Analysing Display Influence on a Close Coupled Task based on a Single User Evaluation

Oliver Otto, Dave Roberts, Robin Wolff

The Centre for Virtual Environments,
University of Salford, Business House, UK
{o.otto, d.j.roberts, r.wolff}@salford.ac.uk

Abstract

In a globalising world, an increasing number of people are working together either locally or from co-located sites. For them it becomes equally important that those from disparate sites can cooperate as well as those at local sites. This means that the cooperative work must be supported by a system that allows natural social human communication (SHC) and interaction. Various forms of teleconferencing systems try to offer such support, yet they have difficulties with sharing objects and the direct social response this involves when participants interact with those objects. In previous work we have shown that a collaborative virtual environment (CVE) can be of service for such cooperation and that immersive displays are of greater help than traditional desktop displays. It is as yet unclear which factors influence the effectiveness of closely coupled collaboration, although other work has indicated that problems exist with the ability to quickly reference an object to indicate its use to others. This paper investigates display relevant factors such as the field of view (FOV) and user interface, by performing a similar task as in previous trials, but excluding the social and team aspect of those trials. A user trial with a number of volunteers was conducted which measured the task performance, including time, task order and locomotion within the virtual environment. In addition, the users were asked to fill out a questionnaire at the end of the test. We discuss why measured task performance is different from perceived performance and why it makes a difference in how users directly interact with an object. More results of this user trial will be shown and discussed in this paper, helping to further understand the process of effective collaboration between co-located users.

Keywords: display influences, collaborative virtual environments, social human interaction

1 INTRODUCTION

Cooperation between people is always centred on a common object of interest. This object can be vocal or physical. In the later case it is important for all parties involved to perceive and understand the object in order to work with it. While we cooperate with other people on this object, we use a variety of social skills to communicate our views and opinion to the others. Be it simply verbally with emotional nuances, with gestures and postures in a non-verbal way or by using the object directly. Those forms of social human communication (SHC) as well as the representation of the object need to be mediated through tele-collaboration technology when interacting remotely.

If we use just a phone or text to communicate, the result will be slow the process due to possible misunderstandings. Using modern video or Internet conferencing systems give us more flexibility and support for non-verbal communication. Yet having multiple cameras connected to screens limits our reach and it is still very difficult for all participants to interact with the object. This becomes even more difficult if one tries to conduct a training or simulation trial with one or more objects.

A possible solution is to represent people and objects at all the sites, which is where collaborative virtual environments (CVE) show their strength. CVEs allow people and objects to be situated in the same virtual environment, see the same things and interact in the same way. Tele-conferencing systems allow people to look into each others space, while CVEs allow people and data to share the same space.

In previous extended trials we investigated closely-coupled interaction through a collaborative virtual environment at both the interface and network levels (Roberts, Wolff, & Otto, 2003; Wolff, Roberts, & Otto, 2004). At the interface level we looked at the impact of display configuration and SHC over a variety of connected tasks involving shared objects. Furthermore at the network level we looked at the maintenance of a consistent environment with the help of suitable consistency and event management. We found that the exclusive use of immersive CAVE-like displays significantly improved task performance and feelings of collaboration & cooperation. Yet we were not sure which factors contribute to this advantage. Was it the display properties, the task or the collaboration that contributed to the differences? For that reason we decided to perform another study which excluded the collaboration and was to focus entirely on the display properties (field of view, interface and task performance) and there effects.

1.1 Related work

Hindmarsh et al. focused in an extensive study on the interaction with objects of two users using desktop systems (Hindmarsh, Fraser, Heath, Benford, & Greenhalgh, 2000). In the furniture world participants were asked to rearrange furniture. With their study they revealed that the limited field of view (FOV) on a desktop was of a great hindrance due to problems of fragmentation of the workflow. It took a relatively long time (>20sec) for users to see each others gestures and to connect them to the places and objects in their conversation. This was because of a lack of information about other's actions due to their limited window into the world. In addition the study found problems with slow applications and clumsy movements as well as the lack of parallelism for actions. A subsequent study tried to resolve some of the issues with peripheral lenses and therefore an enhanced field of view. Although this solution enhanced the awareness, it also showed that peripheral lens distortion can disrupt both a user's own sense of, and their notion of the other's, orientation to actions and features within the environment (Fraser, Benford, Hindmarsh, & Heath, 1999).

