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International Journal of Human–Computer Interaction

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hihc20

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To cite this article: Reza Kazemi, Chae Heon Lim, Min Chul Cha & Seul Chan Lee (06 Nov 2023): Evaluation of Drag-and-Drop Task in Virtual Environment: Effects of Target Size and Movement Distance on Performances and Workload, International Journal of Human–Computer Interaction, DOI: 10.1080/10447318.2023.2276531

To link to this article: https://doi.org/10.1080/10447318.2023.2276531

Published online: 06 Nov 2023.

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https://doi.org/10.1080/10447318.2023.2276531

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Evaluation of Drag-and-Drop Task in Virtual Environment: Effects of Target Size and Movement Distance on Performances and Workload

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ABSTRACT

This study investigated the effects of the target size and movement distance on user performance and workload in a virtual reality (VR) environment. In a repeated-measures laboratory study, 36 participants (18 male and 18 female) performed the drag-and-drop task as a standard human–computer interaction (HCI) task with different target sizes (1, 1.5, 2, 2.5, and 3 cm) and movement distances (5, 9, 13, 17, and 20 cm). Task completion time (TCT), error rate, and movement time (MT) were measured as performance indices, whereas physical load and effort were assessed as workload indices. The results demonstrated that the target size and movement distance significantly affected all performance measures and workload indices. Large target sizes produced better performance and lower workloads; however, large movement distances decreased performance and increased workload. However, sex had no significant effect on the performance or workload during the drag-and-drop tasks. The best target sizes were 2.5 and 3 cm, and the worst size was 1 cm. The best movement distances were 5 and 9 cm, and the worst distance was 20 cm. The results of this study can provide useful reference information for developing VR technology based on human factors and demonstrate that additional basic research is required to reflect the distinctive features of VR in the future.

KEYWORDS

Virtual reality; drag-and-drop task; target size; movement distance; task performance; workload

1. Introduction

Virtual reality (VR) technology has drawn attention because it offers a distinct form of input interface that enables three-dimensional virtual environments and variable fidelity in human–computer interaction (HCI) (Chang et al., 2020; Chen et al., 2021; Madathil & Greenstein, 2017). VR is currently used in various fields including design, engineering, manufacturing, healthcare, aerospace, military, training, and gaming (Elias et al., 2019; Sardar et al., 2023). However, this new technology induces unwanted effects on users, including decreased performance, cognitive workload, cybersickness, and stress, which may result from the design and usability of the interfaces (Chen et al., 2021; Kim et al., 2018; Ko et al., 2013; Kumar et al., 2023; Lavoie et al., 2021; Lim & Lee, 2023; Preece et al., 2015; Ramaseri Chandra et al., 2022). Therefore, it is crucial to study the effects of VR interface design on human factors (Kazemi & Lee, 2023).

Previous studies on HCI have demonstrated that interface design aligns with Fitts' law, which is the most common mathematical model illustrating the interplay between target size, movement distance, and performance (Wright & Lee, 2013). This formulation illustrates that as the movement distance (D) to reach a target increases, the movement time (MT) also increases, whereas MT decreases as the target size (W) increases. This can be expressed as $MT = a + b \log2(2D/W)$, where a and b are empirical constants that denote the intercept and slope of the regression line, respectively. The term, log2 (2D/W), represents the difficulty (ID). This equation predicts that when the 2D/W ratio remains constant, the MT will remain unaffected. Thus, MT and ID have a direct proportional relationship, sharing the same value for various combinations of the movement parameters D and W (Fitts, 1954).

Based on Fitts' law, previous studies on user interfaces in conventional HCI, whether involving desktop computers or touchscreen devices, have demonstrated that specific interface design elements, including the target size and movement distance, are crucial in influencing user performance (Lee et al., 2018, 2019; Tao et al., 2021). For instance, Alhassan et al. (2021) discovered that the speed and mistake rate often improved with an increase in the target size when people performed stationary tasks with personal digital assistants. Wright and Lee (2013) demonstrated that the target and movement distances are the main factors affecting the performance of discrete and serial (continuous) target movements in HCI.

Some of previous studies revealed although there are some similarities between the kinematics of pointing motions in real and VR environments, it is challenging to directly transfer a result from the real world to a virtual world because the input and output modes of interaction in

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virtual environments cannot be considered the same as the mouse-controlled modes (Borish et al., 2020; Zhou et al., 2023). Furthermore, depth perception has been identified as a contributing factor to this challenge in the VR context (Cha & Myung, 2013; Renner et al., 2014; Triantafyllidis & Li, 2021). Therefore, some studies have examined the correlation between Fitts' law and performance in VR environments and customized Fitts' law (Ha & Woo, 2010; Mutasim et al., 2021; Pai et al., 2019). Clark et al. (2020) observed that the target size, radial distance, and inclination angle significantly affected the MT in 3D VR, they developed a new model for the VR environment. Gillan et al. (1990) discovered that Fitts' law behaved uniquely for pointing and dragging tasks. Pointing time correlated with distance but not text width in point-drags, whereas point-drag times were associated with text height. Batmaz and Stuerzlinger (2021) demonstrated that in a VR environment, pitch in auditory error feedback also affects performance on the Fitts' task.

