Content Transfer Across Multiple Screens with Combined Eye-Gaze and Touch Interaction - A Replication Study

Verena Biener *  
Coburg University of Applied Sciences

Jens Grubert †  
Coburg University of Applied Sciences

ABSTRACT
In this paper, we describe the results of replicating one of our studies from two years ago [1] which compares two techniques for transferring content across multiple screens in VR. Results from the previous study have shown that a combined gaze and touch input can outperform a bimanual touch-only input in terms of task completion time, simulator sickness, task load and usability. Except for the simulator sickness, these findings could be validated by the replication. The difference with regards to simulator sickness and variations in absolute scores of the other measures could be explained by a different set of user with less VR experience.

Keywords: Replication, Eye-Gaze, Touch, Multimodal Interaction

1 INTRODUCTION
In recent years researchers have become more aware of the replication crisis in empirical science. Disciplines like medicine or psychology are aware of this and encourage replication for quite some time [3,9]. Yet, it seems like there is less interest in replicating work in the field of HCI, as it is driven to publish novel results. However, some prior efforts were made to raise awareness in several Replication workshops (e.g. [11,12]) resulting in some replication attempts and experience reports [11]. Hornbæk et al. [7] looked at 891 HCI papers and found that only 3% were attempting to replicate prior work and that a lot of papers try to downplay their replication part. The authors also mentioned that by just slightly changing the study design, many of then non-replication studies could have reinforced previous results. In addition, Wacharamanotham et al. [10] analyzed how common it is to share research materials, as this can be an important contribution to facilitate replications. They found that only around 27–37% of materials are shared.

The aim of this work is to replicate one of our previously conducted studies, to validate the findings and reflect upon the process of replication. There are three different styles of replication defined by Hendrick in 1990 [6]. First, a conceptual replication uses a completely different approach to evaluate the same hypothesis as in the original study. Second, in a partial replication only a part of the original study is changed, for example deleting or adding a variable. Third, in a strict replication the experiment is replicated as exactly as possible.

We chose to do a strict replication of our previous work exploring, if combined touch and gaze interaction has benefits over touch-only interaction when interacting across multiple virtual screens [1]. Specifically, we replicate the content transfer task presented in the previous work.

2 INTERACTION TECHNIQUES
The previous work [1] presented two interaction techniques for interaction with multiple displays in VR. Both techniques make use of a touchscreen for precisely controlling a cursor within one of the screens. In that case a one to one CD ratio is used to map the movement on the touchscreen to the virtual screen. Yet techniques differ in how the user can switch the active screen (indicated by the yellow frame in Figure 1) and therefore moving the cursor to that screen.

Bimanual: The bimanual technique uses the finger of the non-dominant hand on the border area of the touchscreen, with a width of 2 cm, as a mode switch (green area in Figure 2a). This means, while touching the border with the non-dominant hand, the dominant hand can be used to swipe through the screens and therefore moves the cursor to another screen. For every 2 cm that is swiped, the active screen will jump to the next one. This ratio was determined by Biener et al. [1].

Gaze-Based: In the gaze-based method the active screen is determined by gaze-direction. This means, the active screen is always the one the user is looking at. To facilitate looking at and selecting objects in the border area of a screen, a threshold of 5% of the screen-size was added to delay changing the active screen.

3 STUDY DESIGN
As in previous work [1] the study was designed as a within-subjects study with two independent variables INTERACTION TECHNIQUE and NUMBER OF SCREENS. INTERACTION TECHNIQUE was either GAZE-BASED or BIMANUAL. NUMBER OF SCREENS was either FOUR arranged in two rows (Figure 1a) and two columns, or FIFTEEN arranged in 3 rows and 5 columns (Figure 1b).
14 participants took part in this study (5 female, 9 male). Their mean age was 27.07 years (sd = 5.99). The mean height of the participants was 172.07 cm (sd = 10.74). Two people had no prior VR experience. Three people used VR once, four used it rarely, four sometimes and one often. No one reported to use it very frequently. One participant never plays video games, six rarely do so, five play games sometimes, one often and one participant very frequently. Eight participants wore glasses or contact lenses during the study. Only one participant was left-handed, yet he uses his right hand for touch-input, so all participants used their right hand to control the cursor. Two participants used their middle finger to touch and the other 12 used their index finger. Only two participants also took part in the previous study.

3.4 Procedure

This replication study was conducted by the same person as in the original study. First participants filled out a consent form and a demographic questionnaire. Then the HTC Vive eye-tracking was calibrated. After that the participants completed all four conditions in different orders, as determined by a balanced latin square (this resulted in 4 different orderings). For each condition the participant could train the techniques in a short training phase with up to 10 tasks. After that, they performed the actual condition with 32 tasks. After completing each condition, participants filled out the system usability questionnaire (USQ), the simulator sickness questionnaire (SSQ) and the NASA task load index. Upon completing all four conditions, a questionnaire about preferences was filled out and a short interview was conducted, asking participants about their preferences. Participants were either taking part during work hours or they were compensated with 10 euros.

4 RESULTS

As in the previous study, repeated measures analysis of variance (RM-ANOVA) with Holm-Bonferroni adjustments for multiple comparisons (initial significance level $\alpha = 0.05$) was used to analyze the task completion time. The subjective data obtained through questionnaires was analyzed using aligned rank transform before applying RM-ANOVA.

