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Collaborating in networked immersive spaces: as good as being there together?

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Abstract

In this paper we present the results of a trial in which two participants collaborated on a puzzle-solving task in networked virtual environments. The task was a Rubik's cube type puzzle, and this meant that the two participants had to interact with the space and with each other very intensively—and they did this successfully despite the limitation of the networked situation. We compare collaboration in networked immersive projection technology (IPT's) systems with previous results concerning collaboration in an IPT system linked with a desktop computer, and also with collaboration on the same task in the real world. Our findings show that the task performance in networked IPT's and in the real scenario are very similar to each other—whereas IPT-to-desktop performance is much poorer. Results about participants' experience of 'presence', 'co-presence' and collaboration shed further light on these findings.

Keywords: Virtual environments; Immersive projection technology systems; Collaboration; Presence; Co-presence

1. Introduction

Collaboration at a distance has long been an important research goal of networked or multi-user virtual reality (VR) systems and virtual environments (VE's). With the recent emergence of immersive projection technology (IPT) displays, this type of collaboration has become possible within highly immersive displays. IPT's such as the CAVE™ were originally described by Cruz-Neira, Sandin and DeFanti [2] and have become increasingly popular in recent years.

In this paper, we present the results of a trial in which two participants collaborated on a Rubik's cube type puzzle-solving task in IPT's networked together to form a shared VE. The task meant that the two participants had to interact with the space and with each other very intensively and without being aware that they were in fact in two different locations. We compare collaborating in networked IPT's with collaboration in an IPT system linked with a desktop computer, and also with collaboration on the same task in the real world.

There are several novel elements of this research. The first is that although there have been a number of demonstrations of the feasibility of collaboration in networked IPT VE's, this is the first time to our knowledge (confirmed by Cruz-Neira, personal communication, 9.11.2000) that networked IPT's have been evaluated in relation to the experience of users. It is also the first time that networked IPT's have been compared with other networked VR technologies (in this case, an IPT system networked with a desktop system) and with performance of the same task in the real world.

We can also mention a second unique feature of this trial: as VR researchers, we are familiar with VE's that are highly visually complex, and which feature detailed scenes that the user typically (passively) navigates

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through. Our Rubik's cube puzzle, in contrast, is visually very simple—but it is much more interactive than the typical VE's (Fig. 1).

By this we mean that the user not only navigates through, but constantly picks up objects, turning and examining and relocating them, and making full use of the IPT's tracking system by bending down and moving around in the space in order to get different viewpoints. Moreover, the user is constantly interacting with another full-size and equally active user. In other words, the combination of the scene in the VE and the task is highly compelling and engaging. And although we can only assert this rather than prove it to the reader—in any case, there are no precise measures or comparisons for our assertion—nevertheless, in our view, and in the reaction that we observed among the participants, performing this task collaboratively in this VE is one of the most truly interactive uses of VE's that we have come across. In this context it can be mentioned that in previous work [8] it has been noted that a high sense of presence is correlated with a greater degree of body movement in an immersive VE, and the research presented below supports this finding.

This paper will present first, the performance results for all three conditions solving the puzzle—IPT-to-IPT (henceforth ItI), real or face-to-face (FtF), and IPT-to-desktop (ItD). Next, we will present the results for collaboration; the extent to which participants thought they collaborated and the extent to which they enjoyed the collaboration. And finally, on the issue of collaboration, we will present the results for how participants judged their own and the other participant's contribution to solving the puzzle.

