Workload, Presence and Task Performance of Virtual Object Manipulation on WebVR

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***Abstract*—WebVR technology is widely used as a visualization approach to display virtual objects on 2D webpages. Much of the current literature on virtual object manipulation on the 2D screen pays particular attention to task performance, but few studies focus on users' psychological feedback and no literature aims at its relationship with task performance. This paper compares manipulation modes with different degrees of freedom (DoF) in translation and rotation on WebVR to explore users' workload and presence by self-reported data, and task performance by measuring completion time and error rate. The experiment results present that the increase of DoF is associated with lower perceived workload, while people may feel a higher level of presence during tasks. Additionally, this study only finds a positive correlation between workload and efficiency, and a negative correlation between presence and efficiency, which means that when feeling less workload or more presence, people tend to spend less time to complete translation and rotation tasks on WebVR.**

Keywords—workload, presence, task performance, virtual object manipulation, degree of freedom, WebVR

I. INTRODUCTION

Virtual reality (VR) technology becomes widespread in people's daily life from mouse- and touch-based interfaces to head-mounted displays. As smartphones and personal computers are the most common interfaces used to access the internet nowadays, webpages may be one of the most direct and convenient approaches for people to obtain VR service from the internet [1]. Besides, VR applications are increasingly available to more people who can enjoy interacting with the virtual world through webpages with VR effect (also known as WebVR) [2], which is based on the WebGL standard.

Previous research studied virtual object manipulation as a critical feature when people interact with various simulated environments, especially with mouse-based interfaces (e.g., WebVR). There are two basic types of manipulation: translation and rotation, transforming 3D objects in the virtual world [3, 4]. Because of the different dimensions between input device (2D) and 3D virtual environment on WebVR, related studies proposed degree of freedom (DoF) separation as an integral approach to enhance task performance, instead of another manipulation mode, the direct manipulation, which refers to the operation of transforming virtual object arbitrarily. Specifically, DoF separation is an approach which limits virtual object to transform on x-, y- and z-axis respectively [5]. It has been recognized to improve the precision of 3D object manipulation on mouse-based interfaces [6]. Previous literature also studied several interactive techniques based on DoF separation to enhance task performance in the virtual world [7]. Besides task performance, psychological feedback is another critical aspect of user experience, including several psychological features, such as workload and presence. Scholars have emphasized that controller naturalness has an impact on users' psychological feedback [4]. However, few studies have examined the user's workload and presence when DoF separation is applied in virtual object manipulation tasks. Furthermore, no studies have explored the correlation between task performance (e.g., efficiency and precision) and psychological features (e.g., workload and presence) in both 2D interfaces and head-mounted displays.

This paper compares the translations and rotations under different DoF to evaluate participants' perceived workload and the feeling of presence on WebVR. Moreover, the correlation between psychological feedback and task performance is assessed as the present study's primary focus. Therefore, this paper's main contribution is to emphasize the correlation between psychological feedback and task performance in virtual object manipulation on WebVR.

II. RELATED WORK

In order to improve task performance, the existing literature extensively highlighted DoF separation in both 2D screen-based virtual environment and immersive environment. Current studies have revealed that the decreased level of DoF is associated with less efficiency and satisfaction, but higher precision in immersive environment [3, 8]. Other studies emphasized that a higher level of DoF separation is more efficient in task performance because it mimics the interactive way with the physical world on mouse- and touch-based interfaces [9]. Previous literature on virtual object manipulation focused particularly on DoF separation and direct manipulation, and these studies have identified similar results as above [10]. Interestingly, existing approaches cannot improve precision and efficiency synchronously, and there should be a tradeoff

between DoF separation and direct manipulation. Thus, existing literature has proposed different interactive techniques for 3D object manipulation utilizing virtual widgets to address this tradeoff on mouse- and touch-based interfaces [11].

From another perspective, there was little literature to explore psychological feedback by adopting DoF separation and direct manipulation. Similar studies, however, can be found to evaluate mental workload for different dimensions of input devices, such as traditional mouse (2D) and 3D mouse on 2D screen [5]. Scholars pointed out that the feeling of presence can be affected by controllers with different dimensions [12]. The 3D input device is claimed to contribute to greater presence and spatial ability [10] in immersive environment. Additionally, researchers illustrated that controller naturalness would affect enjoyment and presence in immersive environment [4].

