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Mutual Proximity Awareness in Immersive Multi-User Virtual Environments with Real Walking

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Abstract

Are users aware of each other in an immersive multi-user virtual environment if they cannot see or hear each other? We present a study on users' awareness of other users who share the same physical space. The goal of our research is to investigate proximity awareness when walking in multi-user virtual environments. The high degree of immersion in our virtual environment is achieved through the use of a head-mounted display and real walking in a large tracked space. In our experiment, pairs of participants are required to walk on pre-defined paths towards or side by side to each other and point at their test partners if they feel their presence. Our results show that 1/3 of the participants who had a-priori knowledge about the possible proximity of their test partners could notice their test partners during the experiment at a distance shorter than 1m. The test subjects who did not have any a-priori knowledge proved to be not aware of other users.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality—H.5.2 [Information interfaces and presentation]: Interaction styles—Evaluation/methodology

1. Introduction

The field of Virtual Reality (VR) has seen rapid development in recent years, assisted by the technological advancement in tracking and display technologies. One of the most important 3D interaction tasks in VR is navigation. As defined by Bowman et al. in [BKLP04], navigation is the task of moving around in an environment and it is composed of travel and wayfinding. Travel is the motor component of navigation by means of which the user controls the change of the position and the orientation of his viewpoint. In the real world, travel is simply the process of physically moving one's body, while in a VR application it can be performed by means of various input devices, such as pressing buttons on a keyboard or joystick, using a treadmill or any other locomotion device or by walking physically. Wayfinding is the cognitive component of navigation and comprises mental activities involved in planning one's path in an environment.

It has been shown by multiple research groups [SBH07] [HBW08] [SBH*09] that real walking is the most natural travel technique that also supports a high degree of immersion and induces less simulator sickness than other methods. However, the use of real walking is often hindered by space limitations in VR research laboratories and its dependence on expensive wide-area tracking equipment. These considerations make the use of real walking in multi-user VR even more difficult. Nevertheless, some examples of such systems have been demonstrated ([WBHB07], [HBV*15]). We believe that with the development of portable and low-cost tracking solutions like those presented in [HBV*15], more multi-user VR systems will become available. In this paper, we use an existing immersive multi-user VR system that allows travel by real walking.

In an immersive multi-user setup, users do not necessarily have to share the same virtual environment (VE) while performing real walking in the shared physical space. Several advantages can be derived from providing different VEs to multiple users at the same time, i.e. to reduce costs by sharing real space or to provide users with the possibility to individually explore multiple levels in one large shared immersive game.

Given such a multi-user VR setup with shared physical space but individual VEs, it is important to know if its users would be aware of each other during their experience. In a virtual scenario that aims at individual VE exploration, awareness of other users can easily create mutual breaks in presence. In this case, means must be provided to prevent

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such occurrences. In a virtual scenario that aims at collaborative exploration, awareness of each other is highly desired. Independent of the intended scenario, safety must be taken into account for multi-user VR development. If users are not aware of each other, robust techniques for collision prevention must be provided from the very early stage of development.

1.1. Contribution

To our best knowledge, no studies of mutual proximity awareness in immersive VEs have been published where users have full freedom of physical movement in a shared real space but miss visual and audio cues coming from other users in the VE. In this work, we present the first examination of mutual proximity awareness in immersive multi-user VR with travel by real walking. While visual and audio information is normally dominant for human perception of others, only tactile cues such as airflow, floor vibration and body heat and olfactory cues such as smell are available for users to notice each other in a multi-user setup within a non-shared VE. We conducted an experiment aiming to investigate if and which of these cues could be attributed to users being aware of each other in such a setup. We observed pairs of users walking in a large physical space (30x7m) towards or next to each other. The experimental task was designed to assess the objective indicators of users mutual proximity awareness while questionnaires served to assess their subjective awareness. Our results show that a-priori knowledge of the presence of others and high attentiveness towards cues coming from the real environment during the VE experience can make users aware of each other. Mutual proximity awareness in a non-shared VE is hardly achieved without these conditions.

After describing some related work in Section 2, we present our hypothesis as well as the VR setup used for our experiment and the experimental task in Section 3. In Section 4, we state our main results, followed by the discussion in Section 5. We draw an outline for future work and conclude the paper in Section 6.

2. Related work

As stated above, there have been no studies of mutual proximity awareness in immersive multi-user VR with real walking. Nevertheless, work has been done in the areas that are related to our research: collaborative multi-user VR, walking in VR and immersive VR systems with real walking.