Several previous studies have examined the correlation between button size and performance in VR environments. Chen and Or (2017) demonstrated that, in pointing tasks, large targets result in quick MTs and reduced error rates, whereas large targets result in high error rates in dragging and dropping activities. Another VR study showed that large buttons required a significantly shorter task completion time (TCT) than small buttons, without significant differences in the number of errors (Hussain et al., 2023). According to Borish et al. (2020), compared to long-distance movements, miniscule distance movements have higher variability, slower movements, and higher rates of mistakes. According to Park's et al. (2020) experimental study, the best button size and spacing levels in virtual environments were 25 and 5–9 mm, respectively, for manually touching and pushing buttons. Additionally, Zhou et al. (2023) suggested that under a clicking distance of 45 cm in a VR environment, the size of the buttons in the user's field of vision should be greater than 2.4°, and the spacing between adjacent buttons should be greater than 1.4°. Previous studies have mostly focused on touching and pointing tasks in terms of the target size and target movement distance. However, the drag-and-drop task, a popular interaction task, has not been extensively studied.

Although Fitts' law and its impact on performance in VR environments have been frequently studied, the connection between the perceived mental workload, a key usability factor, and Fitts' law remains unclear and requires more attention within the context of VR (Chao et al., 2017; Jost et al., 2020). According to one study, the target size has a substantial impact on the physical demand and TCT (Kia et al., 2021). Choe et al. (2021) and Kim et al. (2018) also demonstrated that the scores for other perceived factors in VR, such as motion sickness, which correlate with mental workload, are significantly affected by the size of the buttons. Specifically, the level of motion sickness was higher when small buttons were used.

However, previous studies related to Fitts' law in VR neglected the role of sex. Empirical research has shown that sex is crucial in HCI because of differences in thinking styles, perceptions, behaviors, and attitudes (Stumpf et al., 2020). Several studies have also shown differences in spatial perception between men and women; for example, males outperform females in mental rotation tasks (Halpern, 2004). Other studies have shown that women, unlike men, often underestimate the duration of short time intervals (up to 20 s) (Halpern, 2004). Therefore, sex should be considered in HCI studies to generalize the results to all users.

To address these research gaps, the first aim of this study was to investigate the impact of key parameters in Fitts' law, specifically the target size and movement distance, on task performance measures and workload during the execution of a drag-and-drop task within a VR environment. The second aim of this study was to examine the potential differences in the effects of target size and movement distance on task performance measures and workload between women and men.

2. Method

2.1. Participants

A total of 36 participants (18 male and 18 female) voluntarily participated in the study. Their ages ranged from 20 to 30 years (mean = 25 years, SD = 2.2). All 30 participants were right-handed and had either normal or corrected-to-normal vision along with healthy color vision. Eight participants had no experience with VR devices, whereas the remaining participants had at least one experience.

2.2. Tasks

In this study, the drag-and-drop task was designed based on the multidirectional test described by the ISO (2012) and Pai et al. (2019) in which participants were instructed to manipulate the pointer, drag a generated red circle with a diameter of W (representing the target size), and subsequently release it onto a randomly positioned blue circle (serving as the destination) (see Figure 1). If the center of the red circle (pointer) was within the blue circle, the trial was considered successful, causing the blue circle to fade away. Subsequently, the blue circle was transformed into a red circle (starting point), and the next circle counterclockwise from the previous red circle became the new blue destination. The task was completed through ray-cast pointing, and the Distance A (movement distance) from the start to the goal remained constant, although the destination point varied during the test. If the participant was unsuccessful in relocating to the red circle, it returned to the starting point. Eleven circles were situated along the edge of the central circle, and one starting point was randomly chosen. The task concluded after the participants completed 11 trials around the circle.

2.3. Experimental design

The user experiment is based on a two-way mixed-factorial design. The within-subject variables in the drag-and-drop task were target size (1, 1.5, 2, 2.5, and 3 cm) and movement

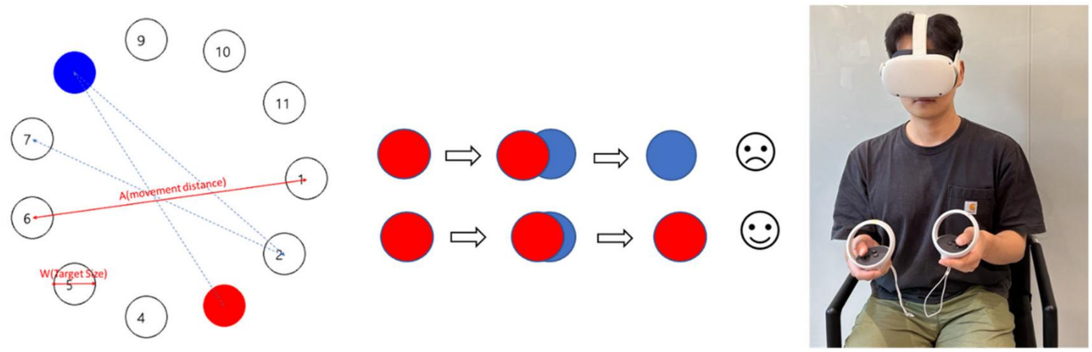

Figure 1. Drag-and-drop task conditions in VR environment.

distance (5, 9, 13, 17, and 20 cm). Furthermore, sex was considered as a between-subjects variable. The order of presentation of the target size and the distance moved was randomized.