III. Methods

In order to address the problems above, this paper chose two main types of virtual object manipulation, namely translation and rotation, to measure and assess participants' psychological feedback and task performance respectively. Thus, two experiments regarding virtual object translation and rotation were designed on WebVR.

Figure 1 presents 3DoF, 2DoF and 1DoF controllers of virtual object translation. 3DoF controller allows translating 3D object without any limitation in the virtual space, which can be regarded as the direct manipulation. When clicking the white dot in the box shown in Figure 1(a), participants can arbitrarily translate virtual objects on the visual plane. The box displayed in Figure 1(b) provides 2DoF controllers in the form of three orthogonal planes inside. With this controller, the box can be translated on two axes (xy-, yz- or zx-plane) synchronously. For 1DoF controllers shown in Figure 1(c), the participants are restricted to translate the virtual box on one specific axis, which means each bar is able to control one direction. From the literature review, the 2DoF and 1DoF controllers belong to DoF-separated manipulation.

Figure 2 also demonstrates three types of virtual object rotation, namely 3DoF, 1DoF with three handles (1DoF-3H)

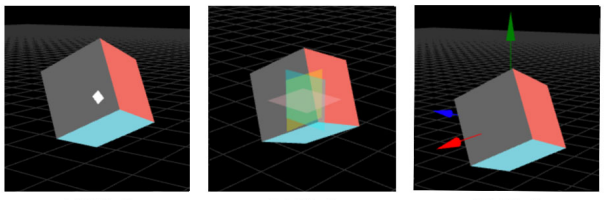

Figure 1. 3DoF, 2DoF and 1DoF controllers of virtual object translation

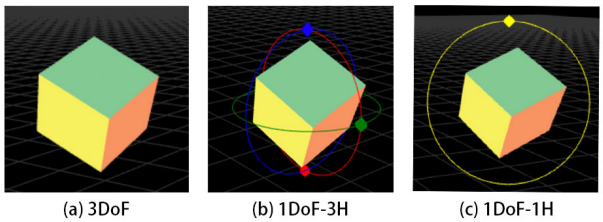

Figure 2. 3DoF, 1DoF-3H and 1DoF-1H handles of virtual object rotation

and 1DoF with one handle (1DoF-1H). Participants can use direct manipulation to rotate 3D objects arbitrarily with 3DoF in Figure 2(a) on x-, y-, z-axes synchronously. Two types of 1DoF controllers belonging to DoF separation are shown in Figure 2(b) and Figure 2(c). 1DoF-3H includes three controllers mapping with x-, y-, z-axes of the coordinate system on WebVR and each controller is able to rotate 3D objects on one specific axis. For example, the green controller in Figure 2(b) only controls the rotation direction on x-axis. 1DoF-1H has only one controller to rotate 3D objects on the visual plane; thus participants need to change their perspective and then rotate objects on another visual plane to achieve the goal of tasks.

The experimental environment consists of a computer and a traditional mouse, shown as (a) and (b) in Figure 3. The computer must access the internet to send the recorded data to a remote server.

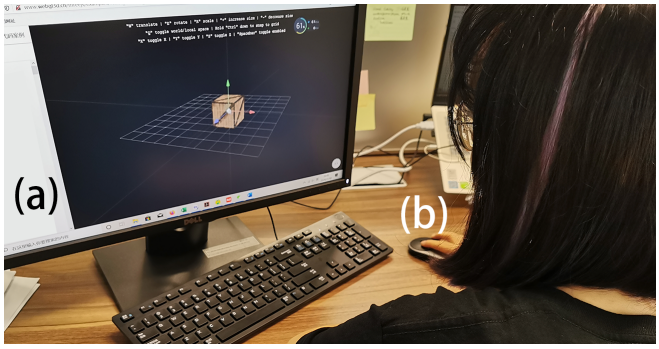

Figure 3. Experimental setup

A. Translation Experiment

In the translation experiment, four experiment webpages were designed as experiment platforms, including a training section with one webpage and a task section with three webpages. The training section was provided for all participants, especially those who had limited prior experience translating virtual objects on WebVR. The participant could read an introduction first and then try to learn how to use each controller. After the training section on experiment webpages, participants were asked to complete tasks with 1DoF, 2DoF and 3DoF controllers respectively in the task section. This experiment aimed to translate the source object to the target object and make them coincide as precisely as possible without time limitation. On these experiment webpages, source and target objects were set to be the same size and located at the same initial position in the virtual space, which means each task's difficulty was the same.