2.1. Collaborative VR

Traditionally, research on multi-user VR focused on collaborative behaviour. Although providing a collaborative experience, VR setups used in many of the published studies do not offer the same degree of immersion as our setup does. For example, test subjects of the experiment published in [JF00] were immersed in the test VE through the use of a head-mounted display (HMD) but remained seated and used a wand for navigation tasks. In [KS06], users had more freedom of movement having their heads and hands tracked. However, they wore stereoscopic see-through HMDs and thus could see each other in the real environment. These two papers focused on the importance of collaboration for the task accomplishment but not on cues providing a collaborative experience.

In [SC07], the authors investigated collaboration in an immersive VR with real walking. In the experiment, pairs of users had to carry a stretcher through an obstacle course in the VE. In various conditions, the participants' awareness of each other was reduced by excluding different types of cues, including a condition with no visuals. Yet the participants were holding the physical stretcher in this condition thus providing force feedback for each other. The study concluded that the test subjects were able to quickly adapt to conditions with reduced information about each other but did not investigate the proximity awareness by itself.

2.2. Walking and Redirected Walking in VR

To overcome space limitations imposed by real walking in VR, Redirected Walking (RW) techniques have been introduced. RW methods make users of immersive VR applications stay within the limits of a tracked space, by either applying additional rotation and gain to their movements ([SB13], [HBW08]) or making different parts of the VE overlap ([SLF*12], [VKBS13]). Research on RW techniques suitable for multi-user VR has been started in [BHZH13].

2.3. Immersive VR systems with real walking

In [WBHB07], users can explore VEs by walking in a 28.5x20.1m physical space. The system supports multiple users walking at the same time. In [HBV*15], an example of a portable VR system is proposed where users are able to walk in a football field sized outdoor space while being immersed in a VE through an HMD. The authors claim the system to be easily scalable for the multi-user scenarios. We have developed a low-cost immersive multi-user VR setup where users can walk. Our system has not been published yet, the publication is in preparation. In this work, we are using our new VR system, the description of its technical characteristics is however beyond the scope of this paper.

Consumer adoption of VR has been long anticipated. First commercial VR solutions that will allow their users to walk freely within VEs and provide a fully immersive experience have been announced recently [VOI].

Research on proximity awareness is relevant for all multi-user VR systems that allow real walking, including the applications of RW. With the growing number of available low-