Dependent variables included task performance measures (total completion time, grab error, drop error, error ratio, and success ratio) and workload (physical load and effort). The total TCT refers to the total time taken by participants to complete the entire set of 11 trials. Any errors such as clicking outside the red circles or making dragging errors such as dropping during the dragging process were categorized as grab errors. Any error that resulted in the red circle not being accurately positioned on the blue circle and not fully covering it was classified as a drop error (Figure 1). The drop error ratio is equal to the drop error/total error (grab + drop), and the grab error ratio is calculated as the number of grab errors/total error (grab + drop). Success rate refers to the number of successful trials in the first or total trials (11). Perceived workload was measured to understand subjective user evaluations of task performance using the NASA Task Load Index (NASA-TLX). This was assessed using two metrics adopted from the NASA-TLX questionnaire: physical demand (How much physical activity was required?) (Was the task easy or demanding, slack or strenuous?) and effort (How hard did you work (mentally and physically) to accomplish your level of performance?). Each item was answered using the 10-point NASA-TLX, which is a widely used subjective workload assessment tool for various HCI tasks (Ramkumar et al., 2017). We selected only two NASA-TLX workload subscales to assess workload because this task appears to be more challenging in terms of physical demand, and this hypothesis is consistent with the results of the study by Kia et al. (2021).

2.4. Apparatus

The VR head-mounted display (HMD) used for the experiment was a Quest2 (Meta, California). The device weighed 503 g, had a high resolution of 1440 × 1600 pixels for each eye, and offered a 89° field of view. Two-handed joysticks are available for users to interact with VR content. A desktop computer (Intel(R) Core i7-10700 CPU at 2.90 GHz, NVIDIA GeForce GTX 1660 Super, 16 GB of memory) was used to generate the VR environments. The drag-and-drop task was performed in Python. The software was run on a PC and connected to the PC using Quest Link, which is the PC connection feature in Quest2. The distance to the screen in the VR HMD was 1 m, and the screen size was 40 inches.

2.5. Procedures

The experiments were conducted in a university laboratory. The participants were free to modify their chair height and position to accommodate the experimental setting, depending on their preferences. Participants received basic information regarding the experiment and provided informed consent. Once the participants agreed to participate, the researcher explained the study background and protocol and asked demographic questions about their age, sex, VR experience, dominant hand, visual ability, and auditory ability. The participants then wore the VR HMD and practiced for approximately 5 min to familiarize themselves with the VR controller operation. Twenty-five conditions depending on five different target sizes and five different target distances were randomly presented. Before starting the experiment, the participants were seated in an experimental chair and re-centered on the VR. Before starting the main task, the participants performed VR re-centering for height adjustment and verbally completed the NASA-TLX physical and effort questionnaires immediately after each condition. This study was approved by the institutional review board (IRB) of the university.

2.6. Data analysis

Raw data for every 11 trials per participant, such as task start time, end time, success or failure, and type of error, were automatically gathered and recorded in an Excel file. Subsequently, the dependent variables, such as the number of grab-and-drop errors, success rate, error ratio, mean MT, and TCT (sum of time to complete 11 trials in a combination), were calculated for all combinations per participant. The data normality of the performance measures and workload were examined using the Shapiro–Wilk test. Normality of the measurements was verified ($p > 0.05$). In cases where the assumption of sphericity was violated, the Greenhouse–Geisser correction method was applied.

A repeated-measures analysis of variance (ANOVA) was performed to examine the effects of the target size, movement distance, and sex on the results. Bonferroni post hoc comparison tests were used to evaluate pairwise comparisons of distances and target sizes. Statistical analyses were performed using IBM SPSS version 27 IBM SPSS Statistics, Armonk, NY.

3. Results

This study aimed to examine the influence of target size, movement distance, and sex on HCI task performance and workload in an immersive VR environment, specifically in relation to Fitts' law. In the following sections, the results comprehensively show the effects of the target size and movement distance on human performance measures and workload, as well as the nuanced differentiation between men and women in this context.