In the next part of the results section, we shall focus on the comparison between the different VR systems: what are the differences between IPT and desktop systems in terms of the extent to which the participants experienced a sense of 'presence' and 'co-presence'? Here

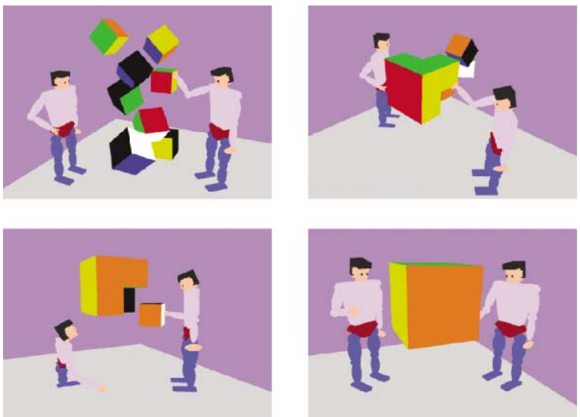

Fig. 1. Two participants completing the Rubik's cube puzzle.

we will distinguish between how participants are affected by each other's sense of presence, and how they are affected by using different systems.

In the discussion section, we shall link the various results by asking: how do the different technologies (or the lack of technology in the case of the real scenario) affect collaboration? And how does the experience of users ('presence', 'co-presence') relate to their experience of collaboration?

2. Previous studies

There is a growing literature in the study of VE's on 'presence' and 'co-presence', but collaboration, particularly in highly immersive VE's, has not been extensively studied. A previous study by Slater et al. [7] of a puzzle-solving task with three participants (one using an immersive head-mounted display system, and two on desktop systems) found that presence and co-presence were correlated, and that leadership varied between a virtual setting in which the more immersed participant was singled out as the leader—as against the same task performed in the real setting where no one was singled out as the leader. In another recent study [1] which examined presence, co-presence and collaboration and compared a task on two VR systems with different levels of immersion (desktop vs. IPT system), it was 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) in relation to the two different systems (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. [3]).

In a further study we reported on a comparison of doing a Rubik's cube puzzle in an ItD condition versus a FtF condition [11]. The main finding of that study that is relevant here is that whereas collaborators in the FtF condition experienced that they participated equally, in the ItD condition they reported that they contributed unequally—despite being unaware of what type of system the other participant was using (as was the case in the Slater et al. [7] study mentioned above, and in the study we report here).

In the study below, we report only on comparisons between groups that did the task for the first time. But we can also mention that for the ItD vs. FtF trial we did the trial both ways—virtual condition and then real, and vice versa. Here we found, against expectations, that whereas doing the 'virtual' task first enhanced the reported collaboration of doing the real task afterwards, doing the real condition first did not (see [11]). In other words, if participants carry out the virtual task first, they experience more collaboration when they carry out the real task afterwards—but not vice versa.

These studies have indicated that there is a need for closer examination of the relationship between presence, co-presence, leadership/contribution to the task and different types of VR systems in order to distinguish between the effects of technology, task dependence, and social dynamic.

3. Technical description and study design

The IPT system that was used at Chalmers University was a $3 \times 3 \times 3\,\mathrm{m}^3$ TAN VR-CUBE (henceforth Chalmers Cube) with stereo projection on five walls (no ceiling). The application was run on a Silicon Graphics Onyx2 Infinity Reality with 14 250 MHz R10000 MIPS processors, 2 GB RAM and 3 Infinite Reality2 graphics pipes. The participants wore CrystalEyes shutter glasses and used a 3-D wand for navigation. A Polhemus magnetic tracking device tracked both the glasses and the hand. According to measurements carried out by the Performer renderer during the trial, the rendering performance was at least 30 Hz.

The IPT system at University College London was a ReaCTor made by Trimension (henceforth UCL ReaCTor). It consists of three $3 \times 2.2\,\mathrm{m}^2$ solid acrylic walls and a 3 m square floor. It is powered by a Silicon Graphics Onyx2 with 8 300 MHz R12000 MIPS processors, 8 GB RAM and 4 Infinite Reality2 graphics pipes. The participants wore CrystalEyes stereo glasses which are tracked by an Intersense IS900 system. The participant holds a device with 4 buttons and an analogue joystick that is similarly tracked. Rendering performance was 45 Hz.