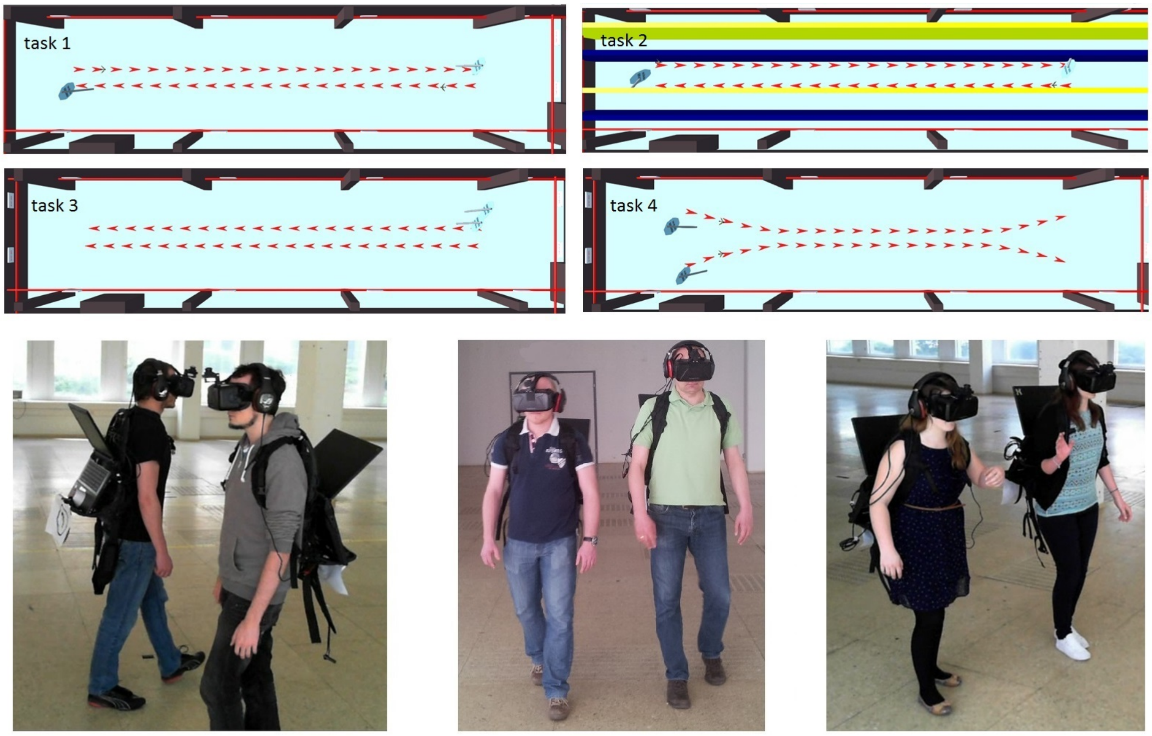

Figure 1: *Top: pre-defined paths for the tasks and the participants walking on virtual paths. In task 2, the yellow corridor is seen by a user walking from left to right and the blue one by a user walking from right to left. Different colours are for demonstration purposes only, corridors were brown for all participants. Bottom left: passing each other during task 1; bottom middle: walking side by side at the closest distance during task 4; bottom right: about to point at each other during task 4.*

cost solutions and appearance of consumer VR, it is important to gain knowledge about the proximity awareness and possible limits in multi-user systems.

3. Experiment design

3.1. Hypotheses

Our main assumption was that three factors could possibly make users of a multi-user VE aware of their co-presence in the same physical space, given that they do not see or hear each other. These factors are the airflow when users pass each other, the floor vibration and the body heat. Depending on users relative positions and walking speeds, these factors can have greater or lesser impact. For example, if two users are heading towards each other with relatively high speeds, the airflow might be noticeable enough to reveal the presence of another person. On the contrary, when users stay close to each other during a longer time, body heat and floor vibration might have larger impact. To investigate these possible cues of awareness, we intended to test situations where users moved with different speeds and on different trajectories relatively to each other.

We also wanted to investigate if the nature of a VE itself possibly contributes to users mutual proximity awareness. Our assumption was that, since vision is the dominant cue for most people, users might be less aware of others when they are exploring geometrically isolated VEs, like narrow streets or corridors. We have formulated the following hypotheses:

H1 : When walking towards each other, users are likely to be more often aware of their mutual proximity when passing each other at higher speeds because of the increased airflow.

H2 : Users are likely to be more aware of their mutual proximity when moving near each other for a longer time than when simply passing each other.

H3 : Users who know in advance that they will be performing tasks near each other are likely to be more often aware of their mutual proximity than the ones who are not given any a-priori information about their relative locations.

H4 : Users walking in an open-space VE are likely to be aware of their mutual proximity more often than the ones walking in a VE with near obstacles.

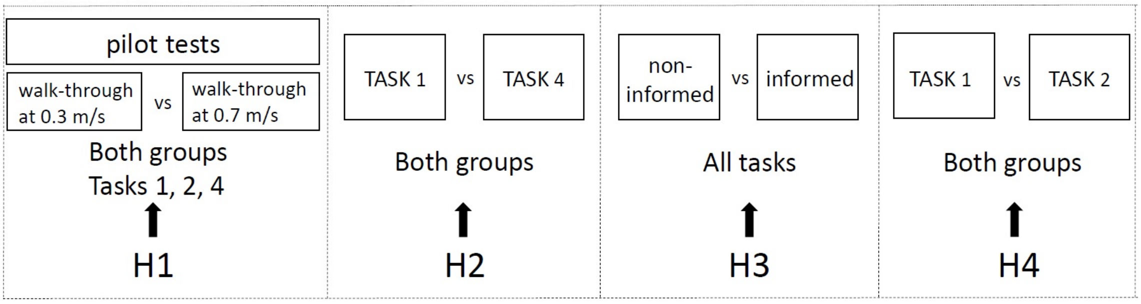

Figure 2: *Assignment of the experimental tasks to test the hypotheses. Hypothesis H3 is tested by comparing the outcomes of all tasks in the informed and non-informed groups, hypotheses H1, H2 and H4 are tested by comparing the outcomes of different tasks performed by all participants.*

3.2. Population and experimental task design

36 participants took part in the experiment. The age of the participants ranged between 20 and 53 years, with the median of 27 years, 12 participants were female and 24 male. We did not explicitly aim to conduct the experiment with naive users only. However, only 4 participants had previous knowledge of VR technology, 3 of them being VR experts and 1 an experienced user.

