Eye-hand movement in 3D displays: A structural equation modeling approach

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Abstract. Eye-hand movements are two important parameters to evaluate the User Experience (UX) in the stereoscopic display (3D). The current study utilized structural equation modeling (SEM) to derive the causal relationship between parallax, index of difficulty (ID), eye movement, hand movement, eye index performance (IP eye), and hand index performance (IP hand) simultaneously. 10 participants voluntarily participated in the current study and they were asked to perform a multi-directional Fitts’ Law task in the projection-based stereoscopic display. The results indicated that parallax had significant effects on eye movement time and hand movement time. In addition, ID was found to have significant effects on eye movement time and hand movement time. Interestingly, parallax and ID were found to have significant effects on IP eye, however, no significant effects were found on IP hand. These findings could be very beneficial for UX researchers and projection-based stereoscopic display developers especially in terms of evaluating UX of an interface.

1. Introduction

Today, User Experience (UX) plays an important role in modern technology. It is an attempt to encompass all aspects of the experiences (perception, reaction, behavior) of a user during the interaction with a system [1]. The term UX is concerned less with technology, product design, or an interface and more with the aid of a digital device, creating a sensible and meaningful experience for the user [1]. UX has been a major concern in one of the hottest topics in modern technology: virtual reality.

Virtual reality has been developed significantly over the past 10 years [2]. It is designed to make possible a human sensorimotor and cognitive activity in a digitally created artificial world, which can be imaginary, symbolic, or a simulation of certain aspects of the real world [3]. Big companies, such as Alibaba, have started to utilize virtual reality in their commercial business. One of the most commonly used platforms to create virtual reality is a projection-based stereoscopic display.

The purpose of the current study was to analyze the causal relationship between parallax, index of difficulty (ID), eye movement time, hand movement time, index of eye performance (IP eye), and index of hand performance (IP eye) by utilizing structural equation modeling. Structural equation modeling (SEM) is a very powerful statistical analysis to derive the interrelationship among selected variables [8]-[14]. The finding of this study could be very beneficial for UX researchers and projection-based stereoscopic display developers especially in terms of evaluating UX of an interface.

Figure 1 represents the proposed 9 hypotheses in the current study. Parallax was hypothesized had
significant effects on eye movement time (H1) \[6\], IP eye (H2), IP hand (H3), and hand movement time (H4). In addition, ID was hypothesized had significant effects on eye movement time (H5) \[6\], IP eye (H6), IP hand (H7), and hand movement time (H8). Finally, IP eye was hypothesized had a significant effect on IP hand. H1 and H5 were proven and the details had been published in our previous study \[6\].

**Figure 1.** The SEM hypothesis constructs for eye-hand movements in the projection-based stereoscopic display.

2. Methodology

2.1. Participants
10 voluntary participants (seven males and three females) participated in the current study. All of them were graduate students at the National Taiwan University of Science and Technology (NTUST). All participants had normal or corrected to normal visual acuity with 1.0 in decimal units. In addition, all participants were right-handed. They were required to fill the consent form and pass the capability to perceive the object in the projection-based stereoscopic display.

2.2. Apparatus
Tobii X2-60 remote eye-tracking system was utilized to record the eye movements. The sampling rate was set to 60 Hz. As recommended by Tobii, the fixation filter Tobii Studio version 3.3.2 was utilized for calibration, testing, and data analysis. Raw eye fixation data collected from Tobii Studio was filtered using an I-VT fixation filter with 30 degrees/second velocity threshold.

Participants were instructed to wear a pair of View Sonic 3D glasses PDF-250 to perceive the 3D in the projection-based stereoscopic display. The 3D glasses PDF-250 were integrated with a 3D View Sonic (PJ6 6251) projector and a 3D vision IR Emitter NVIDIA. The IR Emitter NVIDIA was placed in a certain distance from Tobii X2-60 to eliminate the shuttering effect so the signal of 3D emitter NVIDIA and the infrared from Tobii X2-60 would not affect the eye movement registration \[6-8\]. The width and length of the screen were 108 x 143 cm respectively. Finally, a Logitech C-920 webcam was utilized to record the eye movement data from the screen display.