For the ItI condition, the software used at both sites was a recent version of the Distributed Interactive Virtual Environment (DIVE) toolkit [4]. This has recently been ported to the Performer version of the CAVElib enviroment at UCL. DIVE is designed to support distribution of environments to mid-sized groups of participants over a wide area. The distribution model is a partially replicated shared database maintained by a multicast transmission of data. However, given the lack of multicast connectivity between the two sites, we set up a DIVEBONE connection to act as a bridge [5].

For the ItD trials, we used a desktop system consisting of a Silicon Graphics O2 with one MIPS R10000 processor and 256 MB RAM and a 19-inch screen display. In this case, unlike for the ItI trial, we used dVise 6.0 software. The VE for the ItD/dVise and the ItI/DIVE trial were identical in appearance and functionality, but the avatars were slightly different in appearance. For the ItD trial, an ordinary mouse was used for navigation on the desktop systems. The rendering performance was at least 20 Hz.

We used the Robust Audio Toolkit (RAT) for audio communication between the participants except on one occasion when a mobile phone was used at each end.

Each participant was portrayed to the other by the use of a simple human-like male avatar with a jointed arm. The participant could not see their own avatar, except for a virtual hand drawn in the same position as their physical hand. Although local tracker updates are applied at the fastest rate provided by the tracker driver, network updates are only sent at 10 Hz. The network lag between the two sites for the ItI trials was approximately 180 ms, and faster for the ItD trial (which took place on the network at Chalmers University).

Since the UCL ReaCTor only has three walls plus a floor, it was necessary to enable locomotion with the joystick. Locomotion was disabled at the Chalmers Cube since the puzzle fits within the space of the Cube. In both IPT systems, participants could move the blocks or cubes by putting their hand into the virtual cube and pressing on the button of the 3-D wand. 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 move the mouse in the desired direction. They could also rotate the cube by pressing the right mouse button combined with the shift key.

The task in all three conditions was to solve a puzzle involving eight blocks with different colours on different sides and to rearrange the blocks such that each side would display a single colour (i.e. four squares of the same colour on each of the six sides). For the FtF trial, participants were asked to do the same task with cardboard blocks on a table—where the blocks were the same as in the VE in size and appearance.

The task was therefore similar to, but less complex than, the popular Rubik's cube puzzle which involves nine squares on each side. In our trials the squares were 30 cm along each edge. Participants were given a maximum amount of 20 min to solve the puzzle each time, both in the VE and with the real cubes. For the reader's convenience in following the results below, we include a table which gives an overview of the trials, abbreviations for the trials, and technologies used (Table 1).

Table 1
Overview of trials, labels, and technology used

Trial	Label in text	Technology used
IPT-to-Desktop	ItD	Chalmers cube Desktop system
IPT-to-IPT	ItI	Chalmers cube UCL ReaCTor
Real	FtF	Cardboard blocks

There were 132 voluntary participants in the trials, with 22 pairs in each group (hence 44 participants in ItD condition, 44 in ItI condition and 44 in the FtF condition). Participants were asked to fill out a questionnaire about their background before the trial and about their experience after each trial session. The questions, which will in part be reproduced below, were often based on previous studies (esp. [7,11]) in order to build on and extend earlier results.

4. Results

4.1. Performance

We measured the time each pair took to solve the task. Pairs that did not complete the task within the time limit of 20 min were interrupted and not given a specific time measure. In this study, we were not interested in the performance of participants as such, but in comparing performance and other aspects of collaboration across the conditions. For the ItI condition, 18 groups out of 22 completed the task within a time limit of 20 min ($M = 8.82$, $SD = 4.61$), for ItD 6 groups out of 22 completed the task within the time limit ($M = 15.00$, $SD = 3.10$), and in the FtF condition, all groups completed the task within the time limit ($M = 5.75$, $SD = 3.72$) (Fig. 2).

