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A Collaborative Game to Study Presence and Situational Awareness in a Physical and an Augmented Reality Environment

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Abstract: While augmented reality research has grown into a mature field over the last years, the aspects of situational awareness and presence of augmented reality (AR) are still quite open research topics. This paper introduces a collaborative game to explore the different perception of situational awareness and presence in a physical and an AR environment. The game is employed as an approximation of collaboratively solving complex problems. The goal of the game is to jointly build a tower with either physical blocks in a physical environment or virtual blocks in an augmented reality environment. A first study with 18 users shows the feasibility of the game and questionnaire design for studying the different perception of situational awareness and presence in a physical and an AR environment. The study further identifies necessary future research with regard to the perception of presence and awareness in AR.

Keywords: Collaboration, Augmented Reality, Situational Awareness, Presence
Categories: L.6.2, L.6.1, L.5.1, L.3.1, H.5.3, C.2.4, M.9, J.4

1 Introduction

Augmented reality (AR) has become more mature and versatile with even more products reaching the end-user, positioned towards the 'real environment' edge in the Milgram's virtuality continuum [Milgram, 94]. Virtual co-location relies on AR [Azuma, 01], [Azuma, 87] to create spaces in which people and other objects are either virtually or physically present: it allows people to engage in spatial remote collaboration. Virtual co-location entails that people are virtually present at any place of the world and interact with others that are physically present in another location to solve complex problems as if being there in person. Recent research in the field of Crime Scene Investigation (CSI) has shown that virtual co-location principally allows experts at a distance to interact with investigators on a crime scene and jointly

perform investigation tasks [Poelman, 12]. However, the evaluation revealed several issues with regard to presence and awareness, e.g. remote experts connected via AR reported that they still would like to see the location with their own eyes. On the other side, the local investigator was not always totally aware of the remote expert's activities [Datcu, 12], [Poelman, 12] leading to misunderstandings.

The perception of presence is one of the most prominent characteristics when interacting with virtual or augmented reality environments. Researchers from various disciplines have proposed and debated methods of studying and leveraging the feeling of presence [Lombard, 97]. Yet, collaborative AR environments are still in their infancy and the perception of presence in such environments has not been studied extensively. Neither has the relationship between the use of AR systems and situational awareness. Situational awareness includes, following the broadly accepted definition by Endsley [Endsley, 95] the perception of a given situation, its comprehension and the prediction of its future state. Theory claims that AR may reduce the mental workload for object assembly tasks, as shown in a study by Tang et al. [Tang, 03]. Yet, there are no studies exploring the relationship between task load and the perception of presence and situational awareness in virtual co-location.

According to IJsselsteijn and Riva [IJsselsteijn, 03], presence in the physical environment is no more real or more 'true' than the tele-presence or the immersion in a simulated virtual environment. However, to enable tele-presence to provide similar experiences as presence in the physical environment, adequate support and technical solutions have to be researched and developed. Research on presence, situational awareness and collaboration in collaborative augmented revealed current limitations and challenges for future studies. [Poelman, 12] identified several issues with regard to different perception of presence and awareness in and AR environment enabling virtual co-location. [Datcu, 14] showed that virtual co-location using AR can support information exchange. [Lukosch, 2015] showed that an collaborative AR environment can improve the situational awareness of remote colleagues not physically present at a scene, but also that AR technology introduces a higher workload.

In order to investigate the different perception of presence and situational awareness, and its relation to task load, the complexity of collaborative CSI was scaled down to the context of a game in which players have to collaboratively build a tower out of coloured blocks. A game set-up has been chosen, because it represents an experimental setting, while at the same time enables to develop an immersive situation, where players can probe actions and experience their consequences as if in real world situations [Klabbers, 06]. The tower game is designed as an approximation of collaboratively solving complex problems. None of the players can individually achieve the goal of the game. Instead, the tower game requires players to collaborate to achieve a shared goal. Thereby, the tower game is different compared to other games as, e.g., the collaborative AR Tetris game [Wichert, 02]. The tower game can be played with three players in two environments:

1. **Physical environment**: all players are present in the same location and collaboratively build a tower using physical blocks.
2. **AR environment**: two players are present at the same location (physically co-located). One player is physically remote but virtually co-located. The tower is collaboratively built by using virtual blocks.

In the following section, the paper first discusses related work. Then, the design of the tower game is described in detail. The paper further describes a first study with 18 users to show the feasibility of the tower game to explore the different perception of presence and situational awareness. Finally, conclusions are presented and future work is discussed.

2 Related Work

Communication media do impact the collaboration process. Among such media, shared visual spaces proved to be essential for complex collaborative visual problem solving tasks through maintaining awareness, reducing errors and ambiguities, monitoring comprehension, facilitating grounding and communication [Kraut, 02]. The collaboration process thus benefits from improved performance and conversational efficiency, having higher impact during visually more complex tasks or during tasks that require accuracy. In an effort to diminish the collaborative risks, people naturally adapt the communication, showing a clear tendency for using action as evidence of comprehension, when shared visual spaces are available [Gergle, 04]. When not coordinated in visual attention, other referential forms can be used to direct attention [Gergle, 11]. Moreover, integrated communication models proved to be more effective than language-only and visual-only models [Gergle, 07].