B. Rotation Experiment

In the rotation experiment, the goal of each task was to rotate the source object to match with the target object by using rotation controllers. For instance, the angle and the face of the source object had to be consistent with the target object. In order to assist the participant to achieve this goal quickly and accurately, referenced coordinates were implemented to set around each source object.

C. Questionnaire

After completing all the tasks in each experiment, each participant was asked to fill out a questionnaire consisted of a modified NASA Task Load Index (TLX) and a modified

Presence Questionnaire (PQ). NASA TLX is a widely-used tool to rate workload score. It initially consisted of two sections, and this study applied the first section (6 items) to evaluate workload score for each manipulation mode. PQ with 29 items has four sections, namely involvement, sensory fidelity, adaption and interface quality, while this study only focused on two of them, involvement (7 items) and adaption (5 items) to elicit participants' presence.

In the questionnaire section, the participants were asked to respond using a 7-point Likert scale ranging from 1 ("not responsive") to 7 ("very responsive"). The means (M) and standard deviations (SD) of three psychological features were calculated per participant with the same weights of each question. Then, the Kruskal-Wallis test was used to compare psychological features among different manipulation modes.

Exploring the correlation between psychological feedback and task performance was the main focus of this study and was measured by the Pearson correlation coefficients. These coefficients can be applied to assess the strength of the relationship between two variables statistically, for example, completion time and workload score.

D. Participants

Twenty participants were recruited for this study, and all of them were asked to conduct these two experiments with six tasks totally. There were 8 males and 12 females between 20 and 35 years old. The majority of participants (15 out of 20) had limited prior experiences to manipulate 3D objects on the 2D screen. Participants were required to use a computer with internet access and a traditional mouse to complete tasks on the experimental platform. Their performance data (completion time and error rate) were recorded and sent to the remote server for further study.

IV. Result

A. Translation Tasks

Data from questionnaire were analyzed to assess three psychological features, including workload, involvement and adaption. Participants perceived less workload when translating virtual objects with 3DoF controller, as they rated 3DoF with a higher workload score (M=5.380, SD=0.805) than 1DoF (M=5.290, SD=0.775) and 2DoF (M=5.260, SD=0.961). Furthermore, the participants felt a higher level of involvement (M=5.312, SD=1.311) and adaption (M=4.964, SD=1.028) when using 3DoF controller. By applying the Kruskal-Wallis test, there was no significant difference among the means for all manipulation modes in terms of these psychological features. Together these results provided that 3DoF can have a higher chance of making participants feel more presence and perceive less workload, although there was no statistically significant difference in TLX and PQ analysis.

This paper found that 3DoF controller was the most efficient, but the least precise from performance data. By applying the paired sample t-test, there was a significant difference of 3DoF with 1DoF (t=-3.209, p=0.005) and 2DoF (t=-2.908, p=0.009) on time completion respectively, which means that 3DoF had the highest efficiency among all. The error rate still presented a significant difference of 3DoF with 1DoF (t=-2.973, p=0.007) and 2DoF (t=-2.296, p=0.033), while 3DoF performed the worst precision in all three manipulation modes.

Correlation coefficients between completion time and psychological features were calculated by Pearson correlation analysis. There was a negative correlation between perceived workload and efficiency, and a positive correlation between presence and efficiency. As displayed in Table I, from the correlation coefficients of 1DoF, 2DoF and 3DoF (-0.313, 0.112, and -0.371) between completion time and workload, it can be seen that if participants felt less workload (or rated higher workload score), they tended to spend less time on tasks. Correlation coefficients of other two psychological features, namely adaption (-0.466, -0.022, -0.617) and involvement (-0.310, -0.058, -0.235) also showed a negative relationship, which means that if feeling more presence, the participants usually tended to spend less time on tasks. Correlation coefficients between error rate (or precision) and psychological features were mostly in the range from -0.2 to 0.2 with no significant relationship.

