Comparing Presence, Workload and Situational Awareness in a Collaborative Real World and Augmented Reality Scenario

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ABSTRACT

This paper compares presence, workload and situational awareness in a real world and augmented reality scenario when collaboratively solving a complex problem. A game of jointly building a tower of colored blocks is used as an approximation of a shared task. Individual expertise is modeled as the possibility to move blocks of a distinct color and shared expertise is modeled by the possibility of all players to move blocks of the same color. Such a setup scales down real-life, more complex problems such as in crime scene investigation domain or in engineering domain, to a level which allows for easily investigating the extent to which the current augmented reality oriented technology may be applicable for collaboration. An explorative study describes the first findings on the different perception of findings of presence, workload and situational awareness in a real world and augmented reality scenario.

Keywords: Collaboration, Augmented Reality, Presence, Workload, Situational Awareness.

Index Terms: H.1.2: User/Machine Systems; H.5.3 Group and Organization Interfaces; H.5.1.b Artificial, augmented, and virtual realities

1 INTRODUCTION

The mixed reality domain has become more and more mature and versatile nowadays, with even more products reaching the end-user, positioned towards the ‘real environment’ edge in the Milgram’s virtuality continuum [15].

Researchers from various disciplines have proposed and debated methods of studying and leveraging the feeling of (tele)presence [12], this being one of the most prominent characteristics when interacting with such systems. Yet, augmented reality applications that target the context of multiple users using such systems collaboratively with a common goal are still in their infancy. According to Jsselsteijn and Riva [9], presence is mediated by physical and as well as by culture dependent conceptual tools. As concluded by the authors, the presence in the physical environment is no more real or more true than the tele-presence or the immersion in a simulated virtual environment. Following this observation, this paper presents an explorative study that compares the perception of presence of users in a collaborative game in an augmented reality scenario and a real world scenario.

Crime scene investigation – CSI is one example among the multitude of domains for which the science of studying presence in augmented reality applies. This research stems from a joint project between Delft University of Technology, The Netherlands and The Netherlands Forensic Institute – NFI in The Hague [19] aiming at the development of more efficient methods to analyze crime scenes collaboratively, by using augmented reality – AR technology.

In order to reach an equitable generalization level, the complex scenario of CSI work was scaled down to the context of a collaborative game in which players have to build a tower from real and virtual colored blocks. An explorative study evaluates the different perception of presence, workload and situational awareness when collaboratively playing the game in a real world and augmented reality scenario. Apart from the case of collocated users at the ‘building site’ wearing AR headsets, the study also discusses the perception of a remote AR user who gains access to the AR view of one of the collocated users to perform collaborative work. First findings indicate that compared with playing the game in real world, the AR collaborative experience has a better attention and situational awareness especially for the collocated users. The remote users though have a more artificial feeling interacting with the environment, with higher stress, lower performance and lower immersion in the environment.

These preliminary results as well as our previous findings on remote collaboration in mediated reality [13], point for the need to identify factors and solutions that increase the feeling of presence and awareness on the side of remote users. Improving the technology is still the major issue for improving the presence indicators.

The rest of the paper has the following structure: the next section presents related work, the subsequent section presents the details on the collaborative game design and the system architecture. Then, the setup and results of the explorative study are described. Finally, conclusions are presented and future work is discussed.

2 RELATED WORK

Several papers study the influence of technology on the perception of presence in augmented reality.

Juan and Joelle [10] present a comparative study on the sense of presence and anxiety for the treatment of phobia towards small animals. The authors find that the invisible marker-tracking induces a similar or higher sense of presence compared to the visible marker-tracking system.

In an anxiety focused experiment that implies the user is presented with a virtual hole in the floor that appears to drop three stories, Gandy et al. [7] find that changing the frame rates in the augmented reality visualization does not affect presence measures.

Wagner et al. [18] discuss key components of feeling present in augmented reality such as the feeling of connection between the virtual and real elements, some degree of realism and dynamic representations mapping physical environment events to those in the mixed reality scenes. The authors identify sound as the most
immersive element of the augmented mixed reality experience, paying attention to sound literally drawing the user into the scene.

