Does “Virtually Being There” Help? Comparing Collaborative Work between 3D and 2D conditions

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Abstract. 3D Collaborative Virtual Environments (CVEs) have been in the focus of CSCW research for some time. This paper presents a study comparing teamwork done in a CVE with teamwork done in a 2D remote condition and a F2F control condition. The tasks done were designed for groups without prior knowledge; they did not favor any of the environments. In some dependent variables, the 3D environment outperformed the other conditions while in others it kept on par.

Keywords: CSCW, Virtual Environments

1 Introduction

During the last 20 years, we observed a change of markets where it became increasingly common for companies to globalize and communicate with consumers and business partners all over the world. Traveling costs are high and, therefore, alternatives are used for remote cooperation. Also, work is being done while people are not physically present at the same place [1, 2]. These driving forces spawned increased CSCW research into finding alternatives for supporting remote teamwork [1, 2, 3]. Popular resulting technologies like email, video conferencing and instant messaging offer cheap solutions for replacing face to face meetings [3, 4]. Unfortunately, these solutions do often have problems when they are used in a remote work context. For instance, the reduced spatial awareness and missing secondary communication aspects (e.g., gestures) may hinder the building of trust often needed for successful collaboration [5, 6].

To offer a solution for this problem, different three dimensional Collaborative Virtual Environments (CVEs) have been (and are being) developed. Examples include “Croquet” [7] and “Open Wonderland”[1]. Collaborative 3D environments are becoming increasingly popular and today play a role in many aspects of life, including leisure and education (e.g., “World of Warcraft”[2]: over 10 million users; “Second Life”[3]: 12 million accounts). Also the research area of CSCW has been

[1] Open Wonderland: http://openwonderland.org/
[2] Blizzard Entertainment: http://www.wow-europe.com/de/index.xml
[3] Linden Lab: http://secondlife.com/

investigating CVEs for professional applications for some time [8]. While older studies emphasized technical realization challenges of CVEs, current research projects typically put an emphasis on human computer interaction aspects. Previous research has, for instance, looked at different aspects of avatars like how customization options increase identification with the avatar [9]. This private self-awareness allows for reflecting ones attitudes, standards [10] and emotional states [11]. This is helpful for some group work activities. Other studies have analyzed current CVEs to find social behavior and relationships [12]. CVE environments have also been used in educational research for some time [4, 13].

CVEs have been used successfully in advertising [14, 15], and simulated scenarios based on CVEs were used successfully for treating psychological problems like phobias and social anxiety disorders [16, 17, 18, 19, 20].

CVEs have potential advantages compared to other communication conditions. Compared to *plain text* (e.g., in chats), they include a humanoid avatar which allows for visual identification. The avatars also offer an awareness function indicating where everybody is working and maybe even what he is working on. This information is often common in real life offices, but missing in remote conditions. The inclusion of this information in a digital remote condition can improve work results [21].

Compared to *audio* communication, avatars in CVEs are able to do gestures, therefore adding another layer of information to the communication. Unfortunately, most CVE environments do not yet support a wide range of these natural communication expressions [22]. Most systems do allow for some canned avatar gestures, but still these have to be triggered manually and explicitly. This is still a major problem since studies indicate that about 65% of human communication is non-verbal [23] and often unconscious. The need for this communication was already studied in different areas [24, 25, 26, 27]. E.g., Neviarouskaya and colleagues used software to automatically recognize nonverbal cues directly from the text [28, 29]. The results of these studies included that an automatic recognition and visualization of emotional states can have a significant impact on perceiving social presence.

It is often considered important for people to “feel like being there” – at the place they are working or communicating with each other. Immersion in a 3D environment, intended to lead to this effect, has been studied before [30, 31]. However, devices such as head-mounted displays can generate other problems like unnatural nonverbal communication [32, 33]. Indeed, research shows that non-verbal avatar expressiveness may not need full tracking [23, 32, 34, 35, 36].

Finally, advantages 3D environments may have compared to *video* conferencing include spatial awareness (moving around in a CVE is easier and more meaningful than in a video conference) and the option of including larger groups of people.

Despite these potential advantages over other forms of remote collaboration, there are still few studies investigating if CVEs do really improve cooperative work as compared to other remote conditions. First results include that 3D environments improve the retainability of information in comparison to text chat communication [37] – but what about work efficiency and user satisfaction?

