Virtual Reality (2009) 13:153–158
DOI 10.1007/s10055-009-0119-0

ORIGINAL ARTICLE

Social cooperation and competition in the mixed reality space eXperience Induction Machine XIM

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Received: 31 January 2009 / Accepted: 7 May 2009 / Published online: 24 May 2009

Abstract Although the architecture of mixed reality spaces is becoming increasingly more complex, our understanding of human behavior in such spaces is still limited. Despite the sophisticated methods deployed in ethology and behavioral biology to track and analyze the actions and movements of animals, we rarely find studies that focus on the understanding of human behavior using such instruments. Here, we address this issue by analyzing social behavior and physical actions of multiple humans who are engaging in a game. As a paradigm of social interaction, we constructed a mixed reality football game in which two teams of two players have to cooperate and compete in order to win. This paradigm was deployed in the, so-called, eXperience Induction Machine (XIM), a human accessible, fully instrumented space that supports full body interaction in mixed reality without the need for body-mounted sensors. Our results show that winning and losing strategies can be discerned by specific behavioral patterns and proxemics. This demonstrates that mixed reality systems such as XIM provide new paradigms for the investigation of human social behavior.

Keywords Human behavior · Social behavior · Cooperation · Competition · Proxemics · Mixed reality · XIM · Game play

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1 Introduction

1.1 Systematic assessment of collective human behavior

The regulation of interpersonal distance is a fundamental aspect of social interaction and depends on the context and on the cultural background of the person (Hall 1966). However, thus far, little quantitative information has been reported. This lack of analysis raises the question whether social interactions among humans are too complex to be easily captured in behavioral measures. One particular problem might be that tracking of sufficiently large numbers of humans in real time under ecologically valid conditions is very challenging. At an observational level, the American anthropologist Edward T. Hall (1963) fundamentally investigated the phenomenon of interpersonal distance regulation and the perception of personal space.

Hall introduced the term “proxemics” to describe the different measurable spatial relations among humans as they interact. With his studies, Hall could show that the interpersonal distance regulation is a subtle code of communication and highly affected by the context, cross-cultural influences and the perceived familiarity to others.

While Hall mainly focuses on the interpersonal distance regulation in field studies, we analyze here spatial cues of multiple users in the constructed context of a mixed virtual reality space. In this study, we expose our subjects to a concrete game task that affects their proxemics regulation with respect to their teammates. The question is whether the success of a team is correlated with distinguishable, cooperative and competitive interactions expressed in different spatial strategies. This approach opens the discussion how mixed virtual reality spaces, in general, and concrete tasks in such environments, in particular, can help us to investigate human behavior such as cooperation and competition in terms of proxemics.

1.2 Cooperation and competition

One of the main aspects of social behavior deals with whether subjects cooperate or compete. Cooperation can be defined as a concurrent effort of multiple persons to reach a collective goal. Conversely, competition is a rivalry between individuals or a group for a resource. The concept of cooperation and the interrelated concept of competition show a wide variety of behaviors and actions (Deutsch 1949) and complex mechanism of evolution (Axelrod and Hamilton 1981). On a theoretical level, cooperation and competition have been studied extensively using game theory. One of the best-known cooperative game theory problems is the so-called prisoner's dilemma (Poundstone 1993). An approach that is related to our question on a theoretical level is the study of an online ball game, where users were asked to build cooperative teams and compete against each other (Vogiazou and Eisenstadt 2005). Contrary to this paradigm, which addresses cooperation and competition on a theoretical and abstract level, our interest lays in the behavioral, and spatial aspect of cooperation and competition. Team sports like football or basketball are good examples, where multiple players have to regulate their spatial behavior in the field in a cooperative and competitive manner. The study and observation of identically dressed players in a playfield raise a number of methodological and technical challenges (Bialik 2007; Edgecomb and Norton 2006; Lefèvre et al. 2000; Xu et al. 2005). These challenges may be seen as the main causes for these popular sport games not receiving a lot of attention as paradigms to study cooperation and competition on a spatial level. With the advent of virtual and mixed reality technologies, however, this measurement problem might be resolved.