The distance between the screen and the participants was 181 cm. The 3D View Sonic (PJ6 6251) projector was placed 89 in front of the screen and the Tobii eye tracker was placed 60cm in front of the
participants. All task was performed in a dark room (3.6x3.2x2.5m) covered by black curtains to prevent the light and create a sophisticated 3D environment.

2.3. Independent variables
Following our previous studies [4]-[8], parallax and ID were selected as independent variables. Six levels of ID and three levels of parallax [4]-[8] were utilized in the current study. Table 1 shows the details of the ID and Figure 2 shows the details of the parallax [4]-[8].

![Figure 2. Three different levels of parallax in the current study [4]-[8].](image)

| Distance (unity unit) | Width (unity unit) | ID (bits) | Task Precision Level |
|----------------------|--------------------|-----------|---------------------|
| 40                   | 3.3                | 3.7       | Low                 |
| 40                   | 2.3                | 4.2       | Medium              |
| 40                   | 0.6                | 6.1       | High                |
| 20                   | 3.3                | 2.8       | Low                 |
| 20                   | 2.3                | 3.3       | Low                 |
| 20                   | 0.6                | 5.1       | Medium              |

2.4. Dependent variables
There were four dependent variables in the current study: (1) eye movement time, (2) hand movement time, (3) IP eye, and (4) IP hand. Eye movement time was defined as an elapsed time from the eye fixation point on the origin to the fixation point of the next target [4]-[8]. Hand movement time was defined as an elapsed time from the hand point on the origin to the target [4]. IP eye and IP hand were defined as the ID/MT. The details of each calculation had been published in our previous study [4].

2.5. Experimental procedures
Participants were required to complete the calibration process to ensure Tobii X2-60 could detect the participant’s eye gaze movement. The regular Tobii calibration setting with five red dots was utilized to capture the participant’s eye gaze binocularly. Participants needed to pass this test in order to continue
the next test. In addition, they were also instructed to fill the consent form which conducted according to the ethical guidelines of the National Taiwan University Research Ethics Committee.

Multi-directional Fitts’ Law task was used as a task in this study [15]-[17]. Participants were instructed to click the virtual red ball as accurately as fast as possible [4]-[8]. Unity 3D platform version 4.3.4 was utilized to create the virtual 3D ball. Figure 3 shows the sequence of multi-directional Fitts’ Law task based on ISO 9241-9 [4]-[8]. Finally, the data were analyzed using our previous algorithm and the detailed of the algorithm has been presented in our previous study [4].

![Figure 3](image)

**Figure 3.** The sequence of multi-directional Fitts’ Law task based on ISO 9241-9 [4]-[8].

2.6. **Structural equation modeling**

Figure 1 shows that our SEM had six variables, including two exogenous variables (parallax and ID) and four endogenous variables (eye movement time, hand movement time, IP eye, and IP hand).

SEM was derived by utilizing Amos 22 with the Maximum Likelihood estimation approach. Four sets of tests were used to measure the difference between the observed data and the hypothesized model: full model test, incremental fit indices, the goodness of fit index, and badness of fit index [8]. Since there were three different levels of parallax, six different levels of ID, and tested on 10 participants, a total of 180 data was analyzed. The bootstrapping technique with the bias-corrected 95% confidence interval percentiles was conducted since the sample sized was under 250 [8]. Finally, a two-tailed Pearson-correlation with an alpha value of 0.05 was also conducted to double-check the beta coefficient of each path in the proposed model (Table 2).

|          | Mean | SD  | Range | (1) | (2)    | (3)    | (4)    | (5)    | (6) |
|----------|------|-----|-------|-----|--------|--------|--------|--------|-----|
| Parallax |      |     |       |     |        |        |        |        |     |
| ID       |      |     |       |     |        |        |        |        |     |
| HMT      | 1.587| 0.561| 3.92  | 0.172*| 0.394**| 1      |        |        |     |
| EMT      | 0.165| 0.075| 0.51  | 0.156*| 0.371**| 0.812**| 1      |        |     |
| IPH      | 2.805| 0.785| 4.78  | -0.141| 0.324**| -0.412**| -0.352**| 1      |     |
| IPE      | 27.966| 9.521| 49.27 | -0.167*| 0.320**| -0.589**| -0.598*| 0.751**| 1   |