This paper presents the results of a study comparing four different collaborative conditions. Two conditions are variants of a CVE, these are compared to a 2D remote condition and a face-to-face “benchmark” control condition. In the study, groups had to collaborate on four different tasks in order to produce group results for each of these tasks. The tasks were selected to be not favoring any of the conditions and to be inducing collaboration.

2 Research hypotheses

The main research question for the study presented in this paper was to investigate if 3D environments can improve collaborative work in comparison to 2D remote scenarios. Our main hypothesis here is that 3D environments can support cooperation better than 2D environments can do.

Specifically, this general hypothesis can be broken down in several sub-hypotheses, related to different facets of system usability (effectiveness, efficiency and subjective satisfaction).

- H1: Groups using 3D CVEs are producing better results than groups using 2D collaboration systems (effectiveness). This expectation is based on the assumption that improved awareness information increases productivity.
- H2: Groups using 3D CVEs are producing results faster than groups using 2D collaboration systems, because the improved communication options reduce discussion times (efficiency).
- H3: Cooperative work in 3D CVEs is perceived as more engaging than cooperative work in 2D environments, because they mirror reality better.
- H4: People using 3D CVEs perceive their work tasks as easier than people using 2D tools. If people feel unsatisfied using a tool, their work motivation and performance might drop.
- H5: Adding nonverbal communication channels to a CVE (such as head movements) increases the benefits of a 3D CVE, because the additional communication aspects (head gestures like nodding in agreement) reduce the time needed for communication and coordination.

3 Study description

To answer the research questions, a laboratory study was designed. In this study, different groups had to solve the same tasks in different environments. The group performance was compared between the conditions. In this section, we first describe the tasks that the participants of our study had to complete. Subsequently, we detail the conditions we compared in the study (using a between-subjects design), describe the methods of data collection, the participant sample and the technical setup.

3.1 Tasks

To find out about the possibilities of a 3D environment for supporting group work through increased communication, tasks had to be devised which did not directly favor a 3D environment over a 2D environment (such as 3D modeling tasks would have), and which require cooperation or coordination. Overall, four different tasks were designed. For all tasks, the members of the groups had to agree on one solution.

The first task presented picture riddles to the groups. The participants were shown pictures and had to guess what object this picture represents. The pictures only showed a small portion of the whole object. Here, the participants were supposed to agree on a solution (which was recorded later in individual interviews).

Fig. 1. Example of a picture riddle (part of an AA battery).

The second task was a series of multiple choice (MC) questions. These were general questions about topics such as science, history and movies. Once one user had answered a question, the next question was shown to all participants. Therefore, participants had to agree prior to clicking. An example question was which planet is closest to Earth (with four solution alternatives offered).

The third group of problems consisted of text riddles. The participants were given four different riddles. Again, the participants were supposed to find and agree on a solution and record it individually later. One of the riddles was: "Two men meet on a plane flying from Berlin to Munich. They both fly between these cities quite often. For one of them it is his 13th flight. For the other one it is his 20th flight. One is living in Munich and one in Berlin. Who is having his 13th and who is having his 20th flight?"

The fourth and last task set included the writing of a poem. The users were instructed to write a poem which needed to rhyme and needed to have a minimum number of lines. Each user got a set of two different words to be used in the poem. It was therefore needed to communicate these words and to agree on how to write the poem. The poem task was considered sufficiently solved if the required words were used and if the rhyme and minimum lines were present.

3.2 Conditions and technical setup

For the study, four different conditions were prepared. These included a 3D condition (3D), a 3D condition with a head-tracking software (3D+HT), a 2D remote condition (2D) and, for reference, a face-to-face condition (F2F).

For the 3D and the 3D+HT conditions, Open Simulator and a Second Life viewer were used. The study tasks were presented to the users on virtual white boards (generated using prims, Linden Scripting language and images) located in the virtual world. Here, four virtual white boards were presented. Figure 2 shows a view on this 3D world showing the first three tasks.

Fig. 2. A view on the CVE environment with the participants and the tasks.

The second condition (3D+HT) was a similar one to the first, but differed in one aspect: The avatar's head movements were synchronized with the user's head moves using a head tracking software (a lightweight version which made use of the video camera built into the laptop computers used in the study). The users were not informed that this software was used. Figure 3 shows the video taken by the camera (which was, of course, not visible to the study participants) and the corresponding head movement of the avatar.

