Cubes in the Cube: A Comparison of a Puzzle-solving Task in a Virtual and a Real Environment

Ann-Sofie Axelsson [1], Åsa Abelin [2], Ilona Heldal [1],
Ralph Schroeder [1], and Josef Wideström [3]

[1] Department of Technology and Society, Chalmers University of Technology,
SE-412 96 Gothenburg, Sweden
{asax, ilona,schroeder}@mot.chalmers.se
[2] SSKKII and Department of Linguistics, Göteborg University, Box 200,
SE-405 30 Gothenburg, Sweden
abelin@ling.gu.se
[3] Chalmers Medialab, Chalmers University of Technology,
SE-412 96 Gothenburg, Sweden
josef@medialab.chalmers.se

Corresponding and presenting author: Schroeder, phone: +46-31- 772-3888, fax: +46-31-772-3783,
schroeder@mot.chalmers.se

Summary of main contributions:

- Comparison of presence and co-presence for a highly interactive and highly collaborative task (moving blocks to solve a puzzle)
- Differences between collaboration and leadership in performing the same task in a virtual and a real setting
- Drawing lessons for collaborative virtual environments and for the study of co-presence

1. Introduction

In this study, we are interested in how two people are able to work together on two different types of virtual reality (VR) systems to solve a task with virtual objects - moving blocks to solve a puzzle – and to compare this with how they solve the same task face-to-face in a 'real' setting. The task was selected first, in order to investigate how people interact with each other in virtual environments (VE's), and second, because virtual environments are said to lend themselves to tasks which involve interaction with spatially complex 3-D environments.

The experimental setting was collaboration in a virtual environment between one person on a CAVE-type system and the other person on a desktop system. In the real setting, the collaboration involved face-to-face interaction on similar size blocks or cubes.

The hypotheses to be tested were:

- Co-presence and presence are greater for person in the CAVE-type system – in this case, a so-called 3-D Cube with five projection walls, and co-presence and presence are correlated on both systems.
- In terms of contribution to the task, person in the Cave-type system will be regarded as the leader (greater contribution), but the person on the desktop system will take a more active part in terms of verbal activity. In the

real setting, both partners will contribute equally.

2. Background and Previous Studies

A previous study by Slater et al.(2000) of a puzzle-solving task with three participants found that presence and co-presence are correlated, and that leadership varies between a virtual setting in which the more ’immersed’ participant is singled out as the ’leader’ as against the same task performed in the ’real’ setting where no one is singled out as the ’leader’. A previous study of ours which examined presence, co-presence and collaboration and compared a task on two VR systems with different levels of immersion (desktop vs. Cave-type system) found that although participants were able to make discriminating judgements about their own experience (presence and co-presence) of the different VR systems, they were unable to make discriminating judgements about their joint experience (collaboration and communication) of the two systems (Axelsson et al.1999, cf. the similar finding in the study comparing collaborative work in a VE with and without haptic interaction in a block-moving task by Sallnäs et al, 1999). There are a number of other studies of these issues, which cannot be elaborated here for reasons of space. Nevertheless, the studies just mentioned have indicated a) that there is a need for a closer examination of the relationship between presence, co-presence, leadership and collaboration for different types of tasks and with different types of VR systems and b) that there is a need to investigate the differences between collaboration and communication in VE’s as against ’real’ world settings more generally.

3. Technical Description and Study Design

The participants used two VR systems for the task; a Cave-type system and a desktop system.
The Cave-type system that was used was 3x3x3 meter TAN 3D Cube with stereo projection on five walls (no ceiling). The application was run on a Silicon Graphics Onyx2 Infinity Reality with 14MIPS R10000 processors, 2GB RAM and 3 graphics pipes. The participants wore Crystal Eyes shutter glasses with a Polhemus tracking device and used the dVise 3-D mouse for navigation. The software that was used was dVise 6.0 supported by the Performer renderer. According to measurements carried out during the trial by the Performer renderer, the frame rate was at least 30 Hz.

The desktop system consisted of a Silicon Graphics O2 with one MIPS R10000 processor and 256MB RAM and a 19 inch screen, again with dVise 6.0 software. An ordinary mouse was used for navigation. The frame rate during the task, again according to the Performer renderer, was at least 30 Hz.