4.2. Collaboration

We asked the subjects three questions (in different parts of the questionnaire) concerning collaboration. For the question: "To what extent did you experience that you and your partner collaborated?", the result was $M = 3.67$, $SD = 0.98$ (on a scale of 1–5 where 1 = to a very small extent and 5 = to a very large extent). Please note that the M here refers to the mean value for all the conditions since there was no significant difference between them. The second question, "[T]hink of some previous time (before today) when you enjoyed collaborating with someone. To what extent did you enjoy collaborating with your partner in today's task?", resulted in $M = 4.05$, $SD = 0.86$ (on a scale of 1–5 where 1 = to a very small extent and 5 = to a very large extent). And finally, "[T]o what extent would you, on another occasion, like to carry out a similar task with your partner?" yielded $M = 3.80$, $SD = 0.90$ (on a scale of 1–5 where 1 = Absolutely not and 5 = I would very much like to). An ANOVA showed that there was no significant difference across the three different conditions on the three measures ($p > 0.05$), although the relatively high values indicate that participants enjoyed the collaboration.

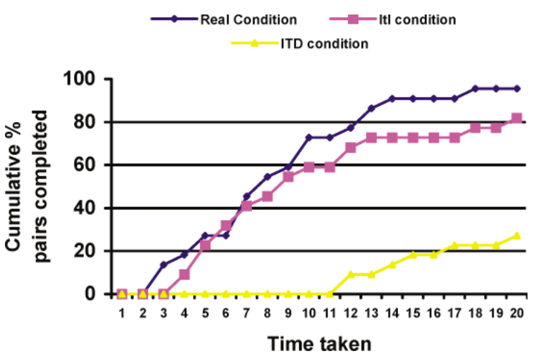

Fig. 2. Cumulative percentage of pairs of participants that completed the task by the given time for each of the three conditions. Note that not all pairs completed the task within 20 min.

4.3. Contribution to the task

Three questions were asked to allow the subjects to evaluate their own and their partners contribution to the task: "How would you estimate your and your partner's share in solving the task?", "To what extent did you and your partner contribute to placing the cubes?" and "Who talked the most, you or your partner?". The first question concerned contribution to the task in general, the second the contribution in placing the cubes, and the third the amount of verbal communication. Evaluations were given in percentage terms where both partners had to add up to 100%, i.e. if they were equal they would add up to 50–50.

Here we need to mention again that our questions about contribution closely followed the questions that have been used in previous studies about 'leadership' [7,9]. The difference in the current study is that we studied pairs of participants, whereas other studies have often involved three participants. But if pairs can be said to have 'leaders', then we could equally have talked about 'leadership' below where contributions are unequal.

If we take first the evaluation of *share in solving the task*, an ANOVA showed that there was a significant difference between the conditions $F(5, 126) = 3.99$, $MS_E = 143.11$, $p = 0.002$, $\omega^2 = 0.10$. A posthoc test (Tukey's) showed that the difference was significant only in the ItD trial where the immersed subject ($M = 54.77$, $SD = 9.94$) and the desktop subject ($M = 41.36$, $SD = 13.20$) evaluated their shares differently such that the immersed subject was perceived as being more active and the desktop subject less active (note that the mean values are self estimations).

In the ItI trial where the subjects worked under the same circumstances (ie. both being immersed in an IPT system) in the Chalmers Cube ($M = 43.64$, $SD = 11.57$) and in the UCL ReaCTor ($M = 50.23$, $SD = 14.51$), the subjects evaluated their own and their partner's share in solving the task as being equal. This equal evaluation applies also to the partners in the FtF trial (Subject A, $M = 52.05$, $SD = 9.34$), (Subject B, $M = 47.95$, $SD = 12.41$) (Fig. 3).