Large displays are often not placed at a distance that is proportional to their increase in size over small displays. Due to space constraints, they are typically relatively closer and cast a larger retinal image, thus offering a wider FOV. It is generally agreed that wider FOVs can increase "immersion" in VEs (Arthur, 1996; Lapointe & Vinson, 2002; Tan, Gergle, Scupelli, & Pausch, 2003). Large displays in these settings are easy for all users to see and interact with (Guimbretière, 2002), providing a conduit for social interaction. Some of these researchers have begun to document performance increases for groups working on large displays (Dudfield, Macklin, Fearnley, Simpson, & Hall, 2001).

Advances in immersive display devices are increasing their acceptance in industry as well as research (Brooks, 1999). Natural body and head movement may be used to view an object from every angle within an immersive display. An object can be reached for and manipulated with the outstretched hand, usually through holding some input device. The feeling of presence, and particularly the naturalness of interaction with objects, may be improved when the user can see their own body in the context of the virtual environment. Schuemie concludes that little is known about what interaction has to do with presence (M.J.Schuemie, 2001). It may be argued that even less is known about the relationship between effective interaction on common objects as a focus of interest (Greenhalgh, Bullock, Frécon, Lloyd, & Steed, 2001) and co-presence.

Desktop systems normally use different methods to interact with objects in a virtual environment such as go-go, ray casting or occlusion techniques (Bowman, Johnson, & Hodges, 2001; Poupyrev, Weghorst, Billinghurst, & Ichikawa, 1998). They can be used in CAVEs but have been developed using HMDs. Desktop systems use 2D interface controls or virtual spheres or mouse picking, whereas immersive displays normally use one- or two-handed direct manipulation (virtual hand) using a tracking system. An evaluation of interaction techniques for immersive displays (Poupyrev et al., 1998; Steed & Parker, 2005) found that the virtual-hand is superior over ray casting for the selection and manipulation of objects.

The VR community is looking into the use of various displays for various tasks, yet is unable to define which choice to make for specific tasks. Comparisons have been made between immersive and desktop displays (Bowman, Gabbard, & Hix, 2002; Schroeder et al., 2001) and they tend to show an advantage for immersion in certain applications.

(Kjeldskov, 2001) specifically found that non-tracked 3D interaction devices work fine for orientating and moving when using partial immersive displays but are problematic when using full immersive displays. In addition they argue partial and full immersive displays have different support for close-by interaction (virtual hand) and different affordances for pointing (virtual beam).

This paper extends a previous study that analysed factors that affected a collaborative task by analysing a similar task carried out by a single user, so that factors affecting collaboration only can be isolated. The aim is to understand which factors influenced the multi-user interaction but were not related to closely coupled collaboration. Section 2 introduces the task and the setup for the various displays. The results are given in section 3, discussed in 4 in relation to previous studies and summarised in section 5.

2 EXPERIMENTATION

This section will introduce the setup of this study, describing the task design, display configuration and the questionnaire.

In order to understand how different display factors influence a collaborative task designed for close coupled collaboration, we modified our existing application of building a virtual gazebo (Roberts et al., 2004; Roberts et al., 2003). It is a structured task that situates a user within a building site that no longer requires teamwork, which was achieved by removing some of the restrictions such as gravity and simulated weight. However, the task is still very similar to previous trials. By removing the team aspects we can focus on user performance, use of display and interface, perception of presence and observe object interactions.

Subjects were asked to build a small structure (Figure 1) with a number of building materials and were required to follow a certain order to achieve this. For example, a screw can only be inserted and fixed after a hole is drilled, but first the user has to carry an object to the construction site. They then have to fix this object using different tools provided near the site. If the correct construction order is applied the object will be fixed at the last position. The aim is to build only a small structure to avoid to too many repetitions.