Several papers study the influence of technology on the perception of presence in AR. Juan and Joele [Juan, 11] 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 presents users a virtual hole in the floor that appears to drop three stories, Gandy et al. [Gandy, 10] find that changing the frame rates in the AR environment does not affect presence measures.

Wagner et al. [Wagner, 09] discuss key components of feeling present in AR such as the feeling of connection between the virtual and physical 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. [Davies, 02], 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 enable users to feel present in blended spaces, Benyon [Benyon, 12] 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 [IJsselsteijn, 03]. 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 MacIntyre et al. [MacIntyre, 04] 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 AR 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. Common ground, or shared understanding of a given context are related concepts to situational awareness, as latter includes the prediction of the future state of a given situation, including the decisions and actions of all actors involved [Endsley, 95]. Azuma [Azuma, 01] concludes that a common problem in AR settings is to ensure that the co-located participants develop a shared understanding of the situation, as it is difficult to ensure that all participants understand what others are referring to within the AR environment.

Livingston [Livingston, 05] describes that humans rely mostly on their visual perception in order to navigate, for example through perceiving an object in space and to predict what would happen if the object had been moved, which can be even more difficult when virtually co-located. Nunamaker et al. [Nunamaker, 09] introduce possibilities to focus attention of virtual teams, because of the difficulty within virtual co-location to concentrate on one task, which is related to task load.

As of now there is no study, which compares the perception of presence in collaborative scenarios of co-located users in a physical environment and virtually co-located users in an AR environment.

3 The Tower Game

To study the different perception of presence and situational awareness in a physical environment as well as an AR environment, a collaborative game is designed. The game offers the possibility to engage players in an immersive decision-making exercise in an artificial, but still realistic environment in order to learn about their decisions' consequences [Sitzmann, 01]. It further enables to model roles, rules and resources [Klabbers, 06] in approximation of real environments. Amongst others, realism seems to be one important element to affect the experience of presence, or what with regard to computer simulations and games, can also be called situated immersion [Witmer, 98].

From a computer science perspective, collaboration can involve humans as well as computational agents, who use technological support in 'a process in which two or more agents work together to achieve a shared goal' [Terveen, 95]. A more specific definition is given in behavioral science, where collaboration 'occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain' [Wood, 91]. In complex design and engineering processes, collaboration is defined as 'an interactive process in which a group of individual group members uses shared rules, norms, and structures to create or share knowledge in order to perform a collaborative task' [Knoll, 13].

Complex collaborative scenarios are thus characterized by individuals that collaboratively work towards a shared goal, e.g. creating an artefact, solving a problem or accomplishing a task in a game. Often the participation in the collaboration is motivated by an individual goal. When collaborating, the individuals bring in their individual and shared expertise to achieve the shared goal. Without the individual expertise of the collaborating individuals, achieving the shared goal often becomes difficult or even impossible.

The above characteristics of complex collaborative scenarios have been leading in the design of the tower game. The shared goal for the players in the tower game is to jointly build a tower by using the coloured blocks available on the game board. In the tower game there are blocks of 4 different colours. Each player can only move blocks of 2 different colours. These 2 colours represent a player's individual expertise. Moreover, all players can move blocks of one shared colour, resembling the player's shared expertise. The order of the blocks making up the tower has to contain an individual colour pattern assigned to each player presenting the individual goal of the players.

The individual expertise, i.e. colours identifying the movable blocks, and the individual goal, i.e. colour pattern, are revealed at the beginning of the game and not shared with the other players. The individual expertise represents information that needs to be shared with the rest of the players during the game. 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. To build the minimal tower and include their individual colour pattern, the players need help from at least one of the other players. To get help, the players are allowed to communicate with each other, by expressing their requests to the game partners. Players are, however, asked to keep their individual goal secret. In the physical block game condition, the block pattern identifying the individual goal is printed on a piece of paper placed in front of each player and is visible only to that player. In the AR game condition, the block pattern of each player is displayed in his/her AR headset and directly on the screen of the laptop computer, in the case of the remote player.

3.1 The Physical Environment

In the physical environment, 3 players are physically co-located and can directly manipulate the physical blocks to build the tower. They sit at the same table and interact with the coloured physical blocks without using any AR support system. An

instructor at the same physical location as the players gives instructions on the game rules and watches for the correctness of the game (Figure 1).

Figure 1: Experimental setup in the physical environment

In front of each player, a cardboard informs the players about which coloured blocks they can move and which colour pattern they need to achieve in the tower. Table 1 shows the colour assignment per player and the solution for the game in the physical environment.

Player	Move	Pattern	Solution
P1			
P2			
P3			

Table 1: Colour assignment in the physical environment

3.2 The AR Environment

The AR tower game requires three players, two of them being physically co-located at the tower 'construction site' and a third being physically located in a separate room. The physically co-located players sit at a table one in front of each other and wear AR HMDs (Figure 2). The AR HMDs are equipped with stereo vision to enhance the sense of depth which is considered an important aspect for the perception of presence [Nichols, 00].