4.1 Performance

The ANOVA results can be found in table 1. We could find significant main effects of the INTERACTION TECHNIQUE on task completion time. Specifically, GAZE-BASED ($m = 3.78s, sd = 1.3$) resulted in a significantly lower task completion time than BIMANUAL ($m = 5.52s, sd = 2.23$). Also, the NUMBER OF SCREENS had a significant influence on task completion time in such a way that it was significantly shorter for FOUR ($m = 3.49s, sd = 0.93$) than for FIFTEEN ($m = 5.81s, sd = 2.14$). In addition, the analysis also indicated interaction effects between INTERACTION TECHNIQUE and NUMBER OF SCREENS. Looking at the graph in Figure 3 it can be seen that for four screens the difference between GAZE-BASED and BIMANUAL is less prominent than for fifteen screens, yet, post-hoc tests still indicate it is significant ($p = 0.001$).

To analyze the accuracy, we used the log-transform of the data as it was not normally distributed. The ANOVA results indicated no significant influence of INTERACTION TECHNIQUE or NUMBER OF SCREENS on the accuracy.

4.2 Simulator Sickness, Workload, Usability

No significant influence of INTERACTION TECHNIQUE or NUMBER OF SCREENS on simulator sickness was found. Yet, BIMANUAL ($m = 22.31, sd = 19.49$) resulted in slightly higher measures than GAZE-BASED ($m = 20.84, sd = 21.04$). Regarding the overall taskload, the results indicate that INTERACTION TECHNIQUE had a significant influence. Specifically, GAZE-BASED ($m = 26.46, sd = 12.12$) resulted in a significantly lower
When comparing the results of the replicated study to the original study, no significant effect could be detected on the performance aspect. The results also indicate that interaction technique has a significant influence on usability, such that gaze-based (\(m = 87.5, sd = 10.8\)) resulted in a significantly higher usability than bimanual (\(m = 78.66, sd = 14.84\)).

### 4.3 Preference, Comments, Observations

When asked which method they prefer, all but one participant answered gaze-based. This participant also felt like bimanual was faster and more accurate. All other participants said that gaze-based was faster and more accurate, except one person found bimanual more accurate in the condition with four screens and one person found it more accurate in the condition with fifteen screens. Participants preferring gaze-based said it was easier (5 participants), faster (5 participants), more intuitive (1 participant), the was no need to coordinate hands (2 participants) and it resulted in generally less physical movement (4 participants). The participant who preferred bimanual said that he found it more precise and it was impractical for him that the screen directly changed by just looking around.

### 5 Discussion: Comparison to Previous Results

When comparing the results of the replicated study to the original one, it can be seen that they are very similar. Both times, a significant main effect of interaction technique and number of screens on the task completion time could be found, such that gaze-based is significantly faster than bimanual and four screens are significantly faster than fifteen. Also the absolute task completion times are very similar in both studies (original study: gaze-based = 37.8s, bimanual = 5.52s). Yet the replication study also revealed an interaction effect between interaction technique and number of screens indicating that for four screens the difference between gaze-based and bimanual is less prominent, yet still significant. Both the original and the replication study did not reveal any effects on accuracy.

Regarding simulator sickness, the original study found a significant difference between gaze-based and bimanual interaction. This effect could not be seen this time, but still gaze-based resulted in a slightly better score than bimanual. However, simulator sickness is generally higher (55%) in the replication study (\(m = 21.58\)) than in the original study (\(m = 13.89\)). This could be explained by the experience of the users [4]. In the previous study all participants had prior VR experience, while in the replication two had none. And while 6 participants in the previous study used VR often or very frequently, only 1 participant from the replication study uses VR often.

Both studies indicate a higher taskload for bimanual. The absolute values were generally slightly higher (16%) in the replication study (\(m = 30.09\)) than in the original study (\(m = 25.94\)). It can again be speculated that this could be due to less experienced participants.

The results for usability were also the same in both studies, with gaze-based being considered significantly more usable than bimanual. The absolute scores for gaze-based are very similar between the original (\(m = 88.75\)) and the replication (\(m = 87.5\)). However, the bimanual technique was considered 8% more usable in the replication (\(m = 78.66\)) compared to the original study (\(m = 72.59\)).

Comparing the effect sizes (\(\eta_p^2\)) shows that they were slightly higher for the data of the original study, especially for the subjective data from questionnaires. For example, the effect size of the main effect of interface on usability was previously \(\eta_p^2 = 0.75\) while it was \(\eta_p^2 = 0.44\) in the replication. And the effect size of the main effect of interface on task load was previously \(\eta_p^2 = 0.7\) ans is \(\eta_p^2 = 0.29\) in the replication. In addition, also the p-values indicated a higher significance level. It was \(p < 0.001\) for the effect of interface on usability in the original study and \(p < 0.01\) in the replication. And similarly it was \(p < 0.001\) for the effect of interface on task load previously and in the replication it was \(p = 0.04\). However, this difference is not reflected in the performance data of task completion time, suggesting a distinct difference between the two groups of participants in how they perceive the system and their own performance.

Finally, in both studies there was only one participant who preferred the bimanual technique. The main reason for preferring gaze-based in the original study was that it is faster. This was also one of the main reasons this time, besides it being easier.

Another important aspect that we noticed when replicating the study setup was, how important it is to have clear instructions of the application and how to use it. Especially in a case like this where multiple systems need to work together, such as the tablet sending the touch data, the Optitrack system providing tracking data of the fingers and tablet and the Vive tracking system. A good documentation would be even more crucial when making code publicly available.

### 6 Conclusion

In this work, we replicated one of our previous studies comparing touch-only input to a multimodal approach combining touch with eye-gaze tracking for interacting with multiple displays in VR. The general findings could be validated. Both the original and the replicated study indicate that the approach combining eye-gaze and touch results in faster task completion times, lower task load and higher usability ratings. However, previously found differences regarding simulator sickness could not be confirmed. Yet, when looking at subjective ratings of simulator sickness and task load, it can be seen that the replication study resulted in generally higher scores. This could possibly be explained by the different set of participants with very apparent differences in VR experience.

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