WeRSort: Preliminary Results from a New Method of Remote Collaboration Facilitated by Fully Immersive Virtual Reality

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Fully immersive virtual reality, with the unique ability to replicate the real world, could potentially aid in real-time communication. Geographically separated teams can collaborate using virtual reality. To test the viability of using virtual reality for remote collaboration, we designed a system called "WeRSort" where teams sorted cards in a virtual environment. Participants performed the task as a team of 2 in one of three conditions-controls-only condition, generic embodiment and full embodiment. Objective measures of performance, time and percentage match with master cards showed no significant difference. Subjective measures of presence and system usability also showed no statistical significance. However, overall workload obtained from NASA-TLX showed that fully immersive virtual reality resulted in lower workload in comparison with the other two. Qualitative data was collected and analyzed to understand collaboration using the awareness evaluation model.

INTRODUCTION

Fully immersive Virtual Reality (VR) or Immersive Computing Technology (ICT), comprises of technology that helps users become immersed in a virtual world (Berg & Vance, 2017). Fully immersive virtual reality has the unique ability to replicate the real world and provides a feeling of belonging to users within this environment (Slater & Sanchez-Vives, 2016). VR utilizes equipment such as a single or multiple connected projection screens, stereo-capable monitors with desktop tracking and head mounted displays, with audio provided using headphones, speaker and surround systems (Berg & Vance, 2017). The three-dimensional simulated environment in fully immersive VR facilitates real-time interaction (Moore, Yufang Cheng, McGrath, & Powell, 2005). Some areas of application of VR include medicine, education, telepresence, and collaborative tasks in engineering and product design (Berg & Vance, 2017; Gopinath & Tucker, 2015).

Computer-supported cooperative work (CSCW) allows teams to complete tasks with the use of technology. This uses enabling technologies including fully immersive virtual reality being one such technology. This technology is especially helpful when team members are separated geographically (Berg & Vance, 2017; Grudin & Poltrock, 2012). Knowledge exchange, data visualization, task analysis and telelmedicine for the geriatric population are areas where computer supported collaborative work can be utilized (Agnisarman et al., 2017a; Fleury, Férey, Vézien, & Bourdot, 2015; Narasimha et al., 2016; Narasimha, Agnisarman, Chalil Madathil, Gramopadhye, & McElligott, 2017).

The user-centered design process involves a multidisciplinary team with product designers, users and stakeholders, and it considers the users' needs at each step (Chalil Madathil & Greenstein, 2011, 2017; Juárez-Ramírez, 2017). Information architecture (IA) design, a form of user centered design, involves organizing schemes, structures, labeling systems and search systems and helps in organizing information in software systems (Rosenfeld & Morville, 2002). To organize information and understand how users categorize information, a tool known as card sorting is employed (Rosenfeld & Morville, 2002). During a card sorting session, participants organize topics into groups that make sense to them. Traditionally this involves all parties to be physically present (Eppinger & Ulrich, 2011; Rosenfeld & Morville, 2002).

The ability of fully immersive virtual reality to connect people remotely makes it a good substitute to in-person card sorting. However, collaboration within virtual environments may differ in comparison with in-person collaboration. Neale, Carroll, & Rosson's (2004) Awareness Evaluation model is used to understand collaboration within the scope of this study. The concept of collaboration within a fully immersive virtual environment is the focus of this study which aims to answer the following research questions (RQ).

RQ1. Is fully immersive virtual reality viable for remote collaborative activities?

RQ2. How does collaboration work within a fully immersive virtual environment?

To answer these questions, this study compares conventional (in-person) card sorting, video-based card sorting and virtual reality-based card sorting in "WeRSort" simulation system. Conventional card sorting serves as the basis of comparison.

METHOD

Participants

A total of 54 participants (M=23.94, SD=3.29) were involved in this study resulting in 27 collaborative groups. These groups performed only one of the three testing conditions with 9 groups each using either conventional, video-based or fully immersive virtual reality-based card sorting. All participants were provided with $10 gift cards for their time. This study was approved by the Clemson University Institutional Review Board.

Hypotheses

H1 – Fully immersive virtual reality performs on par with conventional and video-based card sorting for time taken to finish the task.