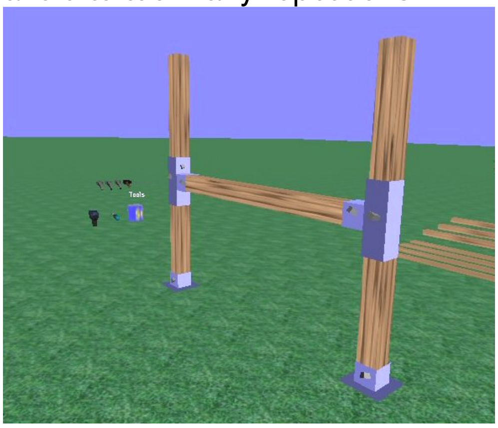

Figure 1: a simple structure to build

For this task we asked 13 student volunteers to participate and each of them got multiple training sessions to make themselves familiar with the interface and the task. Earlier trials showed that after three training sessions the user becomes familiar enough with the interface so that their performance reaches that of an expert user. The trials needed no longer than 5-10 min per session, but due to the extensive training each person spent about two hours for the trial.

After evaluation of the results we found a significant difference in measured and perceived performance, which we partially related to the manipulation and navigation on the desktop. To better understand this difference, we performed a subsequent trial with four people repeating the desktop trial with ray-casting as well as virtual-hand manipulation.

2.1 Display Configuration

We asked all participants to perform this task on a variety of display setups, see Table 1. The order of the displays used was for all participants the same, starting with the desktop and finishing with the CAVE-like display.

Table 1: display configurations

Display device	**Input device**	**OS**	**Stereo**	**Field of view**	**Manipulation technique**
Desktop	keyboard and mouse	Linux	No	60 degree	ray-casting
Workbench	tracked wand	Irix	Yes	110 degree	virtual hand
Reactor (CAVE-like)	tracked wand	Irix	Yes	160 degree	virtual hand

The DIVE CVE was used for experimentation as it is an established benchmark (Frécon, Smith, Steed, Stenius, & Stahl, 2001; Frécon & Stenius, 1998; Greenhalgh et al., 2001; Mortensen et al., 2002; Schroeder et al., 2001; Steed, Mortensen, & Frécon, 2001). We used DIVE version 3.3.5 on all devices and extended this DIVE version with an event monitoring plugin which allows us to monitor the user and object movements for post-trial analysis.

2.2 Questionnaire

Thirteen questions concerning the perception of performance, navigation and presence were asked, in which the user compared the different display combinations.

Errors arising from a user's misinterpretation of a question were reduced by asking sets of related questions. The answer could be given on a Likert-type scale of 1-7 where 1 represented agreement to a very small extent and 7 to a very large extent. The questionnaire included questions concerning how subjects interacted with the object in the different configurations, as well as how they perceived the interaction with the objects. The questions were asked with the purpose in mind of how users perceive different factors on their performance. The subject were similar to those we asked in previous studies to allow us to compare this work (Roberts et al., 2004; Roberts et al., 2003), but mainly related to performance, field of view and presence. The next sections will take a closer look into the questions and results.

3 RESULTS

3.1 General / overall

We asked the users *"how well they performed the task of carrying / fixing an object using the different displays"* and an analysis of variance (ANOVA) showed that there is a significant difference between the desktop and the immersive displays ($F(2,60)= 7.25$, $MS_W=5.80$, $p=0.002$). The perception was that the performance on the desktop was less effective than it was in the CAVE or workbench. In addition, this contrast was stronger for fixing an object then for carrying it. [Figure2]

The question on *"how much did the interface hamper the task"* showed a clear difference between desktop and immersive displays ($F(2,30)= 3.59$, $MS_W=7.36$, $p=0.040$). The keyboard / mouse combination with it's, for CVEs typical, complicated combination of shortcuts was clearly perceived to hamper the task much more than the tracking / joystick combination in the CAVE. [Figure2]

Another question was *"how important was the field of view during the interaction"* and again a clear difference can be seen between the desktop and the immersive display ($F(2,30)= 3.47$, $MS_W=8.39$, $p=0.044$). [Figure2]

Something none of the displays had was a haptic device to allow for the feel of touch. However, the question on *"how much did you miss the feel of touch"* showed that it was expected for the immersive displays but not for the desktop. One of the users expressed it this way: "The sense of touch was not expected when using the desktop, whereas it was when on the workbench and particularly in the CAVE." [Figure2]

Those previous results show that the user in the immersive display felt more involved and present in the task. This is confirmed by their answer to our questions regarding presence. The questions *"of their sense of being there"*, *"realistic appearance of interaction"* and *"feeling of physical space"* show all a very low perception of presence on the desktop but a high perception on the immersive displays ($F(2,30)= 44.67$, $MS_W=45.48$, $p=0.000$). [Figure2]