According to the study of Davies et al. [5], tools for meaningful dialogue, for helping to get at tacit knowledge, to provide structure in the group dynamics and to encourage users to take part, are identified as essential on the role of presence in mixed reality for participatory design. The participants must be able to think themselves into the computer generated environment represented by the tools and to accept this environment as models of the real environment. The study shows how engagement in the design process allows participants to overcome some limitations of the design tools, for example difficulties with the computer generated tool interface.

In an attempt to go beyond mixing realities and develop experiences that enables users to feel present in blended spaces, Benyon [1] considers presence as the interaction between the self and the content of the medium within which the self exists, and place in this medium.

A complete and vivid virtual world offers an experience continuous in space and time that can be interpreted through an illusion based on the opportunistic, economical and top-down nature of the perceptual system [9]. The perceptual illusion of non-mediation implies a level of experience where both the artificial content and physical environment disappear from the user’s awareness, making the transition from a passive, external observer to the complete sensorial immersion. Another social and cultural component of presence is the possibility of building and sharing a common ground through the interaction, allowing for expressing self-concepts and eliciting emotional content.

The work of Maclntyre et al. [14] proposes the concept of aura as an important complement to presence that enriches the understanding of users’ responses to a variety of computer-mediated experiences. The aura stems from significant, cultural and personal aspects of a place or object, and represents a relationship between the person and the place or object. In general, media experiences lack aura, but support the aura a person feels.

Previous works studied the perception of presence in augmented reality given variables such as frame rates, sound, visible/invisible markers, tools for meaningful dialogue, interaction between self and content, perceptual illusions and common ground through interaction. As of now there is no study which compares the perception of presence in collaborative scenarios of co-located users in a real-world scenario and co-located as well as remote users in an augmented reality scenario.

3 THE AR TEST BED

To study the perception of presence AR game is designed. The game session implies three players, two of them being collocated at the ‘construction site’ and a third one being located in a separate room. Each collocated player sits at the table and wears a stereo AR headset, with direct view of a single AR pattern marker placed on the table. The AR systems of collocated players project the augmented game elements as an additional layer on top of the stereo camera video stream, into the AR stereo view of the users. The block construction site is centered at the position of the AR pattern. The collocated players benefit from the sense of depth generated by the AR stereo setup. This is in line with the finding of Nichols et al. [16] that apparent depth in virtual environments is an important determinant of presence.

The remote player sits at a table in the other room with a laptop computer on the table (Fig. 1). This player can connect to the view of any of the collocated players.

An instructor is located in the same room with the collocated players. This person watches the game flow and gives online indications with regard to the rules and state of the game.

In addition to consistent visual updates on the game state, the communication among the players and instructor is realized also by audio channel, using the fixed telephones from the two rooms, set on the speaker mode.

The software prototype of the AR collaborative game system is based on a centralized client-server approach that implies all AR subsystems have connections to a software server running on the computer of the instructor.

![Figure 1: Experimental setup for the Augmented blocks game.](image)

### 3.1 Game Design

Within a game, roles, rules and resources can be modeled [11] that can be seen as simplified representation of complex systems and problems. The goal of the AR game is to jointly build a tower by using the colored blocks available on the game board. The game represents an approximation of a complex shared task. Individual expertise is represented by the ability of each player to manipulate blocks of specific color only. Shared expertise is represented by the ability of all players to move blocks of the same color. The order of the blocks in the tower to be built is not to be randomly set. Instead, the color order of the blocks has to contain the individual color pattern of each user. This color pattern represents the individual task of the players. The individual expertise and the individual task reflect the knowledge of the players and are defined at the beginning of the game session. Table 1 shows the game configurations used in the study.

During the game, the system tracks the actions of players against consistency of rules with individual goal assignments. An on-screen message is then displayed every time a player attempts to select a block of a color other than the colors defining his/her abilities (Fig. 2).