H2 – Fully immersive virtual reality performs on par with conventional and video-based card sorting for percentage match with master card group.
H3 – Fully immersive virtual reality performs on par with conventional and video-based card sorting for total presence.
H4 – Fully immersive virtual reality performs on par with conventional and video-based card sorting for usability.
H5 – Fully immersive virtual reality performs on par with conventional and video-based card sorting for workload.

Apparatus

For the conventional card sorting condition, keywords were written on a set of index cards, a timer to measure time and a table were used. The video-based condition involved the use of a shared screen with keywords, Logitech headphones, Dell desktop and mouse. The fully immersive virtual reality condition consisted of HTC Vive Head Mounted Display (HMD), HTC Vive controllers and Logitech headphones.

Experimental design

The study consisted of three conditions - conventional card sorting, video-based card sorting and fully immersive virtual reality-based card sorting.

1. *Conventional card sorting (Figure 1).* Team members worked in the same room with index cards which were moved on a table to make groups. Time taken to complete the task was measured using a timer and final grouping was photographed for further analysis using a smartphone.

Figure 1. Conventional card sorting condition

2. *Video-based card sorting (Figure 2)*. Team members were in separate rooms for this condition. They sorted cards on a shared screen using a mouse while communicating using Logitech headphones and via video call using Skype. Time taken and final card groups were saved by the simulation.

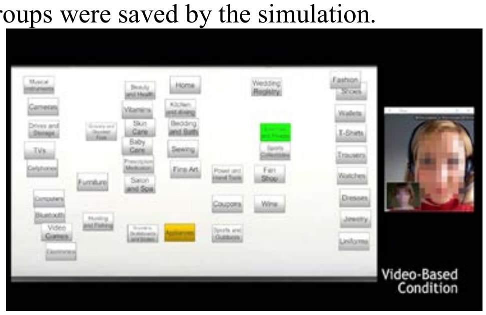

Figure 2. Video-based card sorting

3. *Fully immersive virtual reality-based card sorting*. In this "WeRSort" system, participants sorted cards in VR and worked from two separate rooms. They interacted via a virtual simulation which they entered using HTC Vive HMD. Within the simulation, participants were represented as avatars and sorted cards together on a white board using the HTC Vive controllers while communicating through Logitech headphones. Figure 3 shows the view within the simulation that participants saw through the HMD. Time taken and final card groupings were saved by the simulation.

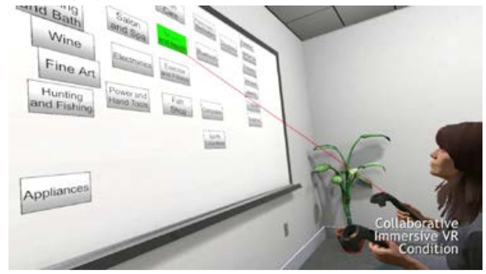

Figure 3. Virtual reality-based card sorting

Procedure

On the day of the study, participants were invited as a group of two members and were greeted. The researchers then provided an overview of the study followed by voluntary consent to be a part of the study. This was followed by a video tutorial about card sorting. Participants were randomly assigned to one of three testing conditions. In the case of the conventional condition (Figure 4), participants were in the same room and sorted a set of 42 cards, chosen from Amazon online shopping portal, on a table. The two test facilitators/researchers remained in the same room to monitor the study without being involved in it. In the video and fully immersive virtual reality conditions (Figure 5), participants were in two separate rooms and performed card sorting on a shared screen using a computer mouse (video-based card sorting condition) for the former and on a white board within the virtual environment using HTC Vive controllers for the latter. On completing the card sorting, participants completed a post-test questionnaire consisting of the Witmer-Singer presence questionnaire (Witmer & Singer, 1998), IBM-Computer System Usability Questionnaire (IBM-CSUQ) (Lewis, 1995) and NASA-Task Load Index (Hart & Staveland, 1988). The study concluded with a post-test retrospective think-aloud session wherein the test facilitators interviewed both participants separately to understand their experience. The study lasted approximately 45 minutes for each group.