The remote player sits at a table in the other room with a laptop computer (Figure 3). The AR user interface allows the remote player to connect to the HMD view of

one of the two physically co-located players. By doing this, the remote player becomes virtually co-located with the other two players. Even more, while connected to the view of one of the physically co-located players, the remote player can select and move virtual blocks as if being physically present next to them at the table, in front of the AR tower 'construction site'.

Figure 2: Experimental setup for the physically co-located players in the AR environment

Figure 3: Experimental setup for the remote player in the AR environment

In the AR environment, the players interact only with virtual blocks, no matter whether they are physically or virtually co-located. There are no physical blocks

involved in the AR environment and the final tower is completely made out of virtual blocks.

Table 2 shows the colour assignment per player and the solution for the game in the AR environment.

Player	Move	Pattern	Solution
P1			
P2			
P3			

Table 2: Colour assignment in the AR environment

The augmented game 'construction site' is centred at a physical AR pattern placed on the table, in the room of the physically co-located players. The white rectangular region in the middle of the AR game board (Figure 4) represents the base of the AR tower to be built.

The user interface of the game consists of 3D transparent visual elements representing an information panel in the top left corner of the view, the game board, the coloured blocks and the cursor (Figure 4). The players are notified about the current game status in an information box in the upper left corner of their view showing the names of the online players (Figure 4). It further gives the following information:

- It shows which coloured blocks the local player can move.
- It identifies the colour pattern the local player needs to create in the tower.
- In the remote player's user interface, it displays to whom the remote player is connected ("I see him").
- In the user interface of the player who is being followed, it displays "Sees me" next to the name of the remote player.

The physically co-located players interact with the AR blocks by using free hands interaction [Datcu, 13; Datcu, 15] (Figure 4) while the remote player can do this by using the mouse device.

In the AR environment, only one player can select and move a virtual block at the same time. The information box in the upper left corner of the user interface identifies the player holding a virtual block by placing the text "Cursor" next to the name of the player (Figure 4). All players have their own virtual cursor in the AR environment. The remote player can additionally watch the cursor of the player whose view he/she is being connected to.

The correctness of the players' actions during a game session in the AR environment are ensured partly automatically and partly by the instructor. The instructor is located in the same room with the physically co-located players and can follow the actions of all players in the user interface of the game server.

Communication among the players as well as the instructor is made possible by using phones set on speaker mode, in the two different rooms.

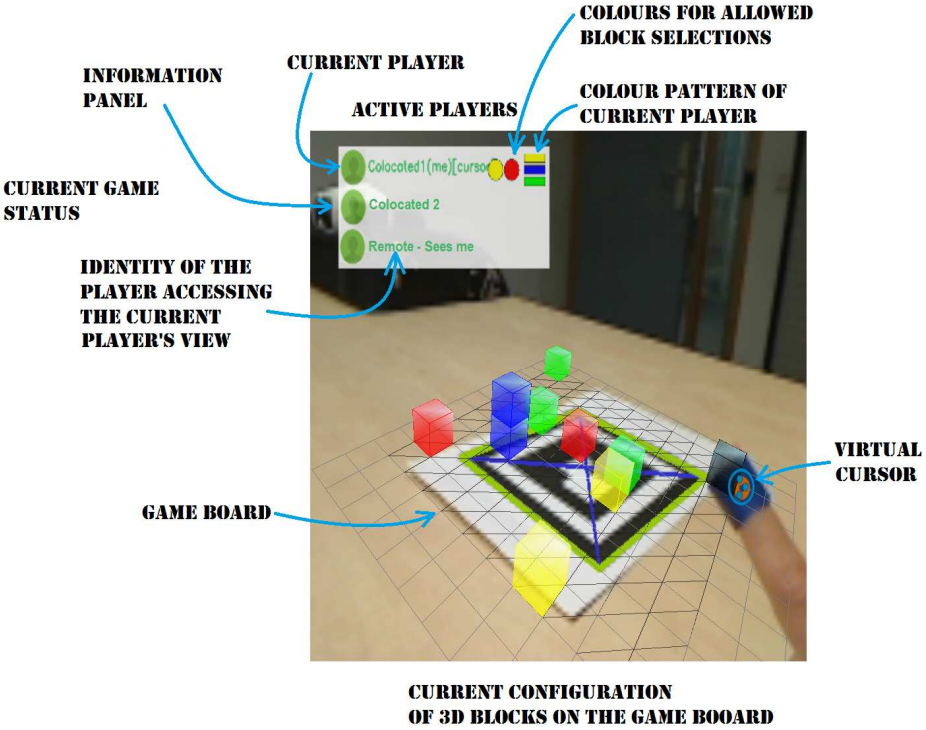

Figure 4: Game user interface in the AR environment

4 Exploratory Study

The differences in perceiving presence and situational awareness in the different environments are explored based on the subjective participant evaluation using a 7-points Likert scale questionnaire.

To be able to assess the relation between presence as well as situational awareness with the workload of the players, the mental and physical workload, performance, stress and pace are measured using the NASA TLX questionnaire [Hart, 88].