When it comes to the evaluation of *contribution in placing the cubes*, an ANOVA showed that there was a significant difference between the conditions $F(5, 125) = 6.68$, $MS_E = 168.46$, $p < .001$, $\omega^2 = 0.18$. A posthoc test (Tukey's) showed that the difference was significant only in the ItD trial where the immersed subject ($M = 58.50$, $SD = 13.09$) and the desktop subject ($M = 37.73$, $SD = 15.72$) evaluated their own share in solving the task such that the immersed subject was more active and the desktop subject less active.

In the ItI trial where the subjects worked under the same circumstances in the Chalmers Cube ($M = 44.32$, $SD = 14.50$) and in the UCL ReaCTor ($M = 52.27$, $SD = 14.37$), the subjects evaluated their own and their partner's share in solving the task as being equal. This equal evaluation applies also to the partners in the FtF trial (Subject A, $M = 50.24$, $SD = 9.15$), (Subject B, $M = 46.14$, $SD = 9.38$) (Fig. 4).

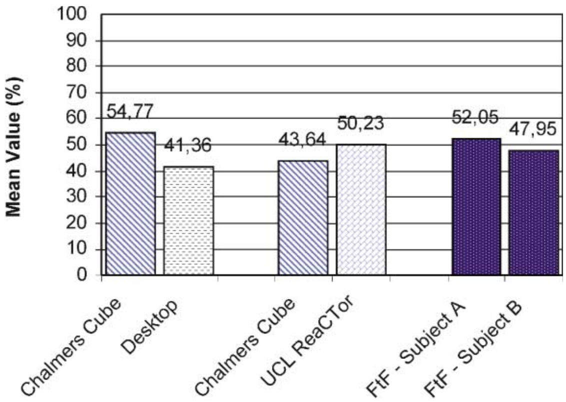

Fig. 3. Share in solving the task.

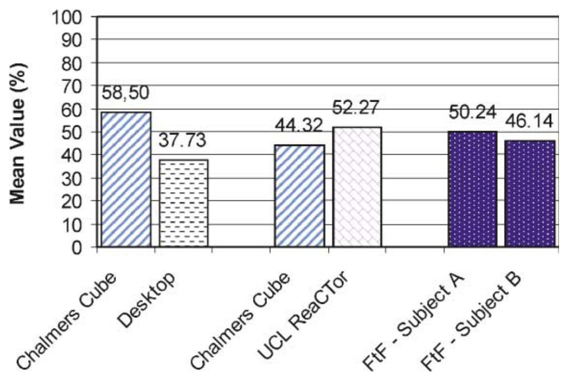

Fig. 4. Contribution in placing the cubes.

For the estimation of the *amount of verbal communication*, there was no significant difference between the conditions ($p > 0.001$), which means that the subjects in all three constellations, i.e. Chalmers Cube ($M = 54.09$, $SD = 9.71$) and desktop ($M = 49.55$, $SD = 7.70$) in the ItD trial, Chalmers Cube ($M = 52.50$, $SD = 12.13$) and UCL ReaCTor ($M = 52.32$, $SD = 16.17$) in the ItI trial, and the two subjects in the FtF trial ($M = 54.55$, $SD = 9.63$) and ($M = 50.00$, $SD = 12.15$) evaluated their own and their partner's verbal activity as being equal.

4.4. Presence

'Presence' in a VE can be defined as having the experience of being in a place other than the one in which you are physically present see, for example, Ref. [8]. In order to find out how present the subjects felt in the VE using the different VR systems, we asked two similar questions about how much the subjects had 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): "To what extent did you have the experience of being in the same room as the cubes?" and "When you think back on the task, to what extent can you have the experience right now that you are moving around in the room where the cubes were?". These two questions were then put together as one measure of presence (hence a total minimum of 2 and a maximum of 10).