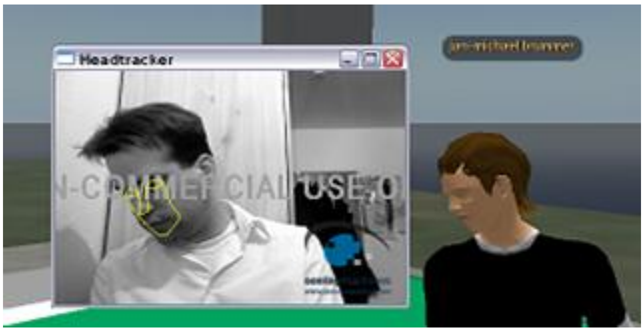

Fig. 3. Head positions of avatar and user

In the 2D remote condition, Skype was used for communication between the participants who had access to a group chat and an audio conference call. The digital white boards used in the 3D conditions were replaced with web pages with the same content and usage (see Fig. 4 for an example of a picture riddle). If one user clicked an answer, the next question showed up for all users (just like in the 3D conditions).

Fig. 4. Webpage of the picture riddle

The last condition was a face-to-face control condition. In Figure 5, a group of study participants is shown working together in the same room. The problems were presented in a browser window (like in the 2D condition), and the participants had an interactive white board and a keyboard at their disposal to interact with the browser.

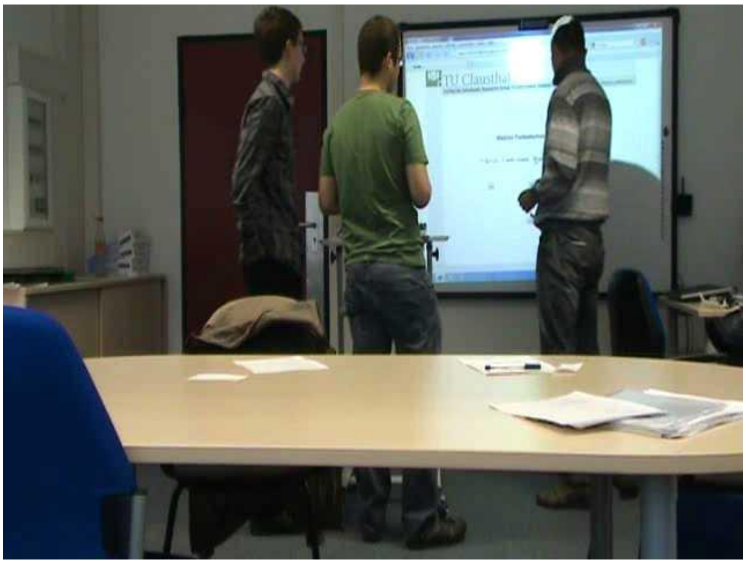

Fig. 5. F2F condition

3.3 Data collection

The study was divided into three parts. First, the participants had to fill out a questionnaire which included questions about computer use habits and previous experience with technologies like 3D games and digital white boards.

During the main part of the study, the participant's response times for the tasks (H2) and correctness of the answers (H1) were recorded. Also, the participants were videotaped to analyze their head movements (H3). The coding scheme for the head movements used within our analysis was proposed in [12] and included the following categories: side-way turn, jerk, waggle, nod, shake, thinking posture and "looking away from the screen". Of particular importance was the "looking away from the screen" category, since this may indicate a low focus on the task (all information needed for the tasks was only presented on screen).

After the main study part, the participants were asked to complete another questionnaire about their opinion about the systems used and the problems presented (H4).

3.4 Participants

The use of 3D CVEs (without extensive training) requires a certain level of computer affinity. Therefore, for the study, the participants were selected from students and interns at a University. All participants were between 21 and 32 years old. This selection of participants increased the chance that the groups had a similar level of background knowledge. This was needed since especially the multiple choice questions were about general knowledge. Therefore, highly heterogeneous age groups might have confounded the study results. The participants were randomly assigned to groups of three persons. The groups were then assigned randomly to study conditions. Participants were paid for participating in the study.