To assess the perception of presence adapted version of the AR presence questionnaire of Gandy et al. [Gandy, 10] is used and distinguishes 4 different categories in relation to presence. The adapted version contains 9 interaction-oriented questions to measure the extent to which the users feel more like participants rather than simple observers. The level of distraction is measured using five interference-oriented questions. The role of touch feedback and the naturalness of moving in the environment are measured using tactile experience oriented and moving in environment oriented questions.

The level of perception and anticipation is measured using a set of situational awareness oriented questions following Endsley [Endsley, 95]. Table 3 shows the resulting questionnaire.

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

Table 3: Questionnaire to assess perception of presence, situational awareness and task load

The questions in the questionnaire are structured in 6 different categories. Category 1 refers to NASA TLX [Hart, 88], category 2 to 5 refer to the adapted AR presence questionnaire by Gandy et al. [Gandy, 10] and category 6 refers to

situational awareness [Endsley, 95]. Table 4 shows these categories in relation to the questions.

Category	Description	Questions
1	NASA TLX	3, 8, 13, 17, 21, 25
2	Interaction	1, 2, 4, 5, 6, 7, 11, 15, 16
3	Interference	14, 18, 19, 20, 24
4	Tactile experience	10
5	Moving in environment	2, 12
6	Situational awareness	9, 22, 23, 26

Table 4: Questionnaire categories

During the experiment all players are video recorded. In the AR environment, additionally user interaction events such as hand gestures, movements of the virtual cursor, block selection and re-positioning are logged.

4.1 Experimental Setup

18 users organized in 6 groups, each group having 3 players participated in the study. Each group played the tower game in two different conditions namely the physical environment (Figure 1) and the AR environment (Figure 2 and Figure 3). In the AR environment, two players are physically co-located (Figure 2) and the third player plays from a remote location (Figure 3).

4.1.1 Equipment

The two physically co-located players in the AR environment use the open source AR HMD Marty [Marty, 14] which consists of a SONY HMZ-T1 headset modified in order to support two Logitech C905 HD webcams. Each webcam has a video frame rate of 30 fps, 2 megapixels resolution and a maximum resolution of 1600x1200 pixels. The autofocus function of each webcam was disabled before being used in experiments. This measure aimed to avoid the rather discomforting visual effect of the unsynchronized autofocus in the two webcams. The SONY HMZ-T1 headset has a resolution of 1280x720 pixels, 16:09 aspect ratio and 45 degree field of view.
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 (Figure 5). The left and right video streams from the two webcams attached to the AR headset were combined to one integrated video stream. The 3D Ready function of the SONY HMZ-T1 headset generates the final 3D content by again splitting the left and right channels from the video sequence generated by our framework. The whole process of processing, merging, splitting and displaying in 3D the video content, has a lag of about 500ms. In practical use, we occasionally experienced larger lag of up to 1500ms, especially when the SONY external hardware unit got overheated, after being in use for a longer time.

From the technical point of view, the collaborative game is supported by a multi-user framework running in parallel the components for data communication and data

processing. In the AR condition, the shared environment is assembled through the visual perspectives of each of the two physically co-located players, the virtual board and the set of virtual blocks in the game. The framework allows the remote player to become virtually co-located with the two local players by sharing their view as provided by the cameras in the HMD. By connecting to the view of one local player, the remote perceives the virtual game setup from the perspective of that player. The game perspective is given by the physical reference of the virtual game board, through a QR marker which is located on the table in front of the local player and which is automatically detected by the AR game system.

In our AR system, the components for detection, recognition and tracking were implemented using C++ programming language, Boost::Thread library [Boost] for parallel computing and the Open Computer Vision library OpenCV [OpenCV]. 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 [Ogre3D]. In our AR system, each player has an Ogre3D user interface running on a separate laptop computer. All user systems communicate with each other via a server, in a centralized architecture. The user computer equipment is interconnected through a local network using wired connections. Our AR system logged all interaction events, player actions and video streams.

Figure 5: Marty AR HMD [Marty, 14]

4.1.2 Procedure

The order in which the game was played in the 2 different conditions was altered from one group to the other. After each game session in one of the two conditions, the players filled in a questionnaire as shown in Table 3. This resulted in 18 questionnaires for the physical environment and 18 for the AR environment. Of the 18 questionnaires for the AR environment 6 are for the remote player and 12 for the physically co-located players.

At the beginning of the experiment for each group, all players further answered general questions on the time and date of the experiment, name, age, gender, occupation, professional background, and the level of experience with AR environments and game in AR specifically.

5 Results

The results are based on the questionnaire on presence, workload and situational awareness as shown in Table 3 and the general information.

The 18 players were between 22 and 42 years old. There were 4 female players with age between 30 and 42 years old. The male players were between 22 and 40 years old. About 50% of the players had no experience related to user interfaces in AR while 11% had extensive experience. A percentage of 56% of the players had no experience related to games in AR, 33% had some previous experience and 11% were well accustomed with AR games.

For reporting the results, the scores on the Likert scale are clustered: 1 to 2 refers to the low category, 3-5 to medium and 6-7 to high. Some questions relate to the assessment of the game workload, others target indicators of interaction, interface, tactile experience, capability of moving in the environment as indicators for the perception of presence in AR, while others are related to situational awareness.