Last but not least we asked the participants on *"how effective this task would have been as a team effort"* as well as *"how effective it was to work alone"*. A significant difference can be seen for the first question ($F(2,27)= 6.54$, $MS_W=25.9$, $p=0.005$), with a clear declaration that in an immersive environment teamwork would be more appreciated and efficient as it would be on the desktop. As for the second question no significant difference can be seen with a similar perception over all displays that this task was slightly more effective alone as it would be in a team. However, the standard deviation for this question was quite high with 25-30%, showing that the users were undetermined about this question. [Figure2]

The questionnaire was used to measure the users perception of their performance, but independently the time was measured for each trial. The results are rather surprising if compared with the user perception and show that on a desktop the task was in average finished after 6min 10sec, on the workbench after 6min 50sec and on the CAVE-like display after 7min 25sec. An ANOVA for the measured time showed no significant difference for any of the displays ($F(2,30)= 1.33$, $MS_W=4.21$, $p=0.280$).

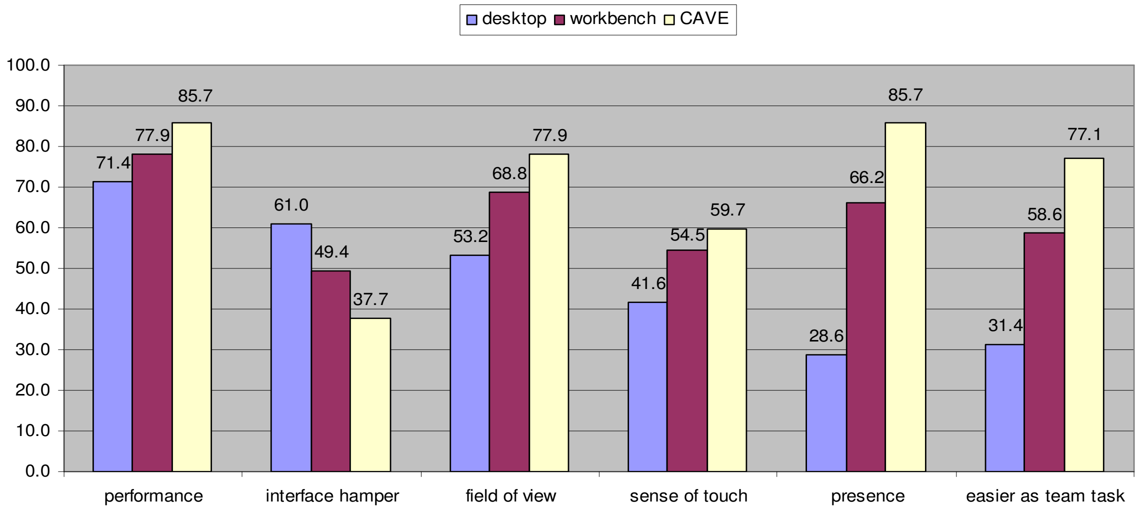

Figure 2: summery of user perception

3.2 Detailed, comparing two extremes

The previous results show that the users perceive the use of immersive displays as more efficient and convenient than the use of a desktop display. However, these results cannot be substantiated by the measurements of the time taken for this task. The average time for all displays was around 6-7 minutes, which does not seem to support the perception of the participants. We will discuss this contradiction later in this paper, but first we will look at two opposite cases. In the first case (case1) the user had a fast time on all displays and in the second case (case2) the desktop time was faster then on the immersive displays. The main difference between the two has been observed in how they used the displays. The former was taking advantage of the displays properties (movability, view frustum, interaction) whereas the later used all displays as if he was fixed in his position (Table 2).