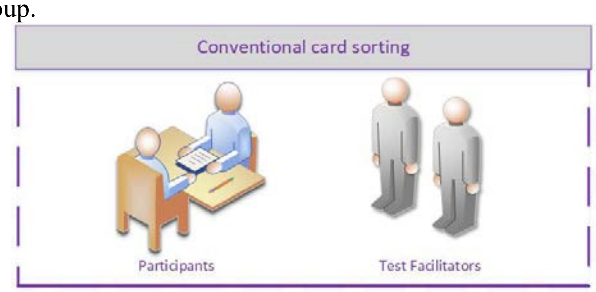

Figure 4. Experimental setup for conventional card sorting

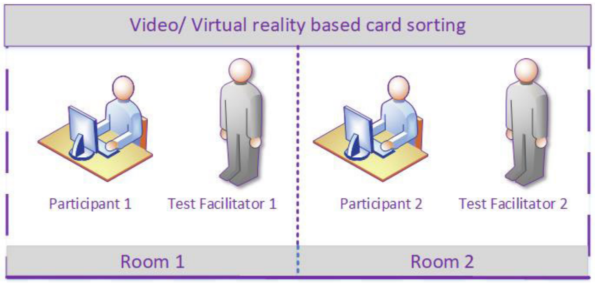

Figure 5. Experimental setup for video- and virtual reality-based card sorting

Dependent variables

Dependent variables were objective and subjective in nature. Objective measures included time to task completion and percentage match with master card group. Subjective measures were total presence from Witmer & Singer's (1998) presence questionnaire, system usability from IBM CSUQ and workload from NASA-TLX.

Analysis

SPSS 22.0 was used to analyze data. A between-subjects ANOVA was carried out on all the metrics for the three card sorting conditions. The outcomes were graphed for easy interpretation. Qualitative data were analyzed to find information regarding users' acceptance of fully immersive virtual reality and their expectations and criticism of the system.

RESULTS

Performance measures

Time. Time data showed no statistically significant difference between the three card sorting conditions $F(2,24)=1.047$, $p=0.36$ as shown in Figure 6.

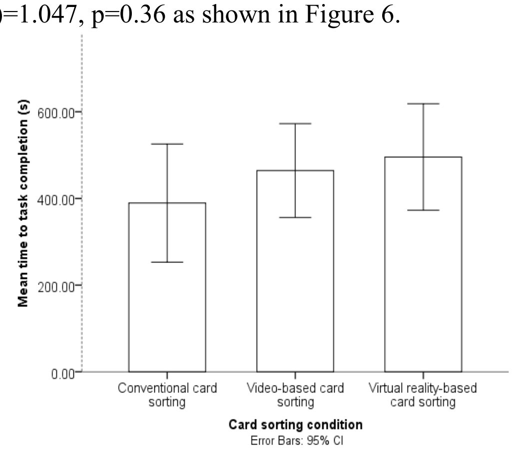

Figure 6. Mean time to task completion

Percentage match with master card set. The grouping of cards by the participants was verified with the original cards obtained from Amazon shopping website. Percentage match of cards also showed no significant difference between the three card sorting conditions, $F(2,24)=0.39$, $p=0.67$ (Figure 7).

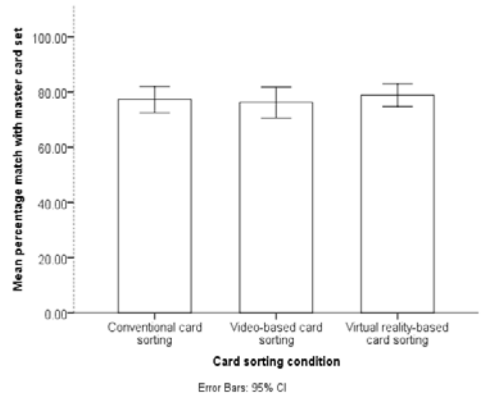

Figure 7. Mean percentage match with master card set

Subjective measures

*Presence***.** The presence questionnaire measures the metrics involvement score, immersion score, interface quality score and sensory fidelity score. The sum of these scores is a measure of total presence score which showed no significant difference between the three card sorting conditions, $F(2,24)=0.17$, $p=0.84$ as shown in Figure 8.