An exploratory factor analysis on the 7-points Likert scale consisting of items Q1 to Q26 (without Q25) indicates that the questionnaire has a good internal consistency (Cronbach's $\alpha = 0.7224$).

Using the players' feedback from the responses at the questionnaire, an in-depth analysis was done on the six categories of questions presented in Table 4, for comparing five different categories:

- C1 Answers of all players in Non-AR condition versus answers of all players in AR condition
- C2 Answers of all AR players in remote condition versus answers of all AR players in local condition
- C3 Answers of all AR players in local condition whose view is shared with a remote player versus answers of all AR players in local condition
- C4 Answers of all players in Non-AR condition versus answers of all AR players in local condition
- C5 Answers of all Non-AR players versus answers of all AR remote players

The categories C2 and C3 both refer to AR conditions, with C3 specifically pointing to the role of the local player in AR. Table 5 illustrates the most notable cases (including cases for which the value of p is around 0.1) comparing game experience in AR condition and in Non-AR condition. For all cases, next to the question index, the result includes the *p* value and the median and inter-quartile-range for each category, in the order appearing in the description of comparison (C_k).

The data for each question and comparison categories is checked using Wilcoxon rank sum test. Out of 135 cases (27 questions x 5 comparison categories), 58 cases provide solid statistical base to check results ($p \leq 0.05$). From these, there are no cases leading to solid statistically proven evidence ($p \leq 0.05$) supporting that game experience in AR condition is better than in Non-AR condition. Only three cases provide evidence that AR condition is better and for Non-AR ($p \leq 0.15$), while 67 cases show evidence ($p \leq 0.15$) that the game experience is better for Non-AR. The game experience could be characterized as more hurried or rushed (Q13) for all Non-AR compared to all AR (C1) and AR remote players (C5). The players seem to be equally "drawn in" to the Non-AR game experience as much as to the AR game experience (Q14, C1).

Category		AR			
	- C1 - Non AR *vs.* AR	**- C2 -** Remote *vs.* Local	**- C3 -** Sharing video *vs.* no video sharing	**- C4 -** Non-AR *vs.* AR Local	**- C5 -** Non AR *vs.* AR Remote
NASA TLX	**Q13**: *p=0.10243* [3.00,2.00] [2.00,3.00]	-	**Q13**: *p=0.01299* [4.00,2.00] [1.00,1.00] **Q21**: *p=0.02597* [6.00,1.00] [3.50,1.00]	-	**Q13**: *p=0.14921* [3.00,2.00] [2.00,2.00]
Interaction	-	**Q01**: *p=0.13661* [3.50,3.00] [5.50,1.00]	-	-	-
Interference	**Q14**: *p=0.06873* [5.00,1.00] [5.00,2.00]	-	-	-	-
Tactile experience	-	**Q10**: *p=0.04977* [1.00,0.00] [2.00,2.00]	-	-	-
Moving in environment	-	**Q12**: *p=0.06227* [3.00,1.00] [2.00,1.50]	-	-	-
Situational awareness	-	**Q23**: *p=0.13973* [5.00,1.00] [4.00,2.00]	-	-	-

*Table 5: Notable results for a statistical analysis based on the Wilcoxon rank sum test, on different categories of questions and comparison of conditions. For each case, the question index is shown, the p value and the median (**Mdn**) and inter-quartile-range (**IQR**) for each category, in the order appearing in the description of comparison **- C_k -***

Comparing AR conditions (C2 and C3), it follows that the AR remote player feels more like an observer than a participant (Q01, C2), the AR remote players could move objects better than local players (Q12, C2) and AR remote players appreciated more than AR locals, that the setup of the game helped in perceiving the actions of the other players (Q23, C2). On the other way, the AR local players appreciated more than the AR remote players, that they were able to actively survey and search the environment using the sense of touch (Q10, C2). Additionally, the AR local players not sharing their view appreciated that the pace of the game task was more hurried or rushed, compared to the AR local players having their view shared with a remote

player (Q13, C3). Similarly, the AR local players not sharing their view appreciated that they had to work harder than the AR local players having their view shared, to accomplish their level of performance (Q21, C3).

Figure 8 depicts a diagram example of the events logged during an experiment session. The figure indicates that during the game, the remote player made 53 block selections of forbidden colours and 11 block selections of allowed colours. The first co-located player had 40 forbidden block selections and 31 allowed block selections. Furthermore, the second co-located player had 51 allowed block selections and no forbidden block selections. The allowed block selections are displayed with blue 'x' markers and forbidden block selections are displayed with yellow 'x' markers, for each player. Continuous blocks refer to time segments when the players are connected to the game server. In addition, a black bar drawn under each continuous block indicates time segments when the game board was visible on the view of the player. Discontinuities along such black bars, while the player is still connected to the game server, indicate time segments of player inactivity during the game. In the data sample of the game in Figure 6, the contribution of the remote was 22.50% from the total activity in the game, the contribution of the first co-located player was 42.50% and the contribution of the second co-located was 35.00%. This shows somehow balanced proportion of player contributions over the duration of the game (the higher player contribution comes from putting in place the coloured block representing the shared expertise by one of the players). Figure 7 depicts examples of player contributions in different game sessions from the experiment.