<table>
<thead>
<tr>
<th>Player</th>
<th>Move</th>
<th>Pattern</th>
<th>Solution</th>
</tr>
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<tbody>
<tr>
<td>P1</td>
<td></td>
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<td>P2</td>
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<tr>
<td>P3</td>
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Table 1: Physical (left) and augmented (right) blocks game setups

In a typical game session, the players are initially accustomed with the information related to their individual task (color pattern)
and their individual abilities (colors identifying the accessible blocks). The shared goal of building the tower is then achieved through a sequential process in which the players have to communicate and to agree upon the action strategy involving the next block to be moved. None of the players can build the minimal tower containing the individual color pattern without help from at least one of the other players. The rules of the game are made in such a way to support collaboration among participants. Partial information available at any time allows for nonlinear game dynamics, process of discovery and gradual development toward fulfilling the shared game task, the building of the tower.

To place a block at a specific location on the game board, the block has to be selected first, moved to the new location and then deselected. To deselect a block, the block has to be kept in the same location for a fixed time period (5 seconds).

The location of the tower is marked with the white color and is located at the middle of the squared game board. At any time, the players are allowed to remove blocks from the already build tower.

When users want to concurrently move blocks, a limitation has been set to allow only the first player to try this, to hold possession of the augmented cursor.

Another special case is that of the remote player manipulating blocks through the view of one of the collocated players. The remote player gets the view of the collocated player he is connected to. This can be a factor of confusion leading to focusing difficulty, when he does not move but the other player does move. The interface of the remote player projects an additional box with video from the remote player.

In addition to this, a second augmented cursor of the remote user is displayed onto the view of the collocated player. These measures are assumed to increase the self-awareness of the remote user and to reduce the confusion of simultaneously interacting with the AR game items. Fig. 4 presents a sample set of snapshots from the views of the three game participants.

3.2 User Interface

As shown in Fig. 3, the augmented content consists of transparent visual elements representing an information panel in the top left corner of the view, the game board, the colored blocks and the cursor. All graphical representations are rendered in 3D.

The collocated players access the AR system by free hand interaction. The system supports multiple inputs from mouse devices, AR pattern in the form of ‘magic wand’, color pattern for the tip of the finger and palm posture detection [3]. An augmented cursor (blue circle) is shown at the location where the tip of the finger is detected. Compared to the co-located users, the remote user interacts by using a regular mouse device.

3.3 Software & Technology

The open source augmented reality head mounted device Marty [20] consists of a SONY HMZ-T1 optics based virtual reality headset modified in order to support two Logitech C905 HD webcams. To take advantage of the full bandwidth at higher resolutions and video frame rates, each webcam has a separate USB connection to the computer. A special 3D printed plastic case replaces the original SONY case of the headset (Fig. 5).
The video signals of the AR headset are processed by a separate hardware that generates the final 3D content. In the AR system, the models for detection, recognition and tracking are implemented using C++ programming language, Boost:Thread library [23] for parallel computing and the Open Computer Vision library OpenCV [21]. Hand detection and tracking run on the video stream of the left video camera attached to the augmented reality glasses. The graphical user interface is implemented using C++ programming language and Ogre library for 3D rendering [22].

4 EXPERIMENTAL STUDY

To measure the differences in perceiving presence, work load and situational awareness in real and augmented games are assessed using a 7-point Likert scale questionnaire coming from the NASA Task Load Index (TLX) questionnaire [8], the AR presence questionnaire of Gandy et al. [7] and questions on situational awareness following Endsley [6]. Table 2 shows the used questionnaire.