As mention earlier DIVE is using ray-casting manipulation at the desktop display and one-handed manipulation in the immersive displays. This has the effect that the desktop user can manipulate objects from a distance, whereas in the immersed setting they must approach the object directly. The advantage on the desktop is an apparent increase in the "field of view" (visible part of the building site). However, this would only work well in an open environment as it is the case in this trial. The effect of this can be seen in Figure 3a where the desktop user moved very little and

Table 2: comparison of two opposite cases, using 7-point Likert-type scale

perception of	**case1** Desktop	**case1** Workbench	**case1** CAVE	**case2** Desktop	**case2** Workbench	**case2** CAVE
performance	4	6	6	4	5	6
field of view	3	5	7	6	4	3
navigation	5	5	5	3	4	5
sense of touch	2	3	4	5	5	4
presence	2	5	7	1	5	6
teamwork	2	3	3	1	4	7
time for task	6 min	6 min	6 min	6 min	7 min	9 min
observation	- good use of all walls in the CAVE - "10min ago I was working on the wall, now I am in the middle and that makes a difference"			- a mental picture of the scene seems to be missing - static physical position on the immersive display, but lots of joystick movements		

performed the object manipulation from a distance. In contrast, the immersive displays require direct manipulation hence the large amount of user movements in Figure 3b and 3c. In addition, the CAVE has a larger amount of movements in a contained space compared to the workbench because the user is able to walk in a 3-by-3 metre space whereas at the workbench the user is restricted to stand in front of the display.

Something the figures show as well is that the user of case1 is moving less and shorter than in the user of case2. This is in harmony with the observations that in case2 the joystick was used much more than in case1 where the user made more use of his physical space to move. This is possible due to the tracking of the body, allowing precise and fast movements around an object, if it is close enough. This includes for the CAVE a quick turn around to a different object on the opposite wall.

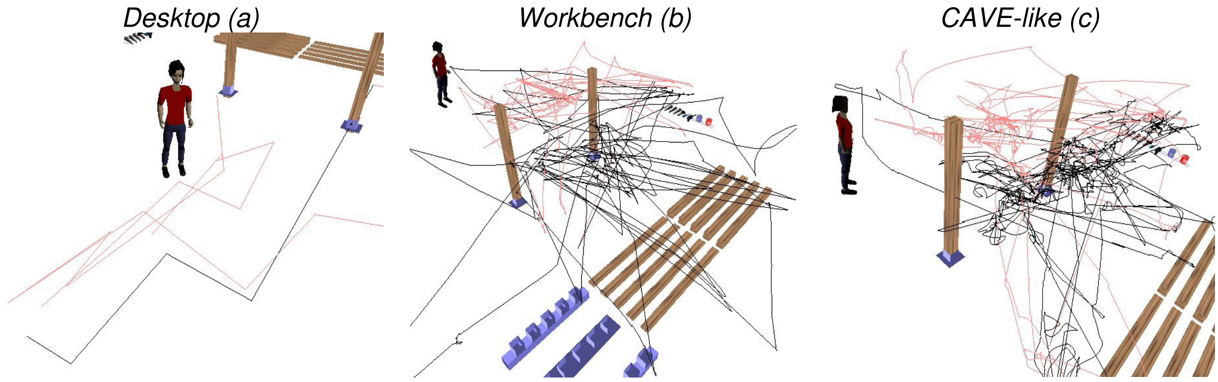

Figure 3: traces of the moving avatar during the task, case1: dark line, case2: bright line

If the user is using those abilities it could increase their feeling of presence and performance (Table 2) as well as reducing their frustration factor because one may "overshoot" the target when trying to get there with the joystick. Similar observations had been made in previous trials during close coupled interaction, leading to some distress when a user needed more time to adjust their position. Thereby the other user had to wait if one's action was needed to finish a cooperative subtask.

4 DISCUSSION

This section is discussing why perceived and measured performance was different, what the FOV has to do with user locomotion & navigation and why the interaction technique influences the user collaboration and performance.

One obvious observation (see Figure 2) is the difference between the perceived performance and the time needed to complete the task. The contradiction of these results can be explained in conjunction with the perception of being there, immersiveness and interaction technique (Figure 4). The results of this study (Figure 2) show significant differences in perceived presence for all displays. The same tendency can be seen for performance, FOV, missing touch and interface problems. Although those tendencies are not as strong as for presence, they show that the more one becomes immersed and engaged the higher the feeling of being there. Presence is not something that can be clearly measured but is a feeling created by a number of factors. Those factors like immersiveness, naturalness of interface and ease of interaction all contribute to a feeling of being there. Small differences of perception (between displays) for all those factors will have a profound influence of the perceived presence. This can also explain the difference between the perceived and measured performance. If one feels more engaged and present, time will seem to pass quicker and the users own activity will enhance the feeling of performance. This can also be seen in the reaction of the users, who consistently mentioned that the use of the immersive display was much more enjoyable than the desktop.