The participants did not know each other and did not meet before the study. In each condition, four groups of three people worked on the tasks together. A short time was allotted for each person to get used to the system (longer for the 3D conditions, shorter for the other conditions). During the preparation in the 3D conditions, the users were allowed to get familiar with the 3D system and to individualize their avatars. Also, a short example of a task was shown to allow users to get used to the handling. For the F2F and the 2D conditions, just some short task examples were shown.

For the tasks, the groups had a total time of 50 minutes. The tasks had to be finished in order.

4 Results

The study was analyzed in different aspects. To find out if the different conditions produced different results, the solutions of the groups were analyzed and compared. For the riddles tasks, the answers given by the individual team members were compared. If the group members had written down the same solution, the answer was accepted as the group's answer. For the poem tasks, a solution was accepted if the criteria were met. All groups had a correct solution for the poem.

To analyze H1, an ANOVA test was conducted to test if there were significant differences in terms of solution quality between the four conditions. The test did not show a significant difference between the results of the tasks, except for the text riddle tasks. Here, however, a follow-up pairwise t-test did not show any significant results between any two conditions. Yet, the 3D settings had the highest average in terms of the number of correct solutions. Table 1 shows the results of the questions and the significance value resulting from the ANOVA test.

Concerning hypothesis H2, the time needed to solve the problems also did not show any difference between the two 3D conditions (for technical reasons, the time recording for the poem task in the F2F condition was not possible).

Table 1. Mean and standard deviation of the number of correct solutions

Task (max. possible correct solutions)	3D+HT Mean(std)	3D Mean(std)	2D Mean(std)	F2F Mean(std)	p
# correct picture riddles (3)	2,2(0,9)	1,7(1,5)	2,0(1,5)	2,0(0,8)	>0,9
# correct MC (20)	14,5(2,6)	14,0(3,2)	13,2(0,9)	12,7(0,5)	>0,7
# correct text riddle (4)	3,7(0,5)	3,7(0,5)	2,7(0,5)	3,2(0,5)	<0,05

To investigate H3, the engagement of the people at the computer was analyzed using the video data. The head movements and gestures of the study participants were coded according to the scheme proposed in [38]. From the coding categories, the most important information was how often people looked away from the monitor (looking around in the room or focusing on tools outside the computer). This movement usually indicated that participants were distracted from their task, since communication and task information were all on screen.

For the F2F condition, a different coding scheme was needed to achieve comparable results. Participants did not only look at the white board but also at each other. For a group working together in a room, this is a common behavior and not a sign of missing focus on the task. Therefore, in the F2F condition, every time a participant was looking away from the whiteboard and from the other group members, this behavior was counted as "off-task". An ANOVA test between conditions was conducted, resulting in a significant difference between conditions. Afterwards, a pairwise t-test was conducted using the method of HOLM to take into account alpha-error accumulation. This analysis showed a significant difference between the 3D+HT and the 2D condition ($p<0.01$). The users using the 3D+HT environment showed much greater focus on the system than the users who accessed the tasks through a 2D interface.

Table 2. Number of head movements away from the monitor/the other participants.

	3D+HT Mean(std)	3D Mean(std)	2D Mean(std)	F2F Mean(std)	p
#movements	5,9(5,0)	15,4(14,4)	21,3(12,6)	12,7(7,8)	<0,05

When analyzing the answers given concerning the *perceived* difficulty of the problems (H4), an ANOVA test showed a significant result (p<0.01) for the picture riddles, with a significant difference between the 3D environment without head-tracking and both the 3D with head-tracking and the 2D remote conditions. The participants of the 3D without head tracking considered the task as more difficult than the users in the other conditions (H5). A similar result holds for the poem task. Here, the ANOVA also showed a significant difference overall, but a pairwise t-test did not give a significant difference between two conditions at the .05 level. Participants in the 3D groups without head-tracking also stated in the post survey that they *felt* that they needed a lot of time to answer the problems. However, this was not really reflected in the actual answering times where there was no statistically significant difference between all groups.