The construction of immersive virtual world platforms and physical accessible mixed reality spaces that control complex multimodal environments has increased in the past years (Bobick et al. 2000; DeFanti et al. 1993; Heldal et al. 2005; Höllerer et al. 2007; Schell and Shochet 2001; Stanton et al. 2001; Steed et al. 2003). Dependent on the use and the function, the applications differ in size, design, number of modalities and their controlling mechanism. Although all these systems provide an interactive mixed reality environment where a group of people can interact with each other or a virtual environment, these systems lack an elaborate framework to observe and quantify human behavior. A notable exception is the Ada exhibition (Eng et al. 2006), built for the Swiss Expo 2002. It was shown how human spatial distribution patterns depend on specific multimodal cues and prior knowledge (Eng et al. 2003). Indeed, not much is known on how humans regulate their behavior at the scale of personal and social space.

We address this issue by focusing on the dynamics of spatial relations of team members as a function of game-induced competition and cooperation. As a controlled paradigm of social interaction, we constructed a mixed reality football game in which two teams of two players have to cooperate and compete in order to win. We hypothesize that the game strategy of a team to cooperate and to compete against the opposing team will lead to discernible and invariant behavioral patterns. In particular, we analyze the features of the spatial position of individual players that are predictive of the game's outcome. We hypothesize that coordinated movement patterns and the regulation of inter-subject distance are specific indicators of social interactions.

2 Methods

One methodological challenge in the investigation of spatial behavior of multiple subjects is to find an appropriate method to collect data. In 1982, William J. Ickner proposed a behavioral game methodology for the study of proxemics (Ickner 1982). The environmental situation should be standardized and the observation quantifiable. The realization of this methodological framework was a hexagonal cubicle, where multiple people could move their positions on a predefined play grid. Because of the lack of suitable observational tools in 1982, scientists had to use such restrictive setups, if they wanted to collect quantitative data of the interpersonal distance regulation.

For our study, we used the eXperience Induction Machine (XIM) (Bernardet et al. 2007), a mixed reality space that can be accessed by multiple users at the same time. XIM provides a controlled environment that allows the continuous collection of observational data of social interaction without interference. If we want to observe behavior in its authentic form, we have to use such standardized setups and observational tools, which do not interfere or affect the actions of the subjects. A marker-less tracking system is used to quantify and analyze the positions of multiple persons over time, the XIM-specific Multi Modal Tracking System (MMT) (Mathews et al. 2007) that allows us to observe and identify multiple subjects in real time (Fig. 2).

XIM is a further extension of ADA (Eng et al. 2003). The main conceptual difference between Ada and XIM is that XIM is embedded in an interactive, virtual world. XIM's architecture can be divided into three different parts: the physical space, the virtual world and the internal controlling mechanism. The physical space measures 30 m^2 and surrounds the visitor on three sides with wide screen projection walls (Fig. 1). The luminous floor consists of 72 pressure-sensitive hexagonal floor tiles (Delbrück et al. 2007). The space has eight loudspeakers that produce a surround sonification. People in the room are tracked by the XIM Multimodal Tracking System (Mathews et al. 2007), which combines infrared tracking information from the overhead video camera with the tactile information from the floor. The MMT is the main perceptual modality of XIM.

The virtual world of XIM is graphically produced by the game engine Torque (GarageGames, Eugene, USA 2008) and the sonification is realized through the real-time interactive composition system Roboser (Manzolli and Verschure 2005). The XIM control system is implemented using the large-scale neuronal system simulator IQR (IQR 2008) and it interfaces the physical system to Torque and Roboser. In this way, XIM is able to produce a mixed reality interactive world that adapts its visual appearance and sonification to the behavior of its users.