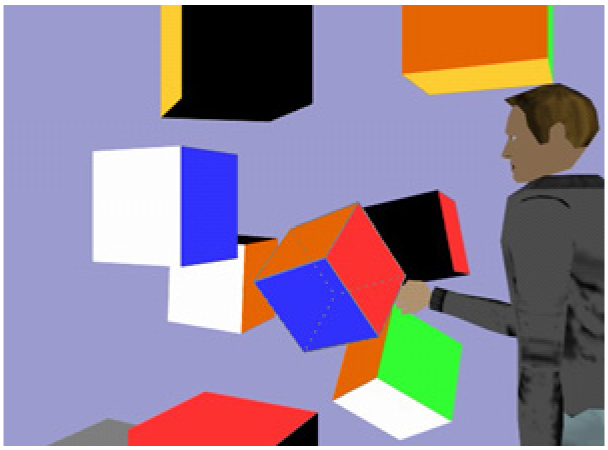
The task was to solve a puzzle involving 8 blocks with different colours on different sides and to rearrange the blocks such that each side displays a single colour (i.e. 4 squares of the same colour on each of the six sides). The task is therefore similar to – but less complex than – the popular Rubik’s cube puzzle which involves 9 squares on each side. In our trials the squares were 30 cm along each edge.

Participants were given a maximum amount of 20 minutes to solve the puzzle each time, first in the VE and then with the ’real’ cubes. There were 44 (voluntary) participants in the trials, and thus 22 groups which completed the tasks first in the virtual and then in the 'real' settings.

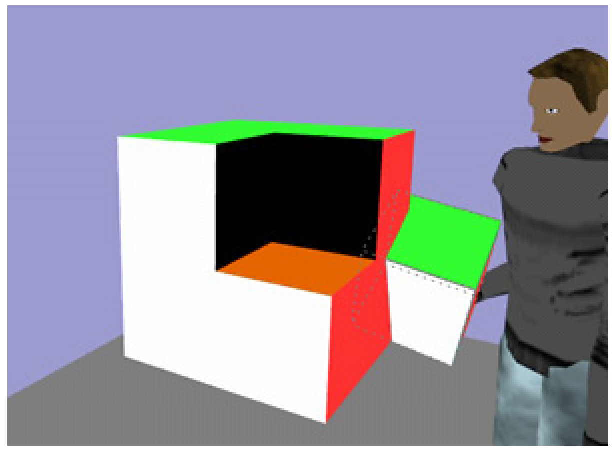
In the Cube system, participants could move the blocks or cubes by putting their hand into the virtual cube and pressing on the button of the 3-D mouse (please note that Cube will be capitalized when referring to the VR system and written with lower-case ’c’ for the blocks). Participants could not use the other buttons on the 3-D mouse as they often can in other systems: navigation was purely by moving around physically and gesturing with the 3-D mouse (navigation by ’flying’ would detract from the task in this case).

On the desktop system, participants could navigate by moving the middle mouse button and select the cubes by clicking on the cube with the left mouse button. To move the cubes, they had to keep the right mouse button pressed and moving the mouse in the desired direction. They could also rotate the cube by pressing the right mouse button combined with the shift key.

In both systems, the movement of the avatars was fixed within the limit of the floor and eye level to avoid participants going through the floor or flying up into the air.
In both systems, users were represented by identical human-like avatars (the standard avatar in the dVise software system) and could communicate via telephones (using headsets so that their hands were free).



Cubes in the cube: beginning the task



Completing the task

4. Results

For reasons of space, we report only a few of our results here.

In this study, we were not interested in comparing the performance of participants as such, but since performance (measured in minutes for completing the task) may be of interest to the reader in the light of our other results, we can briefly say that: for the virtual settings, only 6 groups out of 22 completed the task (M = 15.00, SD = 3.10), wheras in the real setting, all groups completed the task (M = 5.75, SD = 3.72).

4.1 Presence

In order to find out how present the subjects felt in the two VR systems we asked "To what extent did you have a sense of being in the same room as the cubes? " (on a scale of 1-5 where 1 = to a very small extent and 5 = to a very high extent). The subjects reported a stronger sense of presence in the Cube environment than in the desktop environment.

An ANOVA showed that there was a significant difference between the environments $F(1, 42) = 62.60$, MS_E =.80, $p < .001$ (w^2 =.58) such that the subjects reported a stronger presence in the Cube (M = 4.41, SD = .67) than at the desktop (M = 2.27, SD = 1.08). We asked two differently worded questions on presence which indicated the same results.

4.2 Co-presence

Next, in order to find out how co-present the subjects felt in the VR-system, we asked the subjects "To what extent did you have a sense of being in the same room as your partner?" (on a scale of 1-5 where 1 = to a very small extent and 5 = to a very high extent). Co-presence was low in the Cube (M = 2.23) and in the desktop environment (M = 2.45) and there was no significant difference between them. Again, we also asked them a differently worded question which indicated the same result.