TABLE I. Correlation Coefficients Between Completion Time (CT) and Psychological Features, Workload (WL), Involvement (IN) and Adaption (AD), in Translation Tasks

	1DoF CT	2DoF CT	3DoF CT
1DoF WL	-0.3134		
2DoF WL		0.1121	
3DoF WL			-0.3711
1DoF AD	-0.4662		
2DoF AD		-0.0221	
3DoF AD			-0.6176
1DoF IN	-0.3095		
2DoF IN		0.0581	
3DoF IN			-0.2349

B. Rotation Tasks

Data from questionnaire presented a statistically significant difference between 3DoF and 1DoF controllers in terms of psychological features. Participants perceived less workload and rated a higher workload score with 3DoF (M=5.93, SD=1.401). There was a statistically significant difference of 3DoF with 1DoF-1H (χ^2=15.440, p=0.00008) and 1DoF-3H (χ^2=12.200, p=0.0005) by using the Kruskal-Wallis test. Additionally, the 3DoF controller also showed a high score in involvement (M=5.966, SD=1.084) and adaption (M=5.727, SD=0.853) and the mean score was significantly much larger than the other two manipulation modes. Thus, greater level of DoF generally led to less more presence in rotation tasks.

It is clear that the significant difference of 3DoF with 1DoF-3H (t=5.390, p=0.00002) and 1DoF-1H (t=3.324, p=0.003) by using the paired sample t-test, which proved that 3DoF was the most efficient type of manipulation with the shortest completion time. Besides, there was a significant difference of 3DoF with 1DoF-3H (t=3.929, p=0.0007) and 1DoF-1H (t=2.545, p=0.019) while two types of 1DoF controllers have no difference (t=1.386, p=0.180) in terms of error rate.

Correlation coefficients of psychological features and task performance in the rotation experiment were nearly in the range from -0.2 to 0.2. Unlike translation tasks, the general correlation between psychological features and task

performance was not obvious. However, the general trend can be seen clearly in specific aspects as well. As shown in Table II, when the participants adopted 3DoF controller, longer completion time was related to less workload and involvement score with correlation coefficients -0.246 and -0.512 respectively.

TABLE II. CORRELATION COEFFICIENTS BETWEEN COMPLETION TIME (CT) AND PSYCHOLOGICAL FEATURES, WORKLOAD (WL), INVOLVEMENT (IN) AND ADAPTION (AD), IN ROTATION TASKS

	1DoF-3H CT	1DoF-1H CT	3DoF CT
1DoF-3H WL	0.1408		
1DoF-1H WL		0.1255	
3DoF WL			-0.2462
1DoF-3H AD	0.0398		
1DoF-1H AD		0.1791	
3DoF AD			-0.5126
1DoF-3H IN	-0.0008		
1DoF-1H IN		0.1995	
3DoF IN			0.0353

V. DICUSSION

Several studies demonstrated that different controllers are linked with psychological features in the virtual world, due to the naturalness of manipulation modes [8-10]. By comparing psychological features in two experiments, this paper has revealed that DoF separation can be associated with participants' perceived workload and the feeling of presence on WebVR. The results from self-reported data confirmed that the participants feel more presence on average by using 3DoF in both translation and rotation experiments. Specifically, there is a statistically significant difference between 3DoF and others in the rotation experiment. Furthermore, the results in this paper also indicated that participants always tend to have a higher chance to perceive less workload on average when using 3DoF controller in both translation and rotation experiments. In other words, 3DoF controller which mimics the interactive way from the physical world enables the participants to perceive less workload during tasks [3].

Very little has been found in the existing literature on the relationship between task performance and psychological feedback. The result of the translation experiment demonstrated that there is a positive correlation between workload and efficiency, and a negative correlation between presence and efficiency on WebVR. Particularly, when tasks cost much longer time, the participants perceive more workload and feel less presence. Although the relationship between psychological features and task performance is weak in the rotation experiment, the general trend can be seen in the same way. Interestingly, 3DoF controllers contribute to better performance on psychological feedback and efficiency, but it leads to less precision. In the future study, particular attention can be paid to understand the tradeoff between psychological features and precision.

Furthermore, the strong negative correlation between workload and presence is observed in both translation and rotation experiments. The participants tend to have a higher perceived workload during the tasks if they feel less presence on WebVR. The result demonstrated that different types of psychological feedback can always have an impact on each other.

VI. CONCLUSION

The purpose of the current study is to explore users' workload and presence by collecting self-reported data, and task performance by measuring efficiency and precision when applying distinct types of virtual object manipulation on WebVR. Besides task performance, psychological feedback should be an essential aspect to assess user experience. Furthermore, this work contributes to existing knowledge by emphasizing the correlations between psychological features and task performance on WebVR.

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