An ANOVA showed that there was a significant difference between the systems $F(3, 84) = 34.34$, $MSE = 2.20$, $p < 0.001$ ($\omega^2 = 0.53$) such that the immersed subjects (Chalmers Cube in ItI $M = 8.50$, $SD = 1.30$; Chalmers Cube in ItD $M = 8.36$, $SD = 1.18$; UCL ReaCTor $M = 7.68$, $SD = 1.13$) reported a significantly stronger sense of presence than the subjects using the desktop system ($M = 4.55$, $SD = 2.11$). There was no significant difference ($p > 0.001$) between the groups using the different IPT systems (Fig. 5).

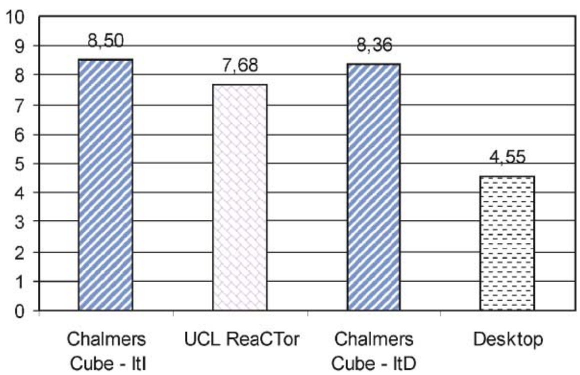

Fig. 5. Presence.

4.5. Place-to-visit

We also asked the subjects a third question relating to presence: "To what extent did you experience the environment as a place you visited rather than something that you were looking at?" (on a scale of 1–5 where 1 = to a very small extent and 5 = to a very high extent).

An ANOVA showed that there was a significant difference between the systems $F(3, 84) = 18.97$, $MS_E = 0.96$, $p < 0.001$, $\omega^2 = 0.38$. A posthoc test (Tukey's) showed that the immersed subjects—Chalmers Cube subject networked with the UCL ReaCTor subject ($M = 4.32$, $SD = 0.65$), Chalmers Cube subject networked with a desktop system ($M = 3.27$, $SD = 0.88$), and UCL ReaCTor subject networked with the Chalmers Cube subject ($M = 3.61$, $SD = 1.13$)—all reported a significantly stronger sense of place-presence than the subjects using the desktop system ($M = 2.14$, $SD = 1.17$).

There was also a significant difference between the IPT's in relation to collaborational partner. Subjects using the Chalmers Cube reported a significantly stronger sense of place-presence when collaborating with the UCL ReaCTor subject ($M = 4.32$, $SD = 0.65$) than when collaborating with a subject at the desktop system ($M = 3.27$, $SD = 0.88$). However, there was no significant difference ($p > 0.001$) between the different types (four- and five-walled) IPT systems (Fig. 6).

4.6. Co-presence

By co-presence we mean the subjective sense of being together or being co-located with another person in a computer-generated environment; a definition that has been used in other studies [7,9,11]. In order to find out how co-present the participants felt, using the different systems, we asked two similar questions about how much the participants had a sense of being in the same room as their partner (on a scale of 1–5 where 1 = to a very small extent and 5 = to a very high extent): "To what extent did you have a sense of being in the same room as your partner?" and "When you continue to think back on the task, to what extent do you have a sense that you are together with your partner in the same room?". These two questions were then put together as one measure of co-presence (hence a total minimum of 2 and a maximum of 10).

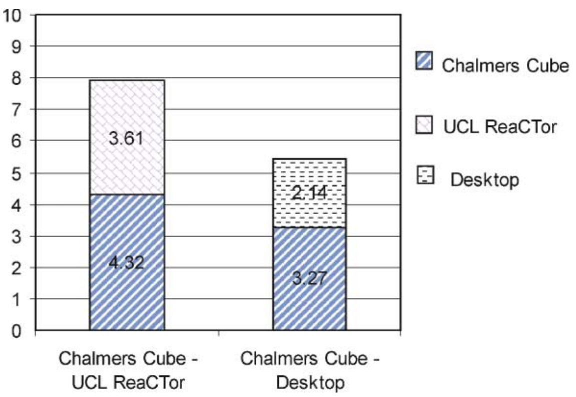

Fig. 6. Place-to-visit.