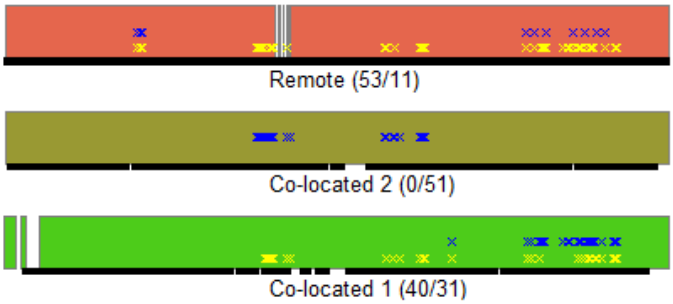

Figure 6: Illustration of the logged events during an experiment session. The blue markers 'x' on the first row relate to allowed block selection events. The yellow markers 'x' on the second row relate to forbidden block selection events. The number of logged forbidden and allowed block selection events is specified in the brackets.

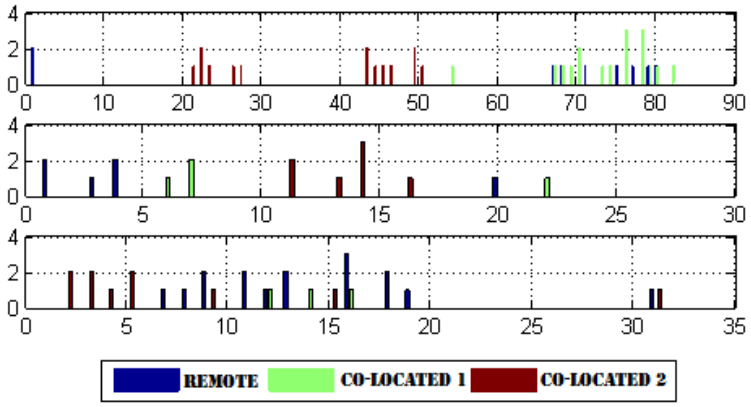

Figure 7: Examples of player contributions in different game sessions.

5.1 Task load

The results of the NASA TLX questionnaire indicate that the real environment is characterized by low mental and no physical demand. Fulfilling tasks in the AR environment is more difficult and has a higher workload, as compared to finishing tasks in the real environment. Interestingly, the AR environment has a slower pace than the real environment. These observations are present in the following detailed results:

- The same number of players in the physical environment as well as AR environment (33% of the players) mentions the game experience being somehow mentally demanding (Q3). A percentage of 67% of the players in the physical environment and 50% of the physically co-located players in AR appreciate the game experience is not mentally demanding.
- None of the players in the physical environment and only 11% of the AR players (16% of the physically co-located AR players and none of the remotes) indicate the game as being very physically demanding (Q8).
- A percentage of 39% of the players in the physical environment indicate that the pace of the game is not hurried or rushed. The pace in the AR game is even lower, as reported by 66% of the players (Q13).
- In the physical environment, all players were successful in accomplishing their task. In the AR setting, 83% of the remote players and 50% of the physically co-located AR players gave high ratings when they are asked about how successful were in accomplishing their game task (Q17). However, this is not a measure to emphasize if players did or did not finish the game.
- In the physical environment, 89% of the players state that they did not have to work hard (Q21). In contrast, 27% of the players in the AR setting report that they had to work hard.
- 89% of the players in the physical environment do not feel insecure, discouraged, irritated, stressed or annoyed (Q25). In the AR environment,

61% of the players report medium scores at this indicator. High scores at this indicator are reported by 33% of the AR remote players and by only 8% of the physically co-located AR players.

5.2 Presence

To evaluate the overall perception of presence, an aggregated indicator was computed by summing up the scores per participant of the 17 questions in the following categories (see Table 4): interaction (category 2), interference (category 3), tactile experience (category 4) and moving in environment (category 5). Then, the mean presence score and the standard deviation (SD) were determined for different game conditions:

- Non-AR: 86.44 (SD 8.51)
- AR: 59.83 (SD 11.46)
- AR remote participants: 57.00 (SD 10.99)
- AR local participants: 61.25 (SD 11.90)
- AR local participants sharing the view with the remote: 58.67 (SD 10.60)
- AR local participants not sharing the view with the remote: 63.83 (SD 13.54)

While the above scores shows the overall perception of presence, the following sections report on the different individual factors in the categories interaction, interference, tactile, and moving in the environment as shown in Table 4.