3.1. Grab error

The grab error was measured using two criteria: number of errors and error ratio. As shown in Table 1, the effects of target size on grab error (F (2.8, 87) = 11.89, $p < 0.001$) and grab error ratio (F (2.8, 87) = 11.89, $p < 0.001$) were significant. There was also a significant effect of movement distance on grab error (F (2.4, 76) = 2.88, $p < 0.05$) and grab error ratio (F (2.4, 76) = 2.88, $p < 0.05$). Figure 2 presents the mean grab error and grab error ratio as functions of the target size and movement distance. The mean grab error and grab error ratio significantly decreased when the target size increased, and increased when the movement distance increased. Table 2 shows that the target size of 1 cm was significantly different from all other sizes, but no significant difference was observed between the other sizes in the grab error and its ratio. A pairwise comparison of different movement distances showed that only the lowest movement distance (5 cm) was significantly different between 13 and 20 cm; however, no significant difference was observed between the other movement distances in grab error and its ratio (Table 3). Table 4 shows that sex had no significant effect on performance or workload. In addition, there were no significant two- and three-way interaction effects among target size, movement distance, and sex on grab error and grab error ratio. Furthermore, analysis also showed no significant differences between men and women, although men performed slightly better than women (Table 5).

3.2. Drop error

The effects of the target size on the drop error (F (1.9, 60) = 20.31, $p < 0.001$) and drop error ratio (F (2, 60) = 20.31, $p < 0.001$) were significant, as shown in Table 1. There was also a significant effect of movement distance on drop error (F (3, 98) = 4.52, $p < 0.05$) and drop error ratio (F (3, 98) = 4.52, $p < 0.05$). Figure 2 shows that the mean drop error and drop error ratio decreased when the target size increased, and significantly increased with increasing movement distance only at the lowest target size (1 mm). However, Table 2 shows that the target size of 1 cm was significantly different from all other sizes, and also 1.5 and 2 cm had significant differences from the 3 cm target sizes. There was also no dominant effect of sex on drop error or drop error ratio (Table 3). Table 4 shows no significant two- or three-way interaction effects between the target size, movement distance, and sex on the drop error and drop error ratio. Further analysis also showed no significant differences between men and women, although women performed slightly better than men (Table 5).

3.3. Success rate

The dependent variables, target size (F (3.2, 124) = 22.32, $p < 0.001$) and movement distance (F (2.7, 86) = 3.86, $p < 0.01$), had significant effects on the success rate. Figure 2 presents the mean success rate as a function of target size and movement distance. The success rate increased when the target size increased, but decreased with increasing movement distance. Table 2 shows that the target size of 1 cm was significantly different from all other sizes, and 1.5 and 2 cm had significant differences ($p < 0.001$) from the 3 cm target sizes.

A pairwise comparison of different distances showed significant differences in success rates between 5 and 20 cm ($p < 0.01$), 9 and 11 cm ($p < 0.05$), and 13 and 20 cm ($p < 0.02$); however, no significant differences were observed between the other movement distances, as shown in Table 1. As shown in Table 4, sex did not have a significant effect on the success rates. In addition, we found no significant two- or three-way interaction effects between the target size, movement distance, or sex on the success rates. Further analysis also revealed no significant differences between men and women, although women performed slightly better than men (Table 5).

Table 1. Results from an analysis of ANOVA for repeated measure target size and movement distance.

	Target size			Movement distance			Target size × movement distance		
Variables	F	p	Effect size	F	p	Effect size	F	p	Effect size
Grab error ratio	11.89	***	0.28	2.88	*	0.08	1.19	0.350	0.04
Grab error	11.89	**	0.28	2.88	*	0.08	1.19	0.350	0.04
Drop error ratio	20.31	***	0.39	4.52	**	0.13	2.04	0.080	0.06
Drop error	20.31	***	0.39	4.52	**	0.13	2.04	0.080	0.06
Success rate	22.32	***	0.42	3.86	*	0.11	0.88	0.620	0.03
Movement time	87.82	***	0.74	122.16	***	0.79	1.46	0.193	0.04
TCT	87.47	***	0.74	121.49	***	0.78	1.46	0.176	0.04
Physical demand	64.28	***	0.68	39.43	***	0.56	.064	0.765	0.02
Effort	75.34	***	0.70	32.46	***	0.51	0.98	0.456	0.03