Several pilot study sessions with experienced VR users were conducted prior to the main experiment. During the pilot test, we wanted to test the effects of various speeds (hypothesis H1) and distances between the users' trajectories. Each pilot session comprised a pair of users walking on predefined paths towards or parallel to each other at different speeds and distances. None of the participants could notice the passing test partner in any of the conditions. We have also discovered that the task of walking fast (speeds varied from 0.7 m/s to 1.5 m/s) was too involving for the participants, so that they could not concentrate enough on the cues coming from the real world. Having analysed the results of the pilot test sessions, we decided to let participants walk with low and controlled speeds on paths that were very close to each other.

In the main experiment, we split the participants into two groups, with nine pairs in each. Six participants from each group were female. The participants from the first group did not know the goal of the experiment. The participants from each pair in this group saw each other at the start of the experiment taking different initial positions in the physical space but it was not explained to them how they were going to move relatively to each other. We will further refer to this group as the "non-informed" group. We explained the purpose of the experiment to the participants from the second group. The participants from each pair were told that they were going to walk in the same physical space and that they would be sometimes far away and sometimes very close to each other. We will call this group the "informed" group. One participant from the non-informed group had previous experience with VR, three participants from the informed group had advanced knowledge of VR.

The main task for the participants from the informed group was to point at their test partners when they noticed them. The participants from the non-informed group were asked to point if they felt something that they could not see close to them. We wanted to see if the participants from the informed group would point at their test partners more often than the participants from the informed group and thus test hypothesis H3 in a between-subject evaluation. The paths in the VE and the participants walking in the real space can be seen in Figure 1.

The experiment consisted of four tasks where users were asked to walk on pre-defined paths in the VE that resembled the real room where the experiment took place. The first task consisted of two walk-throughs during which the participants were walking on parallel paths towards each other each time following a bird flying in front of them with a speed of 0.3 m/s in the first walk-through and 0.7 m/s in the second walk-through. This way, test subjects from each pair passed each other in the middle of the room at a head-to-head distance of about 0,8m. Their arm-to-arm distance was about 0-30 cm. The bird was introduced as means to control the walking speed of the participants. Different walking speeds in the walk-throughs were used to test hypothesis H1. We wanted to see if participants would point at their partners more often when walking at the higher speed than when walking at the lower speed.

In the second task, the participants performed one walk-through towards each other following a bird but there was a corridor surrounding the path. We wanted to test hypothesis H4 by comparing the outcome of this task with the outcome of the first task. We wanted to see if participants would point at their test partners more rarely when walking in a virtual corridor than when walking in an open VE. After the second task, one participant from a pair had to cross the tracking space to reach the starting position for the next task (while staying immersed in the VE and not seeing the other participant). Both participants were walking side by side to each other during the remaining tasks.

In the third task, the participants were asked to walk on a straight path with any speed they felt comfortable with, the distance between their paths being 1m. This experimental sequence was introduced to collect the data about the typical walking speeds in immersive VR.

The fourth task consisted of two walk-throughs where the participants were asked to walk on curved paths following the flying bird again. Their paths got progressively closer to each other towards the middle of the room, the shortest distance between their heads being 0,8 m. Like in the first task, the bird was flying with a speed of 0.3 m/s in the first walk through and 0.7 m/s in the second walk through. We intended to test hypothesis H2 by comparing the outcomes of tasks 1 and 4. We wanted to see if participants would point at their test partners more often when performing task 4 than when performing task 1. A diagram illustrating the connection between the tasks and the hypothesis can be seen in Figure 2.

3.3. System and procedure

The participants wore an Oculus Rift HMD (DK2). The position of each participant was tracked with the use of our own prototype wide area optical tracking system. The evaluation tasks were implemented in our own, yet unpublished, VR framework based on the Unity 3D game engine. It was running on a laptop with the NVIDIA GTX 980M graphics card and an IntelCore i7 processor. The overall rendering framerate was 26 fps. The tracking area where the experiment took place was approximately 30x7 meters large. The positions of both participants within the VE were transmitted to the server machine and visible to the test coordinator. The test coordinator switched the test sequences for each of the two participants according to the progress of the experiment. The test coordinator registered the events of the participants pointing towards their test partners.