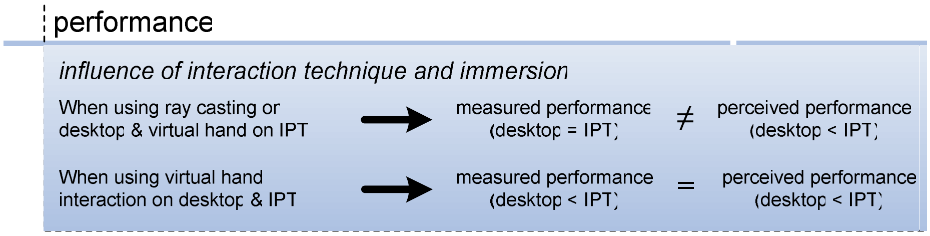

Figure 4: correlation diagram of perceived and measured performance

One point of interest in this study was to determine how much the field of view would influence the task performance. Our hypothesis was that with a wider view frustum the task would be easier, since the scene is more visibly available and therefore objects can be easier accessed. In contrast to the desktop, both immersive displays are similar in the way the user interacts, but the field of view is their main difference. This can also be seen in the data and observations gathered during this trial. At the workbench Figure 3b shows clearly longer ways for locomotion in comparison to Figure 3c. In addition, the observation during the trial was that on the workbench the joystick was used more often to attain an object as compared to the CAVE, where physical walking toward an object was easier and only longer distances needed the use of the joystick (Figure 5a and Figure 5b).

An exception to Figure 5b is the head mounted display (HMD) which has natural rotation (360º) independent of the FOV. This means that with an HMD the user does not need to use a joystick to rotate but rather uses its own body (Bowman, Datey, Ryu, Farooq, & Vasnaik, 2002).

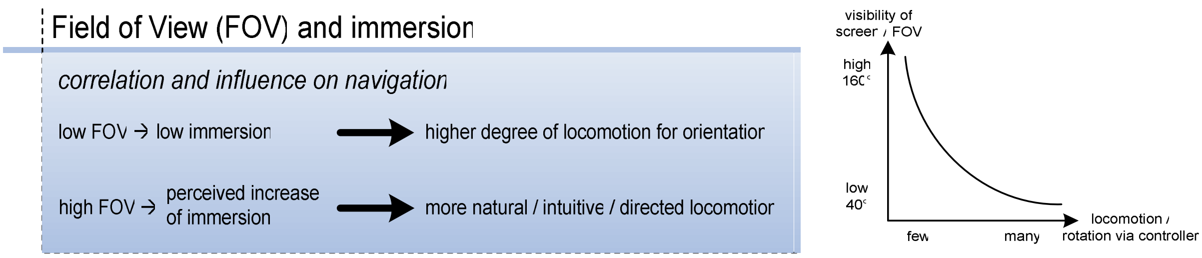

Figure 5a & 5b: correlation diagram of field of view and its influence on navigation

In contrast, the desktop has the smallest field of view of all the tested displays, yet the locomotion recorded during the trial was very low. The reason for this is based upon the ray-casting manipulation of objects. The user did not need to get close to the object, but could do everything from a remote place, from which the whole scene could be observed. However, in previous trials this behaviour was reason for complaint as other collaborating user could not see the correlation between a user and the object they were interacting with (Hindmarsh et al., 2000; Roberts et al., 2004). In addition, working from a remote place is only possible if an environment supports such behaviour, for example in a world without walls or very large rooms. Therefore, in a subsequent trial to this study expert users were repeating the task on the desktop, first from a remote location (using ray casting) and second from a location close to the object (virtual hand). The result was that the time taken to perform the task doubled for the close-up trial. Therefore we can hypothesise that if we try to improve the collaboration between users by allowing only close-object interaction, time-performance for desktop user will drop due to their limitation in field of view hence resulting in extended locomotion time to orientate (see Figure 4). In addition, a study from Steed et al. (Steed & Parker, 2005), who compared ray casting and virtual hand interaction on HMD and CAVE displays, found that virtual hand is superior for selection and manipulation of objects (Figure 6).