An ANOVA showed that there was a significant difference between the systems $F(3, 84) = 8.20$, $MS_E = 4.09$, $p < 0.001$, $\omega^2 = 0.20$. A posthoc test (Tukey's) showed that there was a significant difference between the Chalmers Cube in the ItI trial ($M = 7.18$, $SD = 1.87$) and the desktop system in the ItD trial ($M = 5.00$, $SD = 2.00$) such that the immersed subjects reported significantly higher co-presence, ($p = 0.003$). However, there was no significant difference between the UCL ReaCTor and the desktop system ($p > 0.05$).

Nevertheless, there was a difference between the two IPT systems such that both immersed subjects in the ItI trial (Chalmers Cube, $M = 7.18$, $SD = 1.87$; UCL ReaCTor, $M = 6.39$, $SD = 2.01$) reported a significantly higher sense of co-presence ($p < 0.05$) than did the immersed subject in the ItD trial ($M = 4.50$, $SD = 2.20$). There was no significant difference between the two immersed subjects in the ItI trial, nor between the immersed subject in the ItD trial and the desktop system ($p > 0.05$).

Finally, we can mention that we observed that a number of immersed partners tried to shake hands after completing the task—as in the FtF condition! (Fig. 7).

5. Discussion

5.1. Performance

As we saw, the task took longer for ItD groups than for both ItI and FtF groups. There was no significant difference between ItI and FtF groups. This result was unexpected, and it suggests that for this type of task, networked IPT's will be an efficient tool. Obviously this

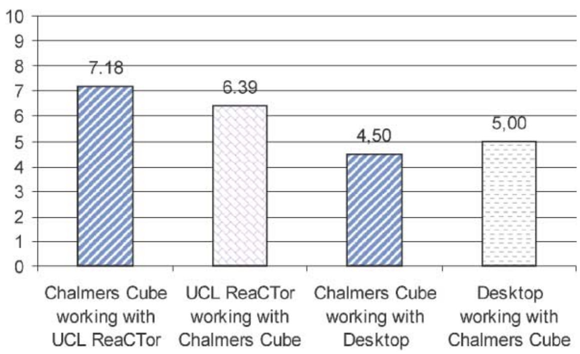

Fig. 7. Co-presence.

finding is highly dependent on the task—in this case a very visual, spatial and collaborative task (it is also a problem-solving task, not a highly interpersonal one). Previous research on VR/VE's, as well as anecdotal evidence, indicates that collaborative tasks in VE's are much more difficult than in equivalent real world settings (we say 'indicates' because virtual vs. real comparisons are not often made). From this perspective, the findings about the various aspects of collaboration below, apart from the light that they shed on VR/VE research, will also have important implications for the practical applications of this technology. It can be added that we obtained this finding despite the fact that we had not refined the system to work smoothly (for example, audio quality could have been better).

5.2. Collaboration

The result of the three collaboration questions shows that participants were disposed in the same way towards collaborating in the three different environments. This result is mainly important in a negative way; that is, since participants were inclined in the same way towards collaboration in all three conditions, this similarity makes it unlikely that the differences that they *in fact* experienced in the various aspects of collaboration (co-presence, leadership, contribution) are affected by their general attitudes towards collaborating in the different conditions.

5.3. Contribution

For share of the task, only the desktop subject evaluated their share as being less, and this in respect both to their contribution in solving the task and to placing the cubes. The verbal contribution, however, was regarded as equal in all cases. These results were not surprising in as much as we would not expect there to be any difference in verbal contribution, but we would expect differences for the spatial part of the task.

At this point, we can pause and take stock: the different technology (desktop) clearly makes a difference to the 'equality' of the contribution, whereas the ItI and FtF conditions allow equal participation. We can bear this difference and similarity in mind as we move on now to 'presence' and 'co-presence', where there are only results from the VE's and not from the FtF condition.