For this study, we programmed a mixed reality football game, where participants played in teams of two against two (Fig. 3). All players had a paddle of the size of one floor tile (65 cm) and were represented as virtual avatars in the surrounding screens. Depending on which team the players belonged to, they played either with a blue or a red paddle. The ball was represented on the floor as a yellow floor tile and on the screen as a yellow sphere. It had a speed of 1.66 m/s. By changing their positions in space, players could move their paddle and hit the ball. They had to defend their side of the field and try to deflect the ball to the other team's side. Players could move freely in space, but were asked to remain in their part of the field marked by their team's color (Fig. 4). A goal was scored when the ball reached the edge of the floor at the end of the field of the opposite team. The kick-off after a goal happened automatically in the middle of the field and the direction of the kick-off was randomized. After each goal, the game

Fig. 1 View into the eXperience Induction Machine (XIM), a fully instrumented human accessible space of 5 × 5 m

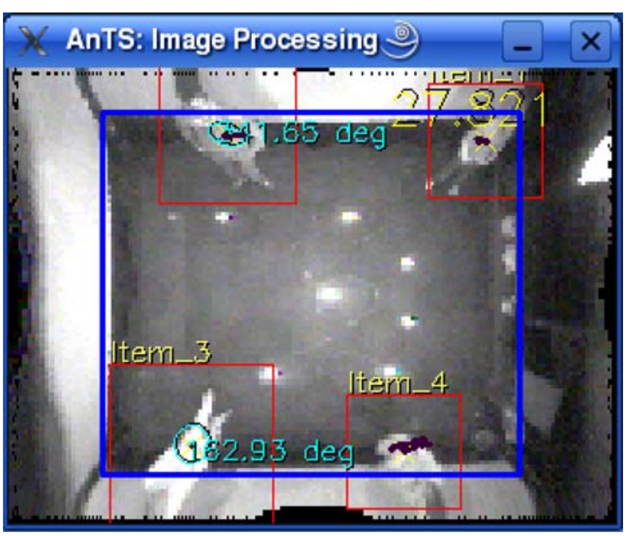

Fig. 2 Overhead image from the infrared camera that is used by the tracking system AnTS to track and label the human players

Fig. 3 Participants are playing the game. The *bright floor tile in the middle of the space* represents the ball. Players controlled either a *red* or a *blue* floor paddle that could deflect the virtual ball

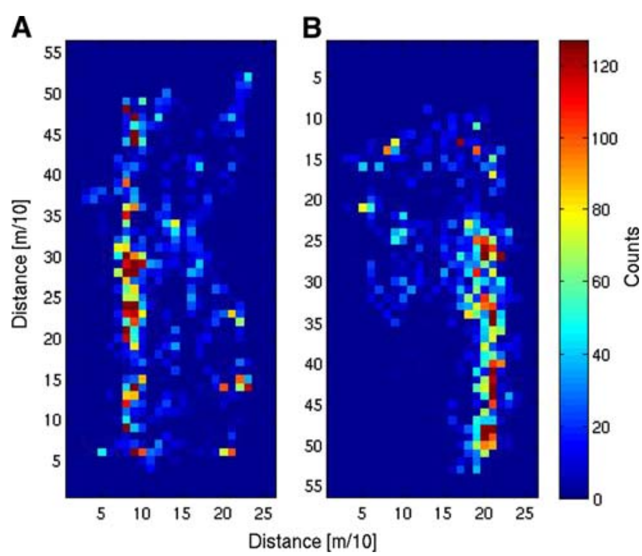

Fig. 4 Energy plot representing overall positions of players during a single game. The *left plot* shows the positions occupied by the members of the team A, while those of team B are shown in the *right-hand panel*. In this example, Team A won the game with a score of 6:5

was paused for 2 s, so that all players could reposition for the new play out. During the whole game, a background sound was played, which helped to communicate the start and end point of the match. Single game events like the collision of the paddle with the ball or the score of a goal were sonificated with short sound effects.