<table>
<thead>
<tr>
<th>Question</th>
<th>Description</th>
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<tbody>
<tr>
<td>1. In the environment did you feel like an observer (rate as low)?</td>
<td>How natural did you feel when moving in the environment?</td>
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<tr>
<td>2. How natural did you feel when moving in the environment?</td>
<td>How natural did you feel when placing blocks seem?</td>
</tr>
<tr>
<td>3. How mentally demanding was the task?</td>
<td>How aware were you of events occurring in the environment around you?</td>
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<tr>
<td>4. How natural did placing blocks seem?</td>
<td>Were you able to anticipate what would happen next in response to placing a block onto the target?</td>
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<tr>
<td>5. How aware were you of events occurring in the environment around you?</td>
<td>How well were you able to actively survey and search the environment using your eyes?</td>
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<tr>
<td>6. Were you able to anticipate what would happen next in response to</td>
<td>How well knew you were able to actively survey and search the environment using your hand feel?</td>
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<tr>
<td>placing a block onto the target?</td>
<td>8. How physically demanding was the task?</td>
</tr>
<tr>
<td>9. How much did the setup of the game catch your attention?</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>10. How well were you able to actively survey and search the environment</td>
<td>How well could you concentrate on the tasks?</td>
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<tr>
<td>using your sense of touch?</td>
<td>11. How well were you able to examine objects in the environment?</td>
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<tr>
<td>12. How well could you move objects in the environment?</td>
<td>12. How well could you move objects in the environment?</td>
</tr>
<tr>
<td>13. How hurried or rushed was the pace of the task?</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>14. How “drawn in” to the experience were you?</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>15. How much delay did you experience between your actions and expected outcomes?</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<td>16. How comfortable did you feel moving and interacting with the blocks by the end of the experience?</td>
<td>How comfortable did you feel moving and interacting with the blocks by the end of the experience?</td>
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<tr>
<td>17. How successful were you in accomplishing what you were asked to do?</td>
<td>How much did the visual display quality interfere or distract you from performing assigned tasks or other activities?</td>
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<tr>
<td>18. How much did the visual display quality interfere or distract you from performing assigned tasks or other activities?</td>
<td>How much did the visual display quality interfere or distract you from performing assigned tasks or other activities?</td>
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<tr>
<td>19. How successful were you in accomplishing what you were asked to do?</td>
<td>How well were you able to actively survey and search the environment using your eyes?</td>
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<tr>
<td>20. How much did the interaction with the blocks interfere with the</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>performance of assigned tasks or with other activities?</td>
<td>How well could you concentrate on the assigned tasks or other activities rather than on the mechanisms used to perform those tasks or activities?</td>
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<tr>
<td>21. How much did the interaction with the blocks interfere with the</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>performance of assigned tasks or with other activities?</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>22. How much did the setup of the game catch your attention?</td>
<td>How did you feel when placing a block onto the target?</td>
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<tr>
<td>23. How much did the setup of the game catch your attention?</td>
<td>How much did the setup of the game catch your attention?</td>
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<tr>
<td>24. How consistent did moving a block with your hand feel consistent with what you were seeing?</td>
<td>How much did the interaction with the blocks interfere with the performance of assigned tasks or other activities?</td>
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<tr>
<td>25. How much did you feel with your hand feel consistent with what you were seeing?</td>
<td>How much did you feel with your hand feel consistent with what you were seeing?</td>
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<tr>
<td>26. How much did the setup of the game catch your attention?</td>
<td>How much did the setup of the game catch your attention?</td>
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</table>

Table 2: AR questionnaire

4.1 Experimental Setup

A group of 15 users organized in 5 groups, each group having 3 players participated in the study. Each group plays the game of building a tower in two sessions, using physical blocks (Fig. 6) in one session and augmented blocks in the other session. In the latter case, two users play collocated (Fig. 7, left) and one user participates from a remote location (Fig. 7, right). The order of sessions is changed from one group to the other.

Figure 6: Experimental setup for the physical blocks game.

Participants are between 22 and 42 years old. There are 3 female participants with age between 30 and 42 years old. The male participants are between 22 and 37 years old. About 53% of the subjects had no experience related to user interfaces in augmented reality while 47% had some experience. No participants were advanced augmented reality users. A percentage of 60% of the subjects had no experience related to games in augmented reality, 33% had some previous experience and 7% were well accustomed with augmented reality games.