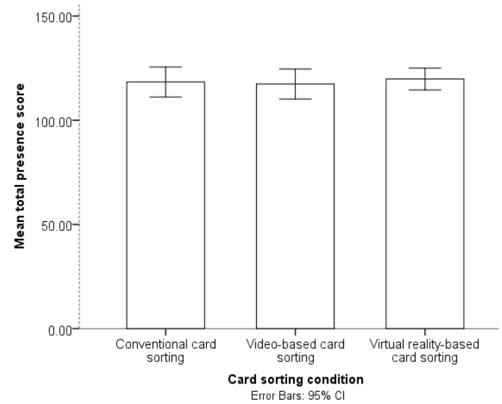

Figure 8. Mean total presence score

IBM-Computer System Usability Questionnaire. This measure includes system usability, information quality, interface quality and the sum of these forms overall usability. Overall usability showed no significant difference between the three testing conditions, $F(2,24)=0.10$, $p=0.90$ (Figure 9).

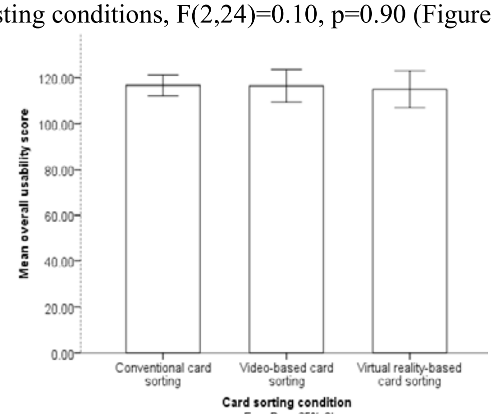

Figure 9. Mean overall usability score

*Workload measure (*Figure 10*)*. NASA-TLX was used to measure workload. Workload measures included mental demand, physical demand, temporal demand, performance, effort and frustration, the sum of which forms total workload.

Mental demand, physical demand and temporal demand, effort and frustration metrics showed no statistically significant differences.

Performance metric in the NASA-TLX application is scored differently from the other metrics with a lower score indicating better performance (less workload) and higher score indicating lower performance (more workload). Performance showed a statistically significant difference between the three card sorting conditions, $F(2,24)=4.74$, $p=0.01$. Further, post hoc pairwise analysis showed that users perceived their performance to be significantly higher in fully immersive virtual reality-based card sorting (M=3.85, SD=2.20) than in conventional card sorting (M=10.4, SD=5.62).

Total workload showed statistically significant differences between the three conditions, $F(2,24)=3.52$, $p=0.04$. Post-hoc analysis showed that total workload was significantly lower in fully immersive virtual reality condition (M=26.77, SD=11.84) than in conventional card sorting (M=40.87, SD=13.20) and video-based card sorting condition (M=38.85, SD=11.38).

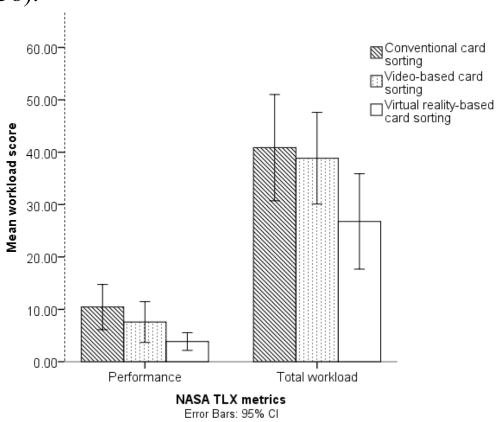

Figure 10. Mean workload score

Qualitative data

The retrospective think-aloud session involved interviews with participants to obtain detailed information about aspects that affected performance, and areas of improvement. Particpants in the conventional condition stressed on the advantage of physical presence with their teammate. They also said moving the cards around on the table was convenient adding that the ability to read the other person's body language was an advantage.

Video-based condition had participants commenting about the convenience of the shared screen along with audio and video capabilities. They also appreciated that the cards changed color when they selected it. However, they did not find the interface very appealing to work with.

In the fully immersive virtual reality-based condition, participants were receptive of the new technology. Participants felt the possibility of remote collaboration, which the technology offered, would be very useful. A few comments were also received about how easy it was to work with the controllers and the interface. They liked the presence of the laser pointer within the simulation that allowed participants to understand which card their teammate was referring to. However, we also received input about areas of improvement. Participants indicated that the graphics required more work along with some changes to the avatar presented in the simulated environment. Some of these comments are provided below –

Conventional card sorting. "It was easy to go off of each other's body language. You could see what the other person was doing and talk to them in real time to figure out what that person was doing."
"Easy to make decision and natural to delegate tasks."