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

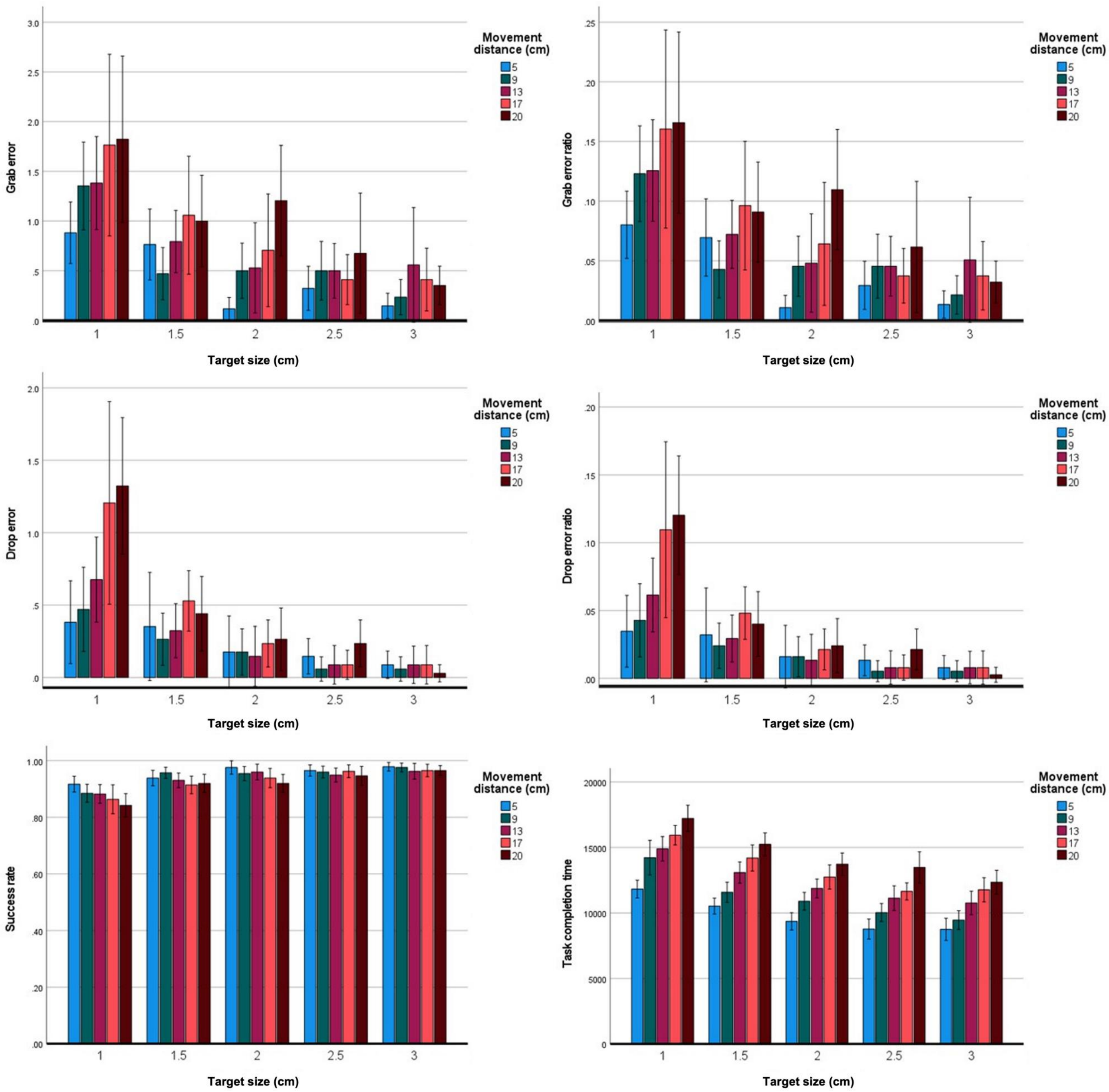

Figure 2. Performance measures depending on target size and movement distance.

Table 2. Target size pairwise comparisons (Bonferroni) of p values.

Target size (cm)		Grab error	Grab error ratio	Drop error	Drop error ratio	Success rate	Movement time	TCT	Physical demand	Effort
1	1.5	**	**	*	*	***	***	***	***	***
	2	***	***	***	***	***	***	***	***	***
	2.5	***	***	***	***	***	***	***	***	***
	3	***	***	***	***	***	***	***	***	***
1.5	2	1.000	1.000	0.069	0.069	0.689	***	***	***	***
	2.5	0.220	0.220	*	*	0.200	***	***	***	***
	3	0.068	0.068	**	***	**	***	***	***	***
2	2.5	1.000	1.000	1.000	1.000	1.000	*	***	***	***
	3	0.708	1.000	1.000	0.094	0.278	***	***	***	***
2.5	3	1.000	1.000	1.000	1.000	0.949	0.523	0.523	0.281	**

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

3.4. Movement time

Table 1 shows the effect of target size on movement time (F (4, 124) $= 87.82$, $p < 0.001$). In addition, movement distance significantly affected movement time (F (4, 124) $= 122.16$, $p < 0.01$). Figure 2 presents the mean movement time as a function of target size and movement distance. The mean movement time decreased when the target size increased, and increased with increasing movement distance.

Table 3. Results from ANOVA for repeated measure of interaction of sex, target size and movement distance.