In the illumination-controlled lab setup, the color pattern for tracking the tip of the finger proved to be the most reliable solution for real-time free-hand based interaction. Fig. 3 depicts a snapshot from the AR view of a collocated player.

During the experiment the remote and collocated participants are video recorded. Additionally, user interaction events with regard to hand gestures, movements of the augmented cursor, block selection and re-positioning, are logged.

5 RESULTS

The results are based on the questionnaire on presence, work load and situational awareness as shown in Table 2. The questions in the questionnaire address different categories (Table 3). Some questions relate to the assessment of the game workload, others target interaction indicators, interface, tactile experience, moving in the environment and others the measurement of situational awareness.

Figure 7: Snapshots of co-located (left) and remote (right) players, taken during the experiment on augmented blocks game.
5.1 NASA Task Load Index

The same number of participants (27% of the players) in physical setup and augmented reality mentions the game experience being somehow mentally demanding (Table 2, Q3). Only 20% of the AR players indicate the game is highly mentally demanding.

A percentage of 73% of the players in the physical setup and 60% of the collocated players in augmented reality being 20% more than the remote users appreciate the game experience is not mentally demanding.

No participant in the physical setup and only 7% of the AR players (10% of the collocated players) indicate the game as being very physically demanding (Q8). A percentage of 87% of the physical game players and 40% of the AR players mention the game is not physically demanding. A percentage of 47% of the participants to the game indicate the pace of building the tower using physical blocks is not hurried or rushed. The pace of the AR game is even lower, as reported by 60% of the players (Q13).

In the same time, 80% of the remote players and half this percentage the collocated players indicate they were successful in accomplishing what they were asked to do (Q17). A percentage of 93% of players in the physical game provide high ratings at this indicator.

A percentage of 10% more remote players than collocated players indicate they had to work hard to accomplish their level of performance. In the physical game almost all players (93%) appreciate this workload indicator at minimum levels (Q21).

While playing with physical blocks, players do not feel insecure, discouraged, irritated, stressed or annoyed (88%). The same is felt by 30% of the collocated players in augmented reality. An equal percentage of remote and collocated players (60%) report medium scores at this indicator (Q25).

5.2 Presence indicators

5.2.1 Interaction

Of the participants playing the game with physical blocks, 93% indicate they feel being more participants than observers, 80% indicating a strong feeling (Q1). In augmented reality 27% of the participants feel being observers while playing the game, this indication being influenced by the 60% of the remote players. The number of users indicating a low degree of participation is comparable for the augmented reality (10% of the collocated players) to the physical setup (7% of the players).

In the augmented reality game, 40% of the remote participants indicate they did not feel natural while moving in the environment compared to only 7% of the participants playing with physical blocks (Q2).

All the players find placing physical blocks natural and only 27% of the AR players (60% of the remote participants) find this type of interaction somehow natural (Q4). A percentage of 90% of the collocated players do not find placing blocks natural, this being more than double the percentage of remote participants giving this answer.

All players in physical setup, 60% of the remote and 70% of the collocated indicate they are aware of the events occurring in the environment around them (Q5).

A percentage of 87% players in the physical setup and 60% of the AR players are able to anticipate what would happen next in response to placing a block onto the target (Q6).

All participants in the game based on the physical setup and 93% of the AR players are able to actively survey and search the environment using their eyes (Q7).

The percentage of 93% of the physical game players indicating they are able to examine objects in the environment is very close to the percentage of 90% collocated players and comparable to the percentage of 80% of all AR players that appreciate this indicator (Q11).

A percentage of 93% players in the physical game and only 13% of the AR participants (20% of the collocated players) indicate they do not experience any delay between their actions and the expected outcomes (Q15).

A percentage of 20% more remote game participants than collocated players mention they felt comfortable moving and interacting with the blocks by the end of the game experience (Q16).

5.2.2 Interference

All participants at the physical game, 60% of the AR remote players and 80% of the AR collocated players reported they are “drawn in” to the experience with the game (Q14).