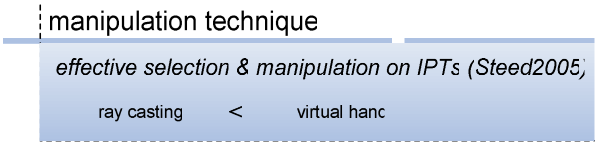

Figure 6: correlation diagram of manipulation technique

This study looks into influences on a single user task. Those influences will sustain in a co-presence situation and may even enhance. For example, problems with interface and manipulation of objects can interrupt the workflow in a closely-coupled situation (Hindmarsh, Fraser, Heath, & Benford, 2001). The previous studies showed that people have a higher perception of the performance of an immersed user, in-depended of the assessment of themselves or others (Roberts et al., 2003). They also show a significant difference between two immersed users and a desktop user, which was related to the easiness of manipulation and navigation.

Obviously, the interfaces of each display have to be suited for the task, which is most difficult to achieve on the desktop. Navigating and at the same time manipulating objects in a 3D environment with just a keyboard and mouse confuses most participants and it takes time to adjust to. This is in greater contrast to the interface at the immersive displays, where hand, head and body movements are directly used to interact. However, if people are accustomed to the use of a joystick for playing games they tend to use this knowledge, which leads to unnecessary locomotion and confusion. The reason is that joystick in games are well adapted with the use of a desktop, but in the CAVE the joystick is only a secondary input device supposed to be used for locomotion to places further away, whereas close-up navigation can simply achieved by body motion.

5 CONCLUSION

Previous studies on closely-coupled collaboration (Roberts et al., 2003) showed an enhanced measured and perceived performance on CAVE-like displays. Yet it was unclear what influencing factors were related to the single user and display. To answer this question we performed this study which excluded the collaboration and was to focus entirely on the display properties (field of view, interface and task performance) and there effects on a task designed for teamwork.

This study shows that different factors lead to an increasing perception of presence and performance. Those factors such as FOV, manipulation technique and navigation may influence our own interaction an in a collaborative task and our perception on and off others (e.g. no fragmented workflow). It should also be noted that immersive displays promote the use of teamwork, as users can see the benefit in collaborative tasks even when they work alone.

In previous studies we measured for CAVE-like displays an increase of performance in a collaborative task (Roberts et al., 2003), yet no such difference could be measured on a single user task. At the same time this new study showed an increase of perceived performance. Since the display and application properties were identical for both studies, it can be concluded that the measured performance increase is due to the collaboration. It seems that CAVE-like displays are better at representing contribution of others, but can trick a single user into thinking they are achieving more than they truly are.

6 REFERENCE

Arthur, K. (1996). *Effects of field of view on task performance with head-mounted displays.* Paper presented at the Human Factors in Computing Systems, Vancouver, Canada, pp. 29-30.

Bowman, D., Datey, A., Ryu, Y., Farooq, U., & Vasnaik, O. (2002). *Empirical Comparison of Human Behavior and Performance with Different Display Devices for Virtual Environments.* Paper presented at the Human Factors and Ergonomics Society Annual Meeting, pp. 2134-2138.

Bowman, D. A., Gabbard, J. L., & Hix, D. (2002). A Survey of Usability Evaluation in Virtual Environments: Classifcation and Comparison of Methods. *Presence: Teleoperators and Virtual Environments, **11***(4), 404 - 424.

Bowman, D. A., Johnson, D. B., & Hodges, L. F. (2001). Testbed Evaluation of Virtual Environment Interaction Techniques. *Presence: Teleoperators and Virtual Environments, **10***(1), 75-95.

Brooks, F. P. (1999). What's Real About Virtual Reality? *IEEE Computer Graphics & Applications, **19***(6), 16-27.

Dudfield, H. J., Macklin, C., Fearnley, R., Simpson, A., & Hall, P. (2001). *Big is better? Human factors issues of large screen displays with military command teams.* Paper presented at the People in Control, pp. 304-309.

Fraser, M., Benford, S., Hindmarsh, J., & Heath, C. (1999, November). *Supporting Awareness and Interaction through Collaborative Virtual Interfaces.* Paper presented at the 2th Annual ACM Symposium on User Interface Software and Technology (UIST'99), pp. 27-36.