	Target size × sex			Movement distance × sex			Target size × movement distance × sex		
Variables	*F*	*P*	Effect size	*F*	*p*	Effect size	*F*	*p*	Effect size
Grab error	0.19	0.942	0.01	0.40	0.710	0.01	1.13	0.344	0.04
Grab error ratio	0.19	0.942	0.01	0.40	0.710	0.01	1.13	0.344	0.04
Drop error ratio	0.13	0.868	0.04	1.36	0.259	0.04	1.37	0.235	0.04
Drop error	0.13	0.868	0.04	1.36	0.259	0.04	1.37	0.235	0.04
Success rate	0.32	0.828	0.01	0.57	0.622	0.02	0.85	0.624	0.03
Movement time	0.51	0.725	0.01	0.56	0.655	0.02	1.53	0.149	0.04
TCT	0.51	0.712	0.02	0.50	0.721	0.02	1.52	0.110	0.05
Physical demand	2.61	0.097	0.08	0.68	0.504	0.02	0.92	0.491	0.03
Effort	3.45	*	0.10	3.54	0.730	0.08	1.03	0.414	0.03

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 4. Movement distance pairwise (Bonferroni) comparisons of *p* values.

Movement distance (cm)		Grab error	Grab error ratio	Drop error	Drop error ratio	Success rate	Movement time	TCT	Physical demand	Effort
5	9	0.639	0.638	1.000	1.000	1.000	***	***	***	***
	13	*	*	1.000	1.000	0.219	***	***	***	***
	17	0.174	0.174	0.634	0.634	0.272	***	***	***	***
	20	*	*	0.180	0.180	**	***	***	***	***
9	13	1.000	1.000	1.000	1.000	1.000	***	***	**	*
	17	0.655	1.000	*	*	0.575	***	***	***	***
	20	0.075	0.649	**	**	*	***	***	***	***
13	17	1.000	1.000	0.367	0.367	1.000	***	***	*	0.201
	20	0.649	1.000	*	*	0.113	***	***	***	***
17	20	1.000	1.000	1.000	1.000	1.000	***	***	*	0.169

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 5. Pairwise comparisons of performance and workload between men and women.

	Mean			95% Confidence interval	
Dependent variables	Men	Women	*p*	Lower bound	Upper bound
Grab error	0.067	0.068	0.962	−.038	0.036
Grab error ratio	0.734	0.744	0.962	−.394	0.413
Drop error ratio	0.341	0.294	0.519	−0.100	0.194
Drop error	0.031	0.027	0.519	−0.017	0.036
Success rate	0.936	0.938	0.837	−0.026	0.0210
Movement time (ms)	1082.63	1139.250	0.298	−52.270	165.510
TCT (s)	1190.00	1253.572	0.295	−1825.250	571.810
Physical demand	2.642	2.184	0.134	−0.1480	1.066
Effort	2.134	2.849	*	0.108	1.323

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

A pairwise comparison of different sizes showed that all the values are significant except for the target sizes of 2.5 and 3 cm, as shown in Table 2. In addition, pairwise comparisons of the different movement distances showed that all values were significant (Table 3). Based on the results shown in Table 4, there was no dominant effect of sex on movement time. In addition, we found no significant two- or three-way interaction effects of target size, movement distance, and sex on movement time. Further analysis also showed no significant difference between men and women, although men performed slightly better than women (Table 5).

3.5. TCT

Table 1 shows the effect of target size on the TCT (F (4, 132) = 87.47, $p < 0.001$). In addition, movement distance had a significant effect on the TCT (F (4, 124) = 121.49, $p < 0.01$). Figure 2 shows the TCT as a function of the target size and movement distance. The mean total TCT decreased when the target size increased, and increased with increasing movement distance.

A pairwise comparison of different sizes showed that all the values are significant except for the target sizes of 2.5 and 3 cm, as shown in Table 2. In addition, pairwise comparisons of the different movement distances showed that all values were significant (Table 3). As shown in Table 4, there was no dominant effect of sex on the TCT. In addition, we found no significant two- or three-way interaction effects between target size, movement distance, and sex on the TCT. Further analysis also showed no significant difference between men and women, although men performed slightly better than women (Table 5).

3.6. Physical demand

Table 1 shows the effect of the target size on the physical demand (F (4, 46) = 64.28, $p < 0.001$). In addition, the movement distance had a significant effect on the physical demand (F (2, 59) = 39.43, $p < 0.001$). Figure 3 presents the physical demand as a function of the target size and movement distance. The mean physical demand decreased when the target size increased, and increased with increasing movement distance.

A pairwise comparison of different sizes showed that all the values are significant except for the target sizes of 2.5 and 3 cm, based on Table 2. In addition, pairwise comparisons of the different movement distances showed that all values were significant (Table 3). As shown in Table 4, sex had no significant effect on physical demand. In addition, we found no significant two- or three-way interaction effects between the target size, movement distance, and sex on physical demand.