4.3 Activity

Three questions were asked to allow the subjects evaluate their own and their partners activity: "How would you evaluate your and your partners level of activity when it came to solving the task?", "To what extent did you and your partner contribute to placing the cubes", "Who talked the most, you or your partner". The first question concerned activity in general, the second the contribution in placing the cubes and the third the amount of verbal contribution.

When the partners evaluated their own activity, in relation to the question of solving the task the answer was that subjects in the Cube were more active. Evaluations were given in percentage terms where both partners had to add up to 100, i.e. if partners were equal they would add up 50 - 50.

An ANOVA showed that there was a significant difference between the groups for the first two questions concerning activity in general $F(1, 42) = 14.49$, $MS_E = 136.50$, $p < .001$ ($w^2 = 0.23$) and contribution in placing the cubes $F(1, 42) = 22.69$, $MS_E = 209.19$, $p < .001$ ($w^2 = 0.33$) The largest difference between Cube and desktop was found in the estimation of contribution in placing the cubes. For communication activity there was no significant difference between desktop and Cube.

In the real world setting, there was no significant difference between participants on any of the three measures for activity.

4.4 Collaboration

We also asked the participants to evaluate collaboration: "To what extent did you experience that you and your partner collaborated?" (on a scale of 1-5 where 1 = to a very small extent and 5 = to a very high extent). The results show that subjects felt that they collaborated to a high degree in both desktop and the Cube environments. There was no significant difference between the two groups. Nor was there any significant difference between subjects in terms of collaboration in the ‘real’ world setting. There was, however, a significant difference between VR and 'real' as shown by a T-test; subjects felt that they collaborated more in 'real' world $T(43) = 5.52$, $p < .001$.

5. Conclusions

Some of our findings are expected: that there was a stronger sense of ’presence’ in the Cube than on the desktop system, and that the task took longer in the VE than in the ’real’ world. It should be mentioned that better performance in the ’real’ world than in the VE should not be regarded as an indication that VR technology is not suitable for this type of task: first, because it may be that the reason for using VR technology may be to enable users to do what they cannot do in the ’real’ world – for example, the cubes can be modified more easily, they do not ’weigh’ anything, etc. Secondly, the reason for using networked VE’s may be to allow users to work together at a distance – in this case, a more appropriate comparison might have been to compare collaborative VE’s with videophones, or with two people collaborating on the cube puzzle by giving each other instructions about how to simultaneously move the ’real’ cubes (of which they would each have to have a copy) over the telephone. It should also be noted that in order to make a definitive comparison of performance (and also of collaboration – see below), the task order should be reversed: that is, real task first, then the task in the virtual. We intend to do this reverse study, but in this paper only report on the virtual-to-real sequence.

There was no significant difference between the two systems in relation to co-presence, but participants in the Cube reported a high degree of presence without a high degree of co-presence. This is surprising because participants did report differences in ’presence’ and because Slater et.al., 2000 (in a study of two participants on a desktop system and one participant with an HMD, and with no manipulation of objects) found a significant correlation between ’presence’ and ’co-presence’. The explanations for this could be a) that participants in the Cube had a greater sense of interaction with the objects, and thus their interaction with their partners was less important than in the study of Slater et al.; or b) that participants on the desktop had an equally detached view of the cubes and of their partner, whereas for Cube participants the cubes where more immediate.

In relation to leadership, which can be defined as contributing the greater share to the task, we found that participants in the Cube were evaluated by both partners as being more active in the task generally and contributing more to placing the cubes, but there was no significant difference in the share of communication. This result could be expected inasmuch as in previous studies, leadership has been correlated with technological advantage in being more immersed (Slater et al., 2000) and has also been correlated with being the navigator in a task where the two partners are equally immersed (Axelsson et al., 1999). In our study, both the different levels of immersion and the interaction devices (3-D mouse vs. conventional mouse) may be responsible for this effect. What is surprising here is that there was no significant difference in terms of leadership in the share of verbal activity. It could have been expected that the desktop partners would ’make up’ for their relative lack of physical activity with verbal activity. Conversely, it might be thought that leadership in the physical part of the task would also carry over into verbal leadership. In our study, however, neither partner was evaluated as being more dominant in verbal activity. (We are in the process of evaluating data from voice recordings and will assess whether quantitative – share of exchange – or qualititave differences – content – can be found.)