Overall, 10 groups of 4 people played the game for 2 min each (40 subjects with an average age of 24 years, SD = 6, 11 women). All subjects played at least one game, some played two to increase the data set ($n = 8$). The team assignment of players who played two games was a randomized process for the first game and changed for the second game to avoid learned social interaction patterns. Whether participants played the game as the blue team or as the red one was chosen randomly. Before the experiment started, all players were informed about the rules of the game outside the space by an experimenter, who used a standardized movie showing other people playing the game. He answered possible questions to make sure that all players understood the rules of the game. Before the game started all the players were informed that XIM was recording data, but not what kind of data, and that they could leave the space at any time. During the game, the players were alone in the space and there was no interaction between the experimenter and the players. Players could talk freely with each other. The game started when the players were standing at their team's side. During the game, people had no knowledge of the score. The positions of the people, of the ball, collision events and the score were recorded.

3 Results

We hypothesize that the specific movement patterns of the players are directly correlated with the outcome of the game. Based on this assumption, we analyzed the distribution of team members in space during the game.

In total, 13 games were recorded. Participants playing the game as the blue team won six games, while participants playing with the red color won five games. Two games were ties. Overall, 114 goals were scored. The score was balanced with respect to the goal ratio (59 blue team goals to 55 red team goals).

We focused our analysis on the spatial behavior of the winning team members before they scored and the spatial behavior of the losing team members before they allowed a goal. For this purpose we analyzed in every of the 114 epochs the team member distance for winning and losing teams. An epoch is defined as the time window from the moment when the ball is released until a goal is scored. For example, if a game ended with a score of 5:4, we analyzed for each of the nine game epochs the intra-team member distances of the epoch winners and the epoch losers, without taking into account which team won the overall game. An explorative analysis of different epoch lengths revealed that the epoch winners and epoch losers for all epochs that lasted longer than 8 s showed significantly different moving behavior. In this analysis, epoch-winning teams stood on average 1.47 ± 0.41 m apart from each other, while epoch-losing teams had an average distance of 1.41 ± 0.58 m from each other (Fig. 5). The comparison of the distributions of team member distances showed a significant difference between epoch-winning and epoch-losing teams ($P = 0.043$, Kolmogorov–Smirnov test).

The average duration of an epoch was 12.5 s, and 20.3% of all epochs did not last longer than 4 s. The analysis of the distributions of intra-team member distances of winners and losers for all epochs did not reach significance (Kolmogorov–Smirnov test, $P = 0.1$). Also we could not find a statistical significant correlation between game winners and the number of scored goals or game winners with the intra-team member distance regulation. Winning teams that chose an intra-team member distance of 1.39 ± 0.35 m scored on average 6 ± 2 goals. The members of losing teams scored 3 ± 1.5 goals and stood on average 1.31 ± 0.39 m apart from each other. The trend that winners chose a bigger intra-team member distance than losers shows no significant difference.

4 Discussion

Our study introduces a new paradigm to assess human social behavior using game play in the mixed reality

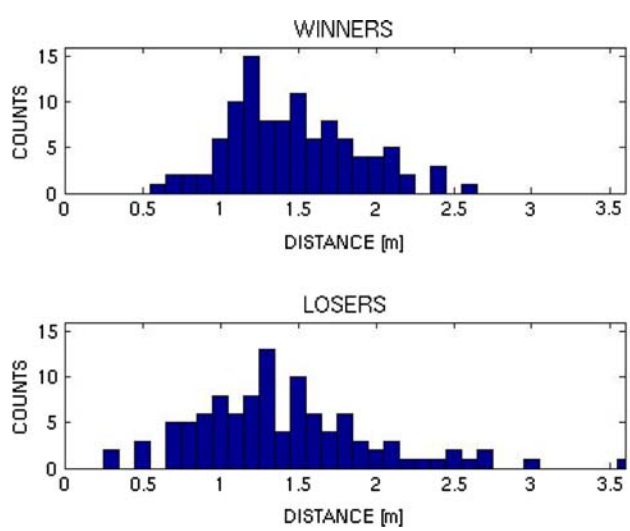

Fig. 5 Comparison of the distributions of the intra-team member distances of winners and losers for epochs greater than 8 s ($P = 0.043$, Kolmogorov–Smirnov test). Epoch winners chose on average an intra-team member distance of 1.47 ± 0.41 m, and epoch losers chose 1.41 ± 0.58 m