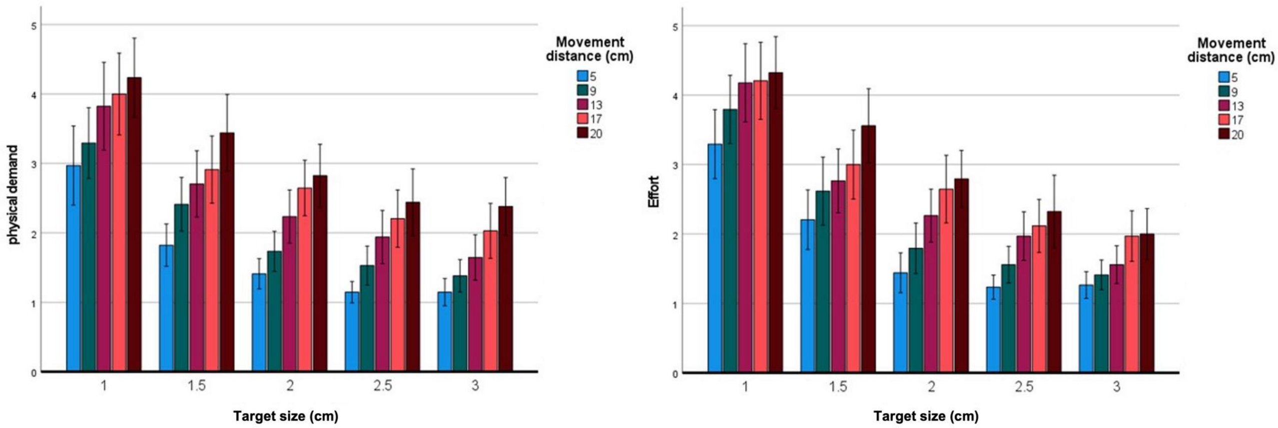

Figure 3. Workload measures depending on target size and movement distance.

3.7. Effort

Effect of target size on effort (F (1.8, 58) = 75.34, $p < 0.001$). In addition, movement distance had a significant effect on effort (F (2.4, 76) = 32.46, $p < 0.01$), as shown in Table 1. Figure 3 presents the effort as a function of the target size and movement distance. The mean effort decreased when the target size increased, and increased with increasing movement distance.

Pairwise comparison of the different sizes showed that all values were significant (Table 2). In addition, a pairwise comparison of the different movement distances showed that all values were significant, except for the movement distances of 13 and 20 cm and 17 and 20 cm (Table 3). Further analysis revealed that the effort level was significantly higher in women than in men (Table 5). In addition, we found no significant two- or three-way interaction effects of target size, movement distance, and sex on effort (Table 4).

4. Discussion

This study aimed to analyze the effects of target size, movement distance, and sex on the performance and workload of HCI tasks during VR immersion by focusing on their alignment with Fitts' law. Performance was measured using the grab-and-drop error, error rate, success rate, and mental workload, which were measured using two subscales of the NASA-TLX: effort and physical demand. The results showed that the target size and movement distance had significant effects on all performance measures and workload indices, which is consistent with Fitts' law predictions. Large target sizes produced better performance and lower workloads; however, large movement distances decreased performance and increased workload, again in accordance with Fitts' law. However, sex had no significant effect on the performance or workload during the dragging and dropping tasks. The best target sizes were 2.5 and 3 cm, and the worst size was 1 cm. The best movement distances were 5 and 9 cm, and the worst distance was 20 cm.

Our results indicate that the target size significantly affect all performance measures. The participants were fast and made few errors while grabbing and dropping large targets. These results align with the findings from other studies conducted in both VR and conventional HCI contexts, indicating their alignment with Fitts' law (Gillan et al., 1990; Ha & Woo, 2010; Suresh et al., 2014). According to previous studies, increasing target width decreased user reaction times, completion times, and errors (Burigat & Chittaro, 2013; Jakobsen & Hornbæk, 2013). Furthermore, as observed in the study by Gillan et al. (1990), both pointing and dragging times in the point-drag sequence were affected by the height of the selected text. However, this result disagrees with that of Chen and Or (2017), who demonstrated that large targets resulted in high error rates in the dragging and dropping tasks. This non-compliance could be owing to the nature of the task setting. In a previous study, small targets indicated more space in the designated area for dropping. However, in our study, we did not have any limitations in movement, and the minimum distance between the drag and drop was 5 cm.

In addition, the workload was affected by the target size. The results showed that increasing the target size decreased physical demand and effort. While there were some basic differences between this study and previous studies, such as graphic-based versus text-based tasks, the results were the same as those of previous studies in which target size affected cognitive demand (Hsiao et al., 2018; Kim et al., 2019). This result is also compatible with that showed. However, it disagrees with that of Kia et al. (2021), who demonstrated that physical demand increased by up to approximately 50% as the target size increased in the omnidirectional pointing task. This inconsistency may be owing to the task interface (VR *vs.* augmented reality), pinching gestures with the right thumb and index fingers, and different target sizes in the two studies. The increased physical demands and effort needed to move small targets likely stem from the need for greater concentration to minimize errors and additional hand muscle exertion to maintain control.