The participants wore ASUS Vulcan Pro headphones with enabled noise cancellation and background white noise (with the average loudness 65dB, maximum 69dB). With the headphones on, the participants could not hear any sounds from the surroundings. The test coordinator was able to give them notifications in the form of signs with short instructions "Stop", "Continue walking", "Task is over", "Get ready for the next task". The "stop" sign was used as emergency if the participants did not exactly stay on their pre-defined trajectories and were at risk of collision. The participants were asked to fill a pre-test questionnaire containing usual questions about their age, previous experience of VR and playing computer games, together with the simulator sickness questionnaire (SSQ) [KLBL93]. Each participant gave an informed written consent of participation in the experiment. The experiment completion times ranged between eight and twelve minutes. After the experiment, the participants were asked to fill out another questionnaire, containing the repetition of the SSQ, questions about the level of immersion and the quality of tracking, as well as questions about the awareness of the presence of the other user. Most of the questions, excluding the SSQ, were presented on the Likert scale with the range from 1 to 7. After the post-questionnaire had been filled out, a short debriefing session took place. The participants were asked if they could feel the presence of the other user next to them; if yes, during which phases of the experiment it happened and what were the main sources of their awareness. The participants were also asked if they could identify their position and their partner position in the real space during the experiment.

4. Results

4.1. Mutual awareness

We used both objective measures, i.e. the number of events of a participant pointing at her/his test partner, and subjective awareness scores obtained from the post-questionnaire.

When analysing the objective measures, we were interested in the overall noticing rate as well as in differences between the tasks and the non-informed and informed groups. 18 pairs of participants performed the total of 18x2x6 = 216 individual walk-throughs. In 30 of these individual walk-throughs, the participants touched each other while walking, so we discarded all the events happened in these walk-throughs. However, 1/3 of the events where participants touched each other were not noticed or remembered by the participants.

The total amount of cases where at least one of the users from a pair pointed at the other one was very low. The numbers for each task are given in Table 1. In only two out of 104 valid walk-throughs in the non-informed group the participants noticed their test partners. These were two different participants. In the informed group, participants noticed their test partners in the total of 18 out of 86 walk-throughs. The higher amount of walk-throughs where the participants could point at their test partners in the informed group supports hypothesis H3. However, these results are produced by only 6 out of 18 participants in the informed group who noticed their test partners. The other 12 participants in the informed group did not feel the other person close to them. From the six participants who noticed their test partners, only one had advanced VR knowledge. The other two participants with expert VR knowledge from the informed group never pointed at their test partners. The only participant who had extensive VR experience in the non-informed group never pointed at his test partner. The participants who noticed their test partners pointed at them right after passing them in the walking towards each other tasks. In the walking side by side tasks, the participants pointed at their test partners when they reached the head-to-head distance of 0.77 - 1.2m. In the informed group, there were several occurrences

NON-INFORMED	TASK 1	TASK 2	TASK 3	TASK 4
TOTAL WALKS THROUGH	36	16	16	32
NOTICED OTHER	2	0	0	0
INFORMED	TASK 1	TASK 2	TASK 3	TASK 4
TOTAL WALKS THROUGH	34	16	14	22
NOTICED OTHER	6	2	3	7

Table 1: *Task outcomes for the non-informed and informed groups. Walk-throughs are counted individually, i.e. one pair of participants performing a walk-through during a task counts as two individual walk-throughs. Tasks 1 and 4 consisted of two walk-throughs each for every participant, tasks 1 and 3 consisted of one walk-through. "Noticed other" line contains the number of walk-throughs for each task where a participant pointed at her/his test partner.*

NON-INFORMED	T1	T2	T3	T4
Mean	1.5	1.3	1.5	1.7
SD	0.8	0.5	1.3	1.6
INFORMED	T1	T2	T3	T4
Mean	2.4	2.4	2.1	2.5
SD	1.7	1.6	1.5	1.9

Table 2: *Mean subjective awareness scores and corresponding standard deviations, on the scale from 1 to 7, where 1 corresponds to no awareness and 7 to a high degree of awareness. T1 - T4: tasks 1 to 4.*

	T1	T2	T3	T4
Mann-Whitney U	96.5	70.5	81.0	28.5
Wilcoxon-W Z	267.5	206.5	234.0	119.5
Asymptotical significance (2 - tailed)	0.076	0.018	0.083	0.286
Exact significance (2*(1-tailed sign.))	0.102	0.029	0.138	0.368

Table 3: *Results of the Mann-Whitney U test for the subjective awareness scores in tasks 1 - 4 (T1 - T4) between the non-informed and informed groups.*

of false positives, i.e. participants pointing at an empty space while they thought their test partners were there. False positives are not included in Table 1.

