ergonomics*, 55(5):526–537.
- Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of experimental psychology*, 47(6):381.
- Gori, J., Rioul, O., Guiard, Y., and Beaudouin-Lafon, M. (2017). One fitts' law, two metrics. In *IFIP Conference on Human-Computer Interaction*, pages 525–533. Springer.
- Group, N. H. P. R. (1986). Nasa task load index (tlx) paper and pencil package.
- Hansen, J. P., Rajanna, V., MacKenzie, I. S., and Bækgaard, P. (2018). A fitts' law study of click and dwell interaction by gaze, head and mouse with a head-mounted display. In *Proceedings of the Workshop on Communication by Gaze Interaction*, pages 1–5.
- Hart, S. G. (2006). Nasa-task load index (nasa-tlx); 20 years later. In *Proceedings of the human factors and ergonomics society annual meeting*, volume 50, pages 904–908. Sage publications Sage CA: Los Angeles, CA.
- Hart, S. G. and Staveland, L. E. (1988). Development of nasa-tlx (task load index): Results of empirical and theoretical research. In *Advances in psychology*, volume 52, pages 139–183. Elsevier.
- Isomoto, T., Ando, T., Shizuki, B., and Takahashi, S. (2018). Dwell time reduction technique using fitts' law for gaze-based target acquisition. In *Proceedings of the 2018 ACM Symposium on*

- Eye Tracking Research & Applications*, pages 1–7.
- Jacob, R. J. K. (1990). What you look at is what you get: Eye movement-based interaction techniques. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '90, pages 11–18, New York, NY, USA. ACM.
- Keele, S. W. and Posner, M. I. (1968). Processing of visual feedback in rapid movements. *Journal of experimental psychology*, 77(1):155.
- Kim, H., Kwon, S., Heo, J., Lee, H., and Chung, M. K. (2014). The effect of touch-key size on the usability of in-vehicle information systems and driving safety during simulated driving. *Applied ergonomics*, 45(3):379–388.
- Komogortsev, O. V., Gobert, D. V., Jayarathna, S., Koh, D. H., and Gowda, S. M. (2010). Standardization of automated analyses of oculomotor fixation and saccadic behaviors. *IEEE Transactions on Biomedical Engineering*, 57(11):2635–2645.
- Lanthier, S., Risko, E., Smilek, D., and Kingstone, A. (2013). Measuring the separate effects of practice and fatigue on eye movements during visual search. In *Proceedings of the Annual Meeting of the Cognitive Science Society*, volume 35.
- MacKenzie, I. S. (1989). A note on the information-theoretic basis for fitts' law. *Journal of motor behavior*, 21(3):323–330.
- MacKenzie, I. S. (2012). Evaluating eye tracking systems for computer input. In *Gaze interaction and applications of eye tracking: Advances in assistive technologies*, pages 205–225. IGI Global.
- MacKenzie, I. S. and Buxton, W. (1992). Extending fitts' law to two-dimensional tasks. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 219–226.
- Parisay, M., Poullis, C., and Kersten-Oertel, M. (2020). Felix: Fixation-based eye fatigue load index a multi-factor measure for gaze-based interactions. In *2020 13th International Conference on Human System Interaction (HSI)*, pages 74–81.
- Pi, J. and Shi, B. E. (2017). Probabilistic adjustment of dwell time for eye typing. In *2017 10th International Conference on Human System Interactions (HSI)*, pages 251–257. IEEE.
- Ruiz-Rabelo, J. F., Navarro-Rodriguez, E., Di-Stasi, L. L., Diaz-Jimenez, N., Cabrera-Bermon, J., Diaz-Iglesias, C., Gomez-Alvarez, M., and Briceño-Delgado, J. (2015). Validation of the nasa-tlx score in ongoing assessment of mental workload during a laparoscopic learning curve in bariatric surgery. *Obesity surgery*, 25(12):2451–2456.
- Schenk, S., Dreiser, M., Rigoll, G., and Dorr, M. (2017). Gazeeverywhere: enabling gaze-only user interaction on an unmodified desktop pc in everyday scenarios. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, pages 3034–3044.
- Špakov, O. and Miniotas, D. (2004). On-line adjustment of dwell time for target selection by gaze. In *Proceedings of the third Nordic conference on Human-computer interaction*, pages 203–206. ACM.
- Velichkovsky, B. B., Rumyantsev, M. A., and Morozov, M. A. (2014). New solution to the midas touch problem: Identification of visual commands via extraction of focal fixations. *Procedia Computer Science*, 39:75–82.
- Velloso, E., Wirth, M., Weichel, C., Esteves, A., and Gellersen, H. (2016). Ambigaze: Direct control of ambient devices by gaze. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, DIS '16, pages 812–817, New York, NY, USA. ACM.
- Wobbrock, J. O., Shinohara, K., and Jansen, A. (2011). The effects of task dimensionality, endpoint deviation, throughput calculation, and experiment design on pointing measures and models. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1639–1648. ACM.
- Zagermann, J., Pfeil, U., and Reiterer, H. (2016). Measuring cognitive load using eye tracking technology in visual computing. In *Proceedings of the Sixth Workshop on Beyond Time and Errors on Novel Evaluation Methods for Visualization*, BELIV '16, pages 78–85, New York, NY, USA. ACM.
- Zheng, B., Jiang, X., Tien, G., Meneghetti, A., Panton, O. N. M., and Atkins, M. S. (2012). Workload assessment of surgeons: correlation between nasa tlx and blinks. *Surgical endoscopy*, 26(10):2746–2750.