5.2.1 Interaction

The results on the interaction part of the presence questionnaire show that the interaction possibilities in the AR environment need to be improved. The remote players in the AR environment feel more like observers and report a lower possibility to examine the objects in the environment. The detailed results are:

- In the physical environment, 94% of the players report they felt more like a participant than an observer (Q1). In the AR environment, there is a significant difference between physically co-located (92%) and remote players (50%).
- 83% of the players in the physical environment report they felt highly natural while moving in the environment (Q2). In the AR environment, this is opposite, as 39% felt not natural. This is also confirmed in Q4. 89% of the players in the physical environment felt highly natural when placing blocks. In the AR environment, 33% of the remote players and 83% of the physically co-located players felt unnatural when placing blocks (Q4).
- 67% of the players in the physical environment were highly aware of events in the environment (Q5). In the AR environment, only 28% of the players reported to be highly aware and 44% report medium awareness (Q5). This corresponds to 50% of the players in the physical environment being highly able to anticipate future actions and only 22% in the AR environment (Q6). The aforementioned observations are supported by Q7 in which 89% of the players in the physical environment confirm that they can highly actively survey the environment compared to only 39% in the AR environment. Q11 further refines this observation, as 94% of the players in the physical environment are highly able to examine objects in the environment

compared to 28% in the AR environment. Interestingly, the physically co-located players in the AR environment report a higher possibility to examine objects, i.e. 92% report a medium and high ability compared to only 50% of the remote players.

- A percentage of 89% players in the physical environment and only 11% of the AR players indicate they do not experience any delay between their actions and the expected outcomes (Q15). Similarly, 89% of the players in the physical environment report to feel highly comfortable when interacting with the blocks. This is only shared by 6% of the AR players. Here, none of the physically co-located players feels highly comfortable compared to 17% of the remote players.
- A percentage of 17% more remote players than physically co-located AR players mention they felt comfortable moving and interacting with the blocks by the end of the game experience (Q16).

5.2.2 Interference

With regard to interference, the interaction in the physical environment is superior to the interaction in the AR environment. Players in the AR environment report that their performance is impacted by the visual quality and the possibilities to interact with blocks. Surprisingly, the players in AR could still concentrate on their tasks, the physically co-located players using HMDs and free hand interaction reporting a higher consistency:

- All players in the physical environment report that they are "drawn in" to the experience with the game (Q14). In the AR environment, this differs significantly. While 83% of the physically co-located report to be "drawn in", only 67% of the remote players report the same. This difference is mainly due to the different visualization.
- None of the players in the physical environment is distracted by the visual display quality (Q18). However, in the AR environment the quality of the visual display is a major factor for the physically co-located players. 66% of all AR players feel strongly distracted. These 66% are split into 50% of the remote players and 75% of the physically co-located players.
- As with the visual display quality, none of the players reports high impact on the performance when interacting with the blocks in the physical environment (Q19). This is valid also when evaluating the consistency of the moving a block (Q24). In the AR environment, there is again a difference between physically co-located and remote players, with 27% more remote players that physically co-located players reporting impact on performance (Q19). In contrast, only 42% of the physically co-located AR players report consistency when moving a block, compared to 83% of the remote players in the AR setting (Q24).
- All players in the physical environment could concentrate on the assigned tasks rather than on the mechanisms used to perform those tasks or activities (Q20). In spite of the above feedback on visual quality, performance and consistency when interacting with blocks, still 67% of the AR players could concentrate on the assigned tasks.

5.2.3 Tactile

In the physical environment, 89% of the players are able to actively survey and search the environment using their sense of touch (Q10). 78% of the players provide high ratings to this indicator. In the AR environment, none of the remote players reports the possibility to survey or use the sense of touch. Surprisingly, 8% of the physically co-located players report a high possibility.

5.2.4 Moving in Environment

All players, in the physical environment, report that they can move objects well (Q12). Compared to this, only 44% of the AR players report that they can move objects well in the environment. When comparing physically co-located players using free hand interaction and remote players using a mouse device to move objects, remote players report a significant better possibility (58% more players) to move objects.

5.3 Situational Awareness

The situational awareness in the physical environment is in general higher than in the AR setting. In the AR environment, the physically co-located players frequently get distracted from performing the tasks due to the visual display quality, the constraints to interact with the virtual blocks or the low fidelity in generating realistic representations of the game elements. Surprisingly, the difference is not that high, as shown by the following detailed results:

- With regard to situational awareness, a percentage of 89% of the players in the physical environment and 83% of the AR players indicate the setup of the game catches their attention (Q9). In the AR environment, 25% more physically co-located players than remote players suggest the setup catches their attention.
- According to 89% of the players the actions of the other players can easily be foreseen in the physical world setting (Q22). In the AR environment, only 78% of the players report that the actions of the other players can easily be foreseen.
- 83% of the AR players report that the game setup helps them perceive the actions of the other players (Q23). In the physical environment, all players report that the actions of the players can be foreseen.
- A comparable percentage of players in the physical environment (94%) and of the AR players (89%) report that the game setup helps them understand the actions of the other players (Q26).

5.4 Discussion

The results of the NASA TLX questionnaire indicate fulfilling the tasks in the real environment is requiring less mental effort. This is opposed to findings in object assembly tasks in which AR has been used as assistive technology explaining next assembly steps [Tang, 03]. Taking a more detailed look on the task load results, one reason could be with regard to the reliability of the free hand interaction, as the physically co-located players were least successful in accomplishing their tasks and

felt most insecure in their activities. This is supported by Billinghurst and Thomas [Billinghurst, 11] who also argue that improving interaction possibilities is one of the major challenges for mobile augmented reality.