In the real task, on the other hand, participants regarded themselves and their partners as being equally active for all three questions. This was expected in the light of the study of Slater et al., which found a similar asymmetry between the more immersed and the less immersed partner in the ’virtual’ task – with, in their case, as in ours, partners who did not know each other before – and the same task carried out in a ’real’ world setting where there was similarly no leader.

In terms of collaboration, the difference, as we have seen, is between ’virtual’ and ’real’: participants felt that there was more collaboration on the task in the ’real’ as opposed to the virtual setting. There was no difference between Cube- and desktop participants. A possible explanation for this is that face-to-face interaction offers ’richer’ communication possibilities than communication via different communications media (for a review of studies of media ’richness’ and ’social presence’, see van Dijk, 1999:206-214). It is also interesting to compare this study with a previous study of ours which compared collaboration of two co-located partners in the Cube as against two partners solving the same puzzle sitting next to each other on a desktop system: in that study, we found that desktop partners thought they were collaborating to a greater extent than Cube partners – even though the Cube partners reported a greater degree of co-presence in the environment than desktop partners (Axelsson et al., 1999).

If we look at leadership and collaboration together, we can see that in the virtual setting, where participants assessed their contributions unequally, they also reported a lower degree of collaboration. In the real setting, on the other hand, they assessed their respective contributions equally, and also reported more collaboration. At this point it may therefore be asked: is the ’division of labour’(between the Cube participant and the desktop participant) experienced as a less collaborative way of performing the task? Put differently, would ’greater equality’ felt to be more collaborative? These questions must be studied if the aim is to design truly collaborative VE's.

If we assume that more equal contributions and higher degrees of collaboration are good for co-working on a task in VE's, then we can see that in this case, the virtual setting and/or the difference between the two types of systems are responsible for a more unequal and less collaborative mode of co-working. Again, this can be put the other way around and from a somewhat different viewpoint: technologically-mediated communication introduces asymmetries into interpersonal interaction and/or takes away social cues. These are issues which must be taken into account in the design of collaborative VE's.

The task we examined in this study involved a high degree of physical interaction with the VE and a high degree of collaboration with virtual objects. It produced different results, as we have indicated, from, among others - both studies which involved mainly verbal collaboration (Slater et al.,2000) and from studies which involved a mainly 'physical' task (Sallnäs et al., 1999). Since these are different tasks on different VR systems and with different modes of collaboration, they are not strictly comparable. But they show that systematic investigation of the issues discussed - presence, co-presence, leadership and collaboration - and disaggregating the various factors responsible for these features of VE's, will be highly rewarding.

6. Future Work

As already indicated, we intend to reverse the sequence of tasks – real to virtual – in order to measure whether this makes a difference to performance and collaboration and whether the knowledge gained in one setting makes a difference to the subsequent task. We will also analyze audio recordings made during our study and examine other correlations that were found. An obvious interesting novel direction would be to allow both participants to work on the same type of VR system: would this enhance collaboration? Other configurations of the study can be envisaged, but a start has been made in examining a highly involving type of task – the most physically ’interactive’ task, to the best of our knowledge - in a collaborative Cave-type VE setting.

Acknowledgements:

This research was carried out as part of a project on ’Intercultural Communication in Virtual Environments’ funded by the Swedish Transport and Communications Research Board (KFB). We would also like to thank Linda Björk Hassing and Alexander Nilsson for their help with the study.

References:

Axelsson, Ann-Sofie; Abelin, Åsa; Heldal, Ilona; Nilsson, Alexander; Schroeder, Ralph and Wideström, Josef. 1999. ’Collaboration and Communication in Multi-User Virtual Environments: A Comparison of Desktop and Immersive Virtual Reality Systems for Molecular Visualization’ in Proceedings of the Sixth UKVRSIG Conference, ed. Terrence Fernando, Salford UK, 14th Sept., pp.107-117.

Sallnäs, Eva-Lotta; Rassmus-Gröhn, Kirsten and Sjöström, Calle. 1999. ’Supporting Presence in Collaborative Multimodal Environments by Haptic Force Feedback’, presented at the 2nd International Workshop on Presence, Wivenhoe, Essex, April 6-7.

Slater, Mel; Sadagic, Amela; Usoh, Martin and Schroeder, Ralph. 2000. ’Small Group Behaviour in a Virtual and Real Environment: A Comparative Study’, forthcoming in Presence: Journal of Teleoperators and Virtual Environments.

VanDijk, Jan. 1999. The Network Society: Social Aspects of New Media, London: Sage.