Table 3. Perceived difficulty of tasks. (1= very difficult, 5= very easy)

	3D+HT Mean(std)	3D Mean(std)	2D Mean(std)	F2F Mean(std)	p
Picture riddle	3,6(1,3)	2,3(1,3)	3,9(0,9)	3,2(1,0)	<0,01
MC	3,2(0,7)	2,6(0,8)	2,8(1,1)	3,0(0,8)	>0,4
Text riddle	3,6(1,3)	3,0(1,2)	3,0(0,9)	3,2(1,3)	>0,5
Poem	3,3(1,1)	2,0(1,0)	3,5(1,5)	3,3(1,3)	<0,05

For most study hypotheses, no significant differences were found between the conditions. But still, some interesting trends could be seen. For example, the users of the 2D remote condition found the usage easier than the F2F group which used exactly the same browser software but a digital board with a pen in comparison to a computer screen with a mouse.

5 Discussion

3D environments have been hyped for some time. Research is required to test if these environments can actually be a good alternative for collaborative work. The first steps in our research, presented in this paper, were to investigate how a 3D environment compares to a 2D one (and to a face-to-face situation).

Since there was no significant difference in the quality of the group results, H1 has to be rejected overall. However, there was also no indication that the 3D and 3D+HT conditions performed *worse* than 2D or (interestingly!) F2F. On the contrary, in case of the text riddles, the 3D environments produced a higher solution quality than the other two settings. Therefore, both 3D settings did not negatively influence the performance of group's work.

Also H2 was not statistically supported. Again, this is not a too bad result considering that the people in the 3D conditions actually had the most difficult tool handling and the participants in our study did not have experience with this 3D environment beforehand. Under these circumstances, one might easily have expected that users in the 3D conditions would have taken longer to solve the tasks. But, according to our data, this was not the case. One might thus hypothesize that if the users had had more experience with 3D CVEs, this might even have resulted in faster solution times for the tasks.

H3 was partially confirmed. The 3D setting did not lead to a significantly better user's focus, but the 3D+HT did improve against the 2D condition. This better focus might be accounted to the aspect that users might have been distracted by the 3D environment itself. Compared to 2D, 3D environments present additional information: a 3D world includes a sky, buildings, and other objects. This information can indeed be a distraction that could explain the increased "looks towards the screen". However, in this study, the 3D environments were purposely kept very simple and did not offer many sources for such distraction. The only main difference between 2D and 3D were the user avatars – as such, it makes sense to attribute the increased attention of the users to the visibility of their cooperation partners. This result that people watched the screen more in the 3D condition can be used to include ambient information in the environment, allowing to convey important awareness information to users even while they are "distracted" [39].

The subjective views of the participants were interesting. People using the 3D condition without the head tracking perceived some (but not all) of the tasks as more difficult and their response time as slower, supporting H4. Interestingly, this effect was not observable for the 3D+HT condition which was on par with the 2D and the F2F conditions.

When it comes to H5, our data shows the general picture that the users in the 3D+HT condition showed better results than their peers in the 3D condition. Not in all measures this difference reached the level of statistical significance (probably due to a relatively low sample size), though. The perceived difficulty measure, for example, was much lower for the 3D+HT than for the 3D. This gives enough motivation to include other awareness tools in the future to see if this margin between "standard avatars" and "avatars with realistic behavior" (for instance, including also body postures in addition to head movements) can be widened.

Comparing the 2D remote and the 3D remote condition, one advantage already showed up during the test itself. The first 2D group looking at the picture riddles first discussed if they were actually seeing the same part of the picture. The users in the 3D environment did not even consider the option that they might be looking at a different picture (even if that would be possible in the 3D world). So the 3D users had the feeling that they were getting the same information.

6 Conclusion

The study presented in this paper was conducted to find out if a 3D environment is capable of helping people work together more effectively and efficiently than other cooperation tools (audio + chat + 2D). The used 3D environment did not show any usability problems and did not lead to a decrease in the quality of the results of the completed tasks. We found indications that 3D environments with awareness techniques like head-tracking can improve collaboration, especially as compared against 2D tools. In our study, a F2F control condition was added as a benchmark to see how technology based cooperation compares to the "gold standard" of rich interaction in the real world. It is a nice surprise to see that the computer mediated solutions are actually very close to F2F concerning work results and user satisfaction.

Future work will include the extension of the 3D+HT environment with different awareness features. Some of the features can be inspired by the gaming community where awareness tools are often designed from player for players. These tools are often designed with different specialized aspects of group work in mind. For collaborative work in a 3D environment, features like miniature maps might help with coordination, for instance. In any case, further studies are needed to see if these environments are a real alternative to other remote CSCW technologies.

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