The mean subjective awareness scores can be seen in Table 2. They resulted from the answers to the question "How aware were you of the presence of your test partner?" for each task. The answers were given on the scale from 1 to 7, where 1 meant "not aware at all" and 7 "very aware". The mean scores for each task are about 1 point higher for the informed than for the non-informed group. The results of statistical analysis given in Table 3 suggest that this difference is significant for task 2 ($\alpha = 0.05$).

In the informed group, the participants pointed at their test partners in 16% of walking towards each walk-throughs (tasks 1 - 2) and 27% of walking side by side walk-throughs (tasks 3 - 4). We could observe that these were the same six participants who pointed at their test partners, both in walking towards each other and walking side by side tasks. There was only one (out of the mentioned six) participant who noticed his partner in tasks 3 and 4 but not in tasks 1 and 2. The mean subjective awareness scores are very close to each other for all four tasks as can be seen in Table 2. Therefore, we conclude that hypothesis H2 cannot be confirmed.

Neither did we find support for the hypothesis H4. Although the number of times of users pointing at their test partners is smaller for task 2, where the participants had to walk in a virtual corridor, as compared to task 1, where they were walking in open space, these numbers are too small to make any conclusions. We believe that in a situation where users generally do not notice each other, the type of VE does not make any difference.

We saw already after the pilot test sessions that hypothesis H1 did not hold. This was confirmed in the main study.

When asked about their awareness of the presence and location of their test partners, only few participants could say that they noticed something. These were mostly the participants from the informed group. The "steps" or floor vibration caused by walking was pointed out as the main reason of their awareness. Two of the participants mentioned that they had felt the increased air flow, both times in walking towards each other tasks. Many of the participants who noticed their test partners when they slightly touched while walking said that they were aware of their test partner being somewhere around them until the end of that particular walk-through but could not any longer say where she/he was when the next session started.

4.2. Simulator sickness, tracking quality and immersion

The mean SSQ score was M = 13.5 (SD = 15.2) for the pre-test and M = 18.1 (SD = 18.0) for the post-test. The results indicate almost no increase in simulator sickness over the time of the experiment. Our post-test questionnaire contained questions aiming to assess the impact of the tracking jitter and lag on the user experience. The users had to specify how noticeable the lag was and to what degree the jitter and

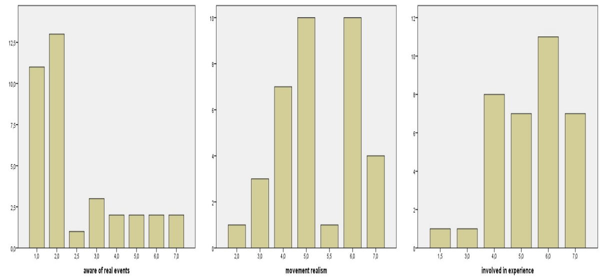

Figure 3: *Distribution of the scores for the immersion-related questions. Vertical axis : number of participants, horizontal axis: the score (on the 1 to 7 scale).*

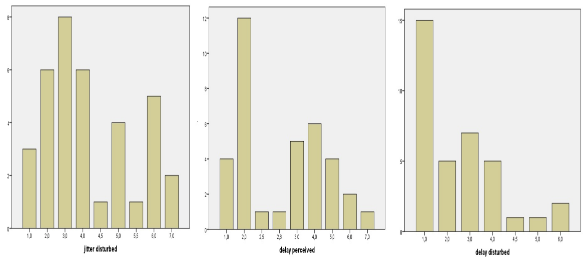

Figure 4: *Distribution of the scores for the tracking jitter- and delay-related questions. Vertical axis : number of participants, horizontal axis: the score (on the 1 to 7 scale).*

the lag disturbed their experience, all three questions on the scale from 1 to 7, where 1 meant the least and 7 the largest degree of disturbance. The distributions of scores for these questions are presented in Figure 4. The results indicate that the participants did not perceive the lag as being strong (M = 3.1, SD = 1.5) and did not find it disturbing (M = 2.4, SD = 1.5). Tracking jitter received higher scores (M = 3.8, SD = 1.7), however the average is not higher than the middle of the scale.