The quality of the visual display and the interaction with the blocks are major factors that influence the game performance in AR.

AR players identify visual display quality (78%) and interaction with the blocks (86%) as factors to affect the performance of the assigned tasks or other activities. While 67% of the remote players report the visual display quality does not influence them from performing assigned tasks or other activities, all collocated players indicate this aspect as a source of interference or distraction (Q18). On the other side according to the participants, the physical game performance is neither affected by the visual display (78%) nor by the interaction with the blocks (79%).

All the physical game players could concentrate on the assigned tasks or other activities rather than on the mechanisms used to perform those tasks or activities. In case of AR, 40% of the remote players and 30% of the collocated players report they could concentrate more on the mechanisms used to perform tasks and activities (Q20).

According to the reports of more 30% participants, moving a block with the hand feels more consistent with what the players see, for remote players as compared to the collocated players (Q24).

5.2.3 Tactile

In the physical setup, players are able to actively survey and search the environment using their sense of touch (87% of the participants provide high ratings to this indicator), compared to 33% of the AR players (50% of the collocated players) (Q10).

5.2.4 Moving in Environment

Only 40% of the AR game participants report they can move objects well in the environment (Q12). Players using the mouse device have a higher degree of control on moving objects in the AR setup, as suggested by 80% remote game participants.

5.3 Situational Awareness

A percentage of 87% of the players in the physical setup and 80% of the AR players indicate the setup of the game catches their attention (Q9). In the AR setting, 20% more collocated players
than remote players suggest the setup highly catches their attention.

According to all the participants, the physical game setup helps perceive the actions of the other players. Moreover, 93% of the players indicate the physical setup helps foresee the actions of the other players.

In augmented reality, the same percentage of collocated and remote participants (80%) report the game setup helps them perceive the actions of the other players. A higher percentage of remote players (88%) than collocated players (70%) indicate the game setup helps them foresee the other player’s actions.

A comparable percentage of players in the physical game (93%) and of AR players (87%) report the game setup helps them understand the actions of the other players. From the perspective of remote players, the AR game setup fully supports this indicator as suggested by all participants. Only 20% of the AR collocated players give low scores at this indicator.

6 CONCLUSION AND FUTURE WORK

The workload indicators suggest that the AR experience can be characterized by low mental demand, no physical demand and low pace. Fulfilling tasks in AR is difficult, with high workload, as compared to finishing tasks in AR, with low workload, stress, and irritation. With the remote participants, the mental demand is higher, the experience is more successful, but more stressful.

Though the degree of feeling as a participant in the environment is comparable in AR and physical games, the interaction in AR is neither natural nor comfortable, especially for the collocated participants. On one hand, wearing a not so light and small-sized AR headset is not natural for the collocated players. On the other hand, interacting by using the non-stationary view of other person who wears the AR headset and moves the head is not comfortable either.

Moreover, the collocated players frequently get distracted from performing the tasks due to the visual display quality. This may be because of the technical problems related to the accuracy of hand-based spatial interaction, high latency or low fidelity in generating realistic representations of the game elements. As mentioned by Billinghamurst and Thomas [2], it is essential to allow users to easily point to or select small details like blocks in the augmented view.

By totally missing the feedback from the real world, typical to the sense of touch while interacting with augmented blocks, the AR players hardly benefit from any tactile experience.

In AR the players benefit from a higher level of attention, with support to perceive and understand each other’s actions. This may be mainly due to the interest and curiosity of the players in the collaborative game and AR technology.

Surprisingly, in comparison with the collaboration in real life, the AR collaborative experience has a better attention and situational awareness for the collocated users. The remote users though have a more artificial feeling interacting with the environment, with higher stress, lower performance and lower immersion in the environment. In line with these preliminary results and previous findings on remote collaboration in mediated reality [13], future research needs to identify factors and solutions that increase the feeling of presence and awareness on the side of remote users. Overcoming technology limitations may also be part of the solution to improve the other presence indicators.

REFERENCES