Our AR system proved to have the capability to support the data communication and data processing around the multi-player AR game environment. The log capabilities of our AR system proved to be essential for storing the clues on the game development and especially on the collaboration among the players. The lag on the video streaming from a physically co-located player to the remote player is not noticeable. The centralized system architecture reliably ensured the consistency of the data among the different computers running our AR system in the local wired network. The lag for the visualization on the AR headset did not generally negatively influence the game experience. Occasionally, higher lag was noticed, especially after longer time in use of the hardware equipment for 3D view formation, attached to the AR headset. The experiments also indicated the limitations of the software marker detection components on the lighting conditions. Following the experiment, our AR system proved to provide proper support for running the collaborative tower game, in the context of studying the presence and situational awareness in AR.

The analysis based on Wilcoxon rank sum test indicated that the game experience could be characterized as more hurried or rushed for all Non-AR compared to all AR and AR remote players. The AR remote player feels more like an observer than a participant. This observation is also doubled by checking the overall perception of presence through summing up the scores from 17 questions in categories 2 to 5 (Table 4). This study indicated that the presence for AR remote players ranks lower than for AR local players (57.00 vs. 61.25).

More, the analysis based on Wilcoxon rank sum test indicated the AR remote players could move objects better than local players and AR remote players appreciated more than AR locals that the setup of the game helped in perceiving the actions of the other players. The AR local players appreciated more than the AR remote players that they were able to actively survey and search the environment using the sense of touch. In addition, the AR local players not sharing their view appreciated that the pace of the game task was more hurried or rushed, compared to the AR local players having their view shared with a remote player.

The interaction part of the presence questionnaire also indicates that the interaction possibilities for the physically co-located players in the AR environment needs to be improved, as those feel most uncomfortable and unnatural in their interaction. Still, the physically co-located players in the AR environment report that their interaction is more consistent and offers tactile experiences. This indicates that though free hand interaction needs to be improved it offers potential to increase the level of presence.

Studying the overall perception of presence by summing up the scores from 17 questions in categories 2 to 5 (Table 4), it follows that presence in AR ranks lower than in Non-AR (59.83 vs. 86.44). In addition, the overall presence in AR perceived by local players sharing the view is lower than for local players not sharing the view (58.67 vs 63.83).

Compared to the remote players in the AR environment, significantly more of the other players report to be highly drawn into the game experience. This confirms a finding of using virtual co-location for CSI where remote investigators argued to miss

something when not being physically present at the scene [Poelman, 12]. While in the real environment players interact with real physical blocks, the physically co-located players in the AR environment are using HMD that allows for 3D visualisation of the virtual blocks. The remote players in the AR environment are, however, perceiving the game only in 2D. Nichols et al. [Nichols, 00] argue that stereo vision is an important aspect for the perception of presence. An HMD for 3D visualisation for the remote player might thus improve their perception of presence.

Players in the AR environment were less aware of events in the environment around them. We see that visual quality, or fidelity, of the AR environment is crucial for the situational awareness of co-located players in the game. On the other hand, when related to the physical environment, the situational awareness is not much lower in the AR environment. Thus, the similarity of the set-up and assignment within both environments seems to be more important for the development of situational awareness than the visual fidelity. Furthermore, being able to understand each other's actions, and predict what will happen after the actions of other players does not differ very much in both set-ups.

6 Conclusions and Future Work

Augmented reality research turns more and more into a mature field. However, studies and instruments to explore the relationship between task load and the perception of presence and situational awareness in virtual co-location do not exist.

We introduced a collaborative game that can be played in a physical environment as well as an AR environment. The game of building a tower approximates complex collaboration scenarios by defining a shared goal and expertise as well as an individual goal and expertise. The rules of the game are designed in such a way that they require the players to collaborate. Partial information available at any time allows for nonlinear game dynamics, for the process of discovery and for gradual development toward fulfilling the shared goal of the game, the building of the tower. In combination with a questionnaire, the game enables research on the relationship between task load and the perception of presence and situational awareness in virtual co-location.

We conducted an exploratory study with 6 groups of 3 players that played the game both in a real environment and an AR environment. Though the number of participants in the study is limited, our above findings confirm previous results on virtual co-location using augmented reality [Poelman, 12], as the physically remote players are least drawn into the experience of the game and have the lowest perception of presence. It also confirms an argumentation of Billinghurst and Thomas [Billinghurst, 11] to improve free hand interaction possibilities for augmented reality.

For future work, we plan further experiments as well as a thorough analysis of the recorded videos and interaction logs. Future research needs to address several issues. First, the interaction possibilities in AR need to be improved. Other possibilities, such as e.g. 3D, for the visualization of the game for the remote player in the AR environment need to be explored. A more robust equipment which involves glasses or smartphones using VR-based techniques is to be further investigated as a potentially more fair way to explore the different perception of situational awareness and presence in a physical and virtual environment. Another research direction consists in

using the collaborative game setup to study what is the emotional awareness, its role and what is the connection with the situational awareness, for physically and virtually co-located users engaged in collaboration game sessions.

It is an open question whether traditional concepts for workspace awareness, as described in [Schümmer, 07], can be transferred to the AR environment and what their effect on presence and situational awareness is going to be. The introduced tower game and corresponding questionnaire provide a means to explore these future research topics and compare the effect of advances to the reported results in this first exploratory study.

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