Frécon, E., Smith, G., Steed, A., Stenius, M., & Stahl, O. (2001). An Overview of the COVEN Platform. *Presence: Teleoperators and Virtual Environments, **10***(1), 109 - 127.

Frécon, E., & Stenius, M. (1998). DIVE: A Scalable network architecture for distributed virtual environments. *Distributed Systems Engineering Journal (special issue on Distributed Virtual Environments), **5***(3), 91-100.

Greenhalgh, C. M., Bullock, A., Frécon, E., Lloyd, D., & Steed, A. (2001). Making Networked Virtual Environments Work. *Presence: Teleoperators and Virtual Environments, **10***(2), 142-159.

Guimbretière, F. (2002). *Fluid interaction for high resolution wall-size displays.* Stanford University, Stanford, CA.

Hindmarsh, J., Fraser, M., Heath, C., & Benford, S. (2001). Virtually Missing the Point: Configuring CVEs for Object-Focused Interaction. In *Collaborative Virtual Environments. Digital Places and Spaces for Interaction* (pp. 115-139). London, UK: Springer Verlag.

Hindmarsh, J., Fraser, M., Heath, C., Benford, S., & Greenhalgh, C. (2000). Object-Focused Interaction in Collaborative Virtual Environments. *ACM Transactions on Computer-Human Interaction (ToCHI), **7***(4), 477-509.

Kjeldskov, J. (2001). *Interaction: Full and partial Immersive Virtual Reality Displays.* Paper presented at the IRIS24, pp. 587-600.

Lapointe, J.-F., & Vinson, N. G. (2002, June 18-21). *Effects of Joystick Mapping and Field-of-View on Human Performance in Virtual Walkthroughs.* Paper presented at the the 1st International Symposium on 3D Data Processing Visualization and Transmission, Padova, Italy, pp. 490-493.

M.J.Schuemie, P. v. d. S., M.Krijn. C.A.P.G.van der Mast. (2001). Research on Presence in VR: a Survey. *Cyberpsychology and Behavior, **4***(2), 183-202.

Mortensen, J., Vinayagamoorthy, V., Slater, M., Steed, A., Lok, B., & Whitton, M. C. (2002). *Collaboration in tele-immersive environments.* Paper presented at the Proceedings of the workshop on Virtual environments 2002, Barcelona, Spain, pp. 93 - 101.

Poupyrev, I., Weghorst, S., Billinghurst, M., & Ichikawa, T. (1998). Egocentric object manipulation in virtual environments: empirical evaluation of interaction techniques. *Computer Graphics Forum, **17***(3), 41-52.

Roberts, D., Wolff, R., Otto, O., Kranzlmueller, D., Anthes, C., & Steed, A. (2004). *Supporting Social Human Communication between Distributed Walk-in Displays.* Paper presented at the VRST 2004, pp. 81-88.

Roberts, D. J., Wolff, R., & Otto, O. (2003). Constructing a Gazebo: Supporting team work in a tightly coupled, distributed task in virtual reality. *Presence: Teleoperators and Virtual Environments, **12***(6), 644-668.

Schroeder, R., Steed, A., Axelsson, A. S., Heldal, I., Abelin, A., Widestroem, J., Nilsson, A., & Slater, M. (2001). Collaborating in networked immersive spaces: as good as being there together? *Computers and Graphics, **25***, 781-788.

Steed, A., Mortensen, J., & Frécon, E. (2001). *Spelunking: Experiences using the DIVE System on CAVE-like Platforms*

Steed, A., & Parker, C. (2005). Evaluating Effectiveness of Interaction Techniques across Immersive Virtual Environment Systems. *forthcoming in Presence: Teleoperators and Virtual Environments, **14***(5).

Tan, D. S., Gergle, D., Scupelli, P. G., & Pausch, R. (2003, April 5-10). *With Similar Visual Angles, Larger Displays Improve Spatial Performance.* Paper presented at the Conference on Human factors in Computing Systems (CHI), Ft. Lauderdale, Florida, USA, Vol. *5*, pp. 217-224.

Wolff, R., Roberts, D., & Otto, O. (2004). A study of event traffic during the shared manipulation of objects within collaborative virtual environments. *Presence: Teleoperators & Virtual Environments, **13***(3), 251-262.