5.4. Presence

In relation to presence, our findings are as expected; namely, that the only major difference is that desktop participants report a lower degree of presence. Otherwise, there is no significant difference for the three IPT conditions (that is, for immersed participants working either with an immersed or desktop partner).

5.5. Place to visit

The interesting result here is that the immersed participant working together with a desktop participant experiences the VE being less of a place visited compared to those working ItI. This suggests that the 'presence' of one's partner makes a difference to how much the VE is experienced as a 'place'. It is also interesting that there is no difference here between the two somewhat different types of IPT's—five-walled versus four-walled—in relation to the question where we would most have expected participants to report a difference between the two systems.

5.6. Co-presence

For co-presence, we find a rank order: the Chalmers Cube in the ItI condition has the highest reported 'co-presence', next comes the UCL ReaCTor in the ItI condition, then Chalmers Cube in ItD, and finally desktop. (The difference between the first pair and the second pair obtained no significant value**,** but the difference within each pair was significant). This finding suggests that the technology (the system used) can be less important than whether you experience your partner as 'co-present' or not. Here we can mention again that participants did not know what type of system their partner was using.

If we take these results together first with the 'presence' results, we can see that since 'presence' in the three IPT's is not experienced as different, the degree to which your partner experiences 'co-presence' can 'override' the type of system used as a factor shaping your joint experience. This finding is given added weight by the fact that the immersed participant collaborating with the desktop partner experiences the VE as less of a 'place visited' than the ItI collaborators. We can note the similarity of this finding with that of Slater et al. [7] who have shown that 'co-presence' is affected by the 'presence' of the co-participant in a collaborative task.

When we consider all of our results together, we can see that in terms of task performance and contribution to the task, the ItD condition and especially the desktop system stands out in contrast with both the ItI and the FtF condition. This finding has obvious relevance to research on 'media richness' and 'social presence', which stipulate that collaboration via networked media are typically degraded because of the absence of social cues [6,10, Chapter 8 for a review of different theories]. Here we find instead that the ItI condition allows a form of collaboration that approximates the FtF condition.

When it comes to 'presence' and 'co-presence' however, the result that stands out is that ItI collaborators report more 'co-presence' than both immersed and desktop collaborators in the ItD trial. The implication of this last finding is that to achieve co-presence, two similarly immersive systems must be used, or the system must be designed in such a way as to produce similar levels of 'co-presence' among partners—where, moreover, as we have seen, the partner's 'co-presence' is related to their sense of 'presence'.

6. Conclusions

We have only reported some of the main results and implications here for reasons of space. We also intend to further analyse responses to open-ended questions and audio recordings. In our future research, we plan to carry out a desktop-to-desktop (DtD) trial as well as trials including networked head-mounted display systems to round out our research results and exhaust all the possible combinations of VE collaborations. Other trials we envisage include those that vary the task, so that the focus is less on a highly spatial and puzzle-like task and more on interpersonal interaction. It is clear that more research is needed—since different tasks and forms of collaboration may produce somewhat different results.

Even without these additional studies, however, we can say that the results we have reported here, if they apply more widely, have important implications for the design of collaborative VE's—including both their technical features and the way we collaborate in them. One implication is that the asymmetry between users of different systems affects their collaboration, a finding that extends the work of previous studies in applying them to IPT's. Another important finding is that the presence of one's partner makes a difference to the experience of the VE as a place. This makes it imperative to focus not only on immersiveness in relation to collaborative systems, but also on the interaction between participants. Finally, we can give a cautiously affirmative answer to the question posed in the title: as long as we remember that the experience of collaboration is influenced not only by immersion but also by the experience of one's partner, and for highly spatial and highly collaborative tasks, networked IPT's are practically as good as being there together in the real world.

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