We have used questions from Witmer et al. [WS98] and Slater et al. [UCAS00] to assess the subjective measure of the degree of immersion experienced by the participants. The questions about immersion were : "How realistic was the sense of moving around inside the virtual environment for you?", "During the test session, how aware were you of the events occurring in the real world around you?", "How involved were you in the VE experience?". The distributions of the scores for these questions are shown in Figure 3.

The participants were also asked to rate their sense of "being there" in the VE, as well as the occurrences of moments when the VE became the "reality" for them and their perception of the virtual world as something that they saw as opposed to something that they visited, as suggested by Slater et al. [SU94]. The mean SUS-score ([UCAS00]) for the sense of being present was M = 4.8 (SD = 1.5). High mean SUS-score, low awareness of real events (M = 2.6, SD = 1.7) and high involvement into the experimental task (M = 5.3, SD = 1.3) indicate a high degree of immersion experienced by the participants. We have not found any difference in the sense of immersion between gender or the non-informed and informed groups.

5. Discussion

The subjective awareness scores for both groups and the number of times when the participants of our experiment noticed their test partners were generally very low. Only two participants from the non-informed group pointed at their test partners, each of them during only one walk-through. Six participants from the informed group pointed at their test partners. Each of them could point at their test partners in several walk-throughs. Given these results, we can interpret the ability to be aware of another user walking in the same physical space as a very difficult task dependent on the personal attention and concentration. If users' attention is not specifically pointed towards other users they are not likely to notice them, as we saw with our participants from the non-informed group.

The participants from the non-informed and informed groups had different tasks assigned. The participants from the informed group received a very clear instruction of what they were expected to concentrate their attention on whereas the participants from the non-informed group could only guess what they had to point at. As we discovered in debriefing sessions after the experiment, the participants from the non-informed group tended to think that they had to point at something happening in the VE around them and not in the real world. This fact has clearly affected the outcome of the test. However, we believe that the non-informed group in our experiment is more representative for a typical VR application where a user is immersed in the VE and is not trying to concentrate on anything happening in the real world.

To our surprise, the majority of the participants were not able to describe their trajectories in the real tracked space, even though the VE used in the experiment was the exact copy of it, except for one additional wall present in the VE. We attribute this finding to the fact that only few of the participants were familiar with VR technology in any form and were clearly overwhelmed by the experience. This reasoning is clearly supported by the reaction to the VE that we could observe in our participants, numerous exclamations and comments about the virtual world being "all around". The same argument counts for the fact that many participants forgot about their unexpected "collisions" with their test partners very fast and would not be able to say where they were just several steps after the encounter. However, we do not think that low awareness of mutual proximity can be attributed to the novelty of immersion alone. The experienced users in our experiment demonstrated a better ability to describe their movement in the VE and, obviously, were not surprised when seeing the VE. However, they did not perform better at noticing their test partners. While the number of experienced users in our test was not large enough to conduct proper statistical analysis, we believe that the immersive nature of VR itself plays a decisive role in low mutual proximity awareness. More experiments with non-naive users would be of interest to see how and if the experience with VR changes users' perception of it.

Although the purpose of the study was not to investigate the experienced presence in our VR setup, we could see both from the subjective questionnaire scores and from our observations that the participants were highly immersed in the VR experience. We are convinced that if more involving tasks and more appealing graphics were introduced in such an already immersive system, its users would not be able to notice much of the events happening around them at all, including other people moving nearby.

This way, collision prevention techniques appear to be especially important for immersive VR setups with non-shared VEs to guarantee the safety of all users.

6. Conclusion and future work

We have conducted an experiment aiming to investigate whether users of an immersive non-shared multi-user VE are aware of each other in the same tracked real space. Our results show that only 8 out of 36 participants were able to notice the presence of another person, even though there were situations where participants were very close to each other in the real space. Six out of eight participants who pointed correctly at their test partners were informed about the eventual presence of their test partner in their immediate proximity and were instructed to concentrate on the cues coming from the real environment. We conclude that the highly immersive nature of the investigated environment was the reason for the participants to not pay any attention to other sensory cues, although very limited, coming from the real surroundings. However, scenarios with a "more crowded" tracking space may need additional investigation, in the area of both co-presence awareness and collision avoidance methods. We intend to focus on collision avoidance methods in future work.

7. Acknowledgements

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