The results of the paired comparison showed that a target size of 1 cm differed for all sizes in terms of performance and workload; therefore, this size was unsuitable for designing targets in virtual media. The 1.5 cm size also had no significant difference in grab and drop error rates compared to other sizes, but there was a significant difference in most cases, such as drop error, success rate, moving time, physical demand, and effort compared to the other sizes, especially the 2.5 and 3 cm sizes. This indicated that this size was unsuitable for the design. The best performance was related to the sizes of 2.5 and 3 cm, because these two sizes did not show a significant difference except for the effort, which was significantly higher at 2.5 than at 3 cm.

The second main variable analyzed in this study was movement distance. Similar to the target size, this variable significantly affected all dependent variables such as performance measures and workload scales. Our results showed that the performance for small target sizes (1, 1.5, and 2 cm) decreased significantly when the movement distance increased, while this relationship between performance and movement distance is unclear in large target sizes (2.5 and 3 cm). Previous studies have disregarded the role of movement distance in performance; therefore, their results are not comparable to those of other studies. However, this is in agreement with the results of conventional HCI studies. For example, Tao et al. (2021) showed that the interaction distance had a significant effect on errors in a one-directional pointing task and dragging task in a conventional large display interaction. This result was adopted from the Fitt's law. Based on this law, task difficulty is related to target size and movement distance when movement distance increases task difficulty, which has a negative relationship with the target size (Choe et al., 2021). In addition, by increasing the movement distance, the participants maintained their hand/finger gestures throughout the dragging procedure to grip the target (virtually) and pull it steadily in the direction of the target.

In the pairwise comparison of distances, the movement time, TCT, physical demand, and effort were significantly different across all distances. Conversely, they increase with increasing distance. In addition, the distance of 5 cm was significantly different from that of 20 cm in terms of performance indicators such as grab error and success rate. The largest differences in volume were observed at 5–20 cm (the smallest and largest distances) and 9–20 cm. This indicated that a distance of 20 cm was unsuitable.

Despite increasing requests in recent years to consider sex when developing or evaluating software, websites, and other digital technologies (Stumpf et al., 2020), in this study, sex had no significant effect on the performance and workload of VR in the drop and drag tasks. This inconsistency may be owing to the simplicity of the task in terms of perception and cognition. Perhaps more complicated and difficult tasks will lead to different results, which should be considered in future studies. However, the effort required by women to perform the task was significantly greater than that required by men, indicating that women must put in additional effort to maintain their performance (Park et al., 2020). This may be owing to the differences in physical strength (Lopes et al., 2015; Stumpf et al., 2020). This finding is consistent with that of Hsiao et al. (2018), who demonstrated that sex has no significant impact on reading speed or error rate under various lighting conditions, font sizes, and contrast ratio settings in a VR environment.

This study has several limitations. First, similar to most other studies (Chen & Or, 2017; Tcha-Tokey et al., 2018), this study only assessed short-term task performance behaviors. Second, we subjectively assessed workload based only on physical demands and effort, which are likely subject to self-reporting bias. Therefore, an objective assessment of other workload dimensions, like EEG, that in previous studies have shown its accuracy in VR environments is desirable in future studies (Volmer et al., 2022). Future evaluations may consider the muscle activity of the upper extremities and neck and an electroencephalography-based study, which can be used to more precisely and objectively indicate physical stress and mental workload, respectively. Third, our study examined only a simple drag-and-drop task and joystick interaction in VR. Other types of VR tasks (Liu et al., 2022), interaction types, and new branches of VR, such as reality and mixed reality, also exist. Interaction performance and workload can differ across different types of tasks, interaction types, and new VR technologies. Finally, the participants' stereoscopic vision ability was not considered, even though it is important for visual-based tasks in 3D environments and may potentially affect the results of gender comparisons. Measurement of this ability could be beneficial in future studies.

5. Conclusion

In this study, we conducted a comprehensive analysis with a primary focus on the principles of Fitts' law to investigate the profound impact of the target size and movement distance on human performance and workload in dragging and dropping tasks within a VR environment encompassing both male and female participants. The outcomes underscored the strong correlation between the manipulated target size and movement distance and the resultant dependent variables of performance and workload. As anticipated by Fitts' law, increasing the target size enhanced the performance while reducing the workload, with the optimal target sizes identified at 2.5 and 3 cm, and the least effective at 1 cm. Similarly, in accordance with Fitts' law, the findings demonstrated that increasing movement distances hindered performance and escalated the participants' workload burden. Specifically, the study revealed that movement distances of 5 and 9 cm were the most favorable, whereas 20 cm was the least optimal distance. Despite previous research indicating possible differences in HCI outcomes between genders owing to distinct perceptual and cognitive attributes, our investigation revealed no discernible disparity in performance and workload between men and women during drag-and-drop tasks within the VR realm. Ultimately, these findings offer valuable insights into the advancement of VR technology rooted in human-centered design principles, highlighting the need for further fundamental research to capture the unique intricacies of the virtual experience.

Disclosure statement

The authors declare no potential conflicts of interest regarding the research, authorship, or publication of this manuscript.

Funding

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MSIT) (No. RS-2023-00213454).

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Data availability statement

The data will be available upon reasonable request (owing to privacy and ethical restrictions).

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