3. **Results & Discussion Conclusions**

The initial SEM of eye-hand movements in the projection-based stereoscopic display is presented in Figure 4. Based on this figure, two paths were found not significant. Therefore, a revised model was derived by removing these two paths: Parallax-IP Hand and ID-IP Hand. The revised SEM of eye-hand movements in the projection-based stereoscopic display is presented in Figure 5 and the parameter estimates and goodness of fit are presented in Table 3.
The SEM approach indicated that parallax had significant effects on eye movement time ($\beta$: 0.16), hand movement time ($\beta$: 0.17), IP eye ($\beta$: -0.17), however, no significant effect was found on IP hand ($\beta$: -0.02). Higher parallax was found to lead to longer eye movement time, hand movement time, and lower IP eye. Similarly, ID was found had a significant effect on eye movement time ($\beta$: 0.36), hand movement time ($\beta$: 0.39), IP eye ($\beta$: 0.32), however, no significant effect was found on IP hand ($\beta$: 0.10). The higher ID was found to lead to longer eye movement time and hand movement time. Interestingly, the effect of parallax on hand movement time was found slightly higher than on eye movement time, however, the effect of ID on hand movement time was found higher than on eye movement time. Future research to investigate further about this phenomenon through a more comprehensive eye-hand coordination study would be very valuable.

**Figure 4.** The initial SEM of eye-hand movements in the projection-based stereoscopic display.

**Figure 5.** The revised SEM of eye-hand movements in the projection-based stereoscopic display.
Table 3. The goodness of fit measures of the SEM.

| The goodness of fit measures of the SEM | Parameter Estimates | Suggested cut-off | Recommended by |
|----------------------------------------|---------------------|-------------------|----------------|
| p-value for Chi-square (x²)            | 0.238               | > 0.05            | [8]-[14]       |
| Chi-square statistic (x²)              | 4.229               |                   |                |
| Degree of freedom                      | 3                   |                   |                |
| Normed chi-square                      | 1.410               | < 2.0             | [8]-[14]       |

**Incremental Fit Indicates**

| Normed Fit Index (NFI)                  | 0.994               | > 0.95            | [8]-[14]       |
| Tucker Lewis Index (TLI)                | 0.990               | > 0.95            | [8]-[14]       |
| Comparative Fit Index (CFI)             | 0.998               | > 0.96            | [8]-[14]       |

**Goodness-of-fit index**

| Goodness of Fit Index (GFI)             | 0.992               | > 0.95            | [8]-[14]       |
| Adjusted Goodness of Fit Index (AGFI)   | 0.946               | > 0.90            | [8]-[14]       |

**Badness-of-fit index**

| Root Mean Square Error of Approximation (RMSEA) | 0.048 | < 0.07 | [8]-[14] |

Interestingly, we found that the effect of ID on eye movement time (β: 0.36) was higher compared with the effect of parallax on eye movement time (β: 0.16). Similarly, the effect of ID was found to be higher on hand movement time (β: 0.39) compare with the effect of parallax (β: 0.17). Future research would be very worth to investigate this phenomenon.

4. Conclusions

Virtual reality has been a key parameter in today’s UX [18]-[24]. The current study utilized structural equation modeling (SEM) to derive the causal relationship between parallax, index of difficulty (ID), eye-hand movements, eye index performance (IP eye), and hand index performance (IP hand) simultaneously. Seven males and three females voluntarily participated in the current study and they were asked to perform multi-directional Fitts’ Law task in the projection-based stereoscopic display. The results indicated that parallax had significant effects on eye movement time and hand movement time. In addition, ID was found to have significant effects on eye movement time and hand movement time. Interestingly, parallax and ID were found to have significant effects on IP eye, however, no significant effects were found on IP hand. In addition, the effect of parallax on hand movement time was found slightly higher than on eye movement time, however, the effect of ID on hand movement time was found higher than on eye movement time. These findings could be very beneficial for UX researchers [25] and projection-based stereoscopic display’s developers especially in terms of evaluating UX of an interface.

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