Video-based card sorting. "I liked that we had the same exact screen. Whereas, if we were just over Skype, it would have been harder to communicate."
"I liked that the cards would turn different colors that was nice. So, I could know when he was moving something."

Fully immersive virtual reality-based card sorting. "It really looks like a classroom."
"The accessibility is awesome for someone who's never used it. I feel like even my employees who never went to college, I could teach it to them in two minutes."
"I felt like it was animated. Almost like it needs more dimension to it. If you look at my skin it's not just brown it has more colors to it. There's hair and stuff..."

DISCUSSION

This study used a VR system called "WeRSort" to test the possibility of using virtual reality for a remote collaborative task. Objective data pertaining to performance, time and percentage match with master card set, showed no significant differences between the three testing conditions. Although the fully immersive virtual reality condition did not perform better than the other two conditions, the lack of significance may indicate that performing the task using fully immersive virtual reality was no more effortful than in the conventional and video-based condition.

Measure of presence showed no significant differences between the three conditions. The lack of significant differences may be due to the low fidelity simulation in the video and fully immersive virtual reality-based environment when compared to in person communication. However, the fully immersive virtual reality condition did not fare significantly worse than the other two conditions which is promising.

Overall usability scores from the IBM-Computer Systems Usability questionnaire also showed no significant differences between the three card sorting conditions. The participants commented that both the video and fully immersive virtual reality-based simulations required more attention to make it more appealing to the participants. Also, the task chosen for this study did not contain error messages in the simulation. These factors together led to overall usability and therefore the observed lack of significant difference was expected.

The workload measures from the NASA-TLX questionnaire did not show significant difference between the three card sorting conditions for the metrics of mental demand, physical demand and temporal demand. Some reasons for this may include relative ease of the card sorting task, lack of physical effort involved and absence of time constraints may be some causes leading to the observed results. Effort and frustration metrics also showed no significant differences which may be due to the relative ease of the task and easy-to-use mouse/controllers in video and fully immersive virtual reality conditions. Performance metric showed that participants felt they performed significantly better in the fully immersive virtual reality condition. The ability to see all the cards in front of them and see their teammate point at a card using the laser pointer may have facilitated their performance. In addition, one participant commented “It was nice to not be limited by the size of the table. It was all on a board and I felt like there was more space”. Further some participants also commented, “..our hands may get in the way when we are moving the cards around the table”, which indicates one reason for the poor performance in the conventional condition. Total workload, a sum of these metrics, was again lower in the virtual reality condition which, we believe is due to the above-mentioned reasons of ease of viewing in the simulation and, unobstructed ability to work in the simulation. Lower workload in the fully immersive virtual reality condition is a very promising result.

The awareness evaluation model (Neale et al., 2004) was used to understand collaboration, subjectively, using the interview data. Contextual factors, work coupling and common ground are the main factors in this model with several underlying factors contributing to them. Team members having a knowledge of the context in which they are working, who they are working with and the relation between them form contextual factors. Some interview data relating to this include “The way the environment was set up helped to establish the sense of this is where I am.” and “Just because you are in proximity, you can see what the other person is doing and quickly adapt.”. Work coupling focuses on the amount of communication that is required to do the task which is affected by coordination, collaboration and cooperation. Qualitative data indicating the presence of work coupling are “We analyzed the cards for a minute or so and tried to think of categories they could belong to before trying to find header cards to categorize the others”, “We communicated and delegated tasks” and “Once we had a sensible organization, we did some minor refining until we felt our arrangement was optimized”. Finally, common ground refers to information that team members believe they share with each other. They must update this knowledge periodically, which may occur not only by verbal communication but also by interaction with the environment. From observations made during the study, participants constantly communicated leading to good common ground.

Although this study comes with its limitations, it has provided some promising insights regarding the use of fully immersive virtual environments for collaboration. This study used a relatively simple task and had a small sample size. These study limitations must be overcome in the future. Future research in this area must focus on quantifying collaboration within these environments, study the possibility of fully immersive virtual reality for other, more complex tasks, and study the effect of larger teams in simulated environments.

Acknowledgement

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