environment XIM. We hypothesized that the distance regulation between players can be understood as a measure of social interaction. Based on the expected dependency of the game's success by cooperative behavior, we focused on the correlation between the outcome of the game and the spatial interactions of team members. Indeed, our results show that winners and losers employ a different strategy as expressed in the intra-team member distance. This significant difference in distance patterns between winners and losers can be understood as different levels of cooperation within a team or the way the team members regulate their behavior to adjust and thus compete with the opposing team.

The basic characteristics of the applied game task are that team members have to organize their spatial positions with respect to each other. Coordinated movements minimize the amount of open space and thereby reduce the probability of getting a goal of the opposing team. Our study shows that in long epochs, winners chose to stand farther apart from each other than losers. Our interpretation of this behavioral regularity is that this strategy leads to a better defense, i.e., regulating the size of the gap between the team members with respect to the two gaps at the sideline. Long epoch-winning teams coordinated their behavior with respect to each other in a more cooperative way than long epoch-losing teams.

There are multiple interpretations for the behavioral patterns that are statistically different for the long epochs. We assume that in short epochs, factors such as chance, the starting direction of the ball after a goal or the readiness of the players had a higher impact on the score than in longer epochs where the team play itself was more decisive. Short epochs indicate that players were not ready to play yet or the kick-off gave one team an advantage. Influencing effects like the duration of the break after a goal was scored or the direction of the ball after the kick-off will be considered for future tests.

The methodological concept we are proposing here provides an example of how we can face the challenge of quantitatively studying complex social behavior in mixed reality spaces. Despite the advantage, systematic observations using such experimental frameworks are rare. Contrary to the lack of analyses of spatial behavior in mixed reality environments, we find studies focusing on proxemics using immersive virtual world platforms (Bailenson et al. 2001, 2003). Those applications allow visitors to access a virtual world either by a head-mounted display (HMD) or a conventional computer. Despite that the interface restrictions affect the natural behavior of users, the studies show that the personal space is affected by mutual gaze control and the behavior of a virtual avatar. Additionally, Bailenson et al. reveals a gender effect for the interpersonal distance regulation. A study by Gillath et al. (2008) assesses social spatial interaction of users who are confronted with a virtual person in need in a virtual environment. In Second life (Linden Lab, San Francisco, USA 2003) Yee et al. (2007) compared the interpersonal distance and the eye gaze control between male and female avatars.

In contrast to immersive virtual world platforms, where the interpersonal interaction always remains on a virtual level, large-scale physical mixed reality environments can be entered by multiple users at the same time and therefore allow physical interactions between them. Visitors of such spaces are not dependent on body-mounted interfaces to access the virtual world. Hence their mobility and natural behavior is not affected, compared to conventional virtual world applications. We propose that mixed reality spaces such as XIM provide essential experimental infrastructures for the study of complex social behavior.

In further experiments, we will analyze how behavior and team performance are affected by the body representation and the level of intra-team member communication. In this case, teams of players are formed, where a number of players of the team will be present in XIM and the others will play the game over a network using a computer. These remote players will be represented in XIM in the same way as the real player, i.e., an illuminated floor tile and virtual body on the screen. With this setup, we would like to test the effect of physical presence versus virtual presence on social interaction.

Acknowledgments We acknowledge the use of the Original Floor System developed by the Institute of Neuroinformatics of ETH Zurich and of the University of Zurich. This work was carried out as part of the PRESENCCIA project, a EU funded integrated project under the FP6-IST FET program (project number 27731).

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