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Exploring behaviour towards avatars and agents in immersive virtual environments with mixed-agency interactions

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Abstract

Immersive virtual environments (IVEs) in which multiple users navigate by walking and interact with each other in natural ways are perfectly suited for team applications from training to recreation. At the same time, they can solve scheduling conflicts by employing virtual agents in place of missing team members or additional participants of a scenario. While this idea has been long discussed in IVEs research there are no prior publications on social interactions in systems with multiple embodied users and agents. This paper presents an experiment at a work-in-progress stage that addresses the impact of perceived agency and control of a virtual character in a collaborative scenario with two embodied users and one virtual agent. Our future study will investigate whether users treat avatars and agents differently within a mixed-agency scenario, analysing several behavioural metrics and self-report of participants.

Keywords: Collaborative Virtual Reality, Avatars, Virtual Agents

1 Introduction

Immersive Virtual Reality (IVR) systems that allow navigation by walking in large spaces are a promising platform for a range of applications for teams of users, from team training and rehearsals to recreational scenarios. While such team applications implemented in VR present many advantages compared to real-world scenarios - flexible choice of environments, possibility of repeating exactly the same events, accessibility of different perspectives and embodiments - they are subject to scheduling conflicts and availability issues of team members just as real-world team activities. In contrast to the real world, IVR can provide a unique solution for the lack of participants for a team activity - employing virtual agents controlled by a computer algorithm in place of human users. Indeed the idea of mixed teams of embodied human users and virtual agents performing tasks together in immersive virtual environments (IVEs) has always been prominent in VR research [8, 13, 18]. Research has shown that users behave socially with both avatars (virtual representations controlled by humans) and agents (virtual representations controlled by computer algorithms) justifying their use in IVEs [6, 7]. In practice however, although virtual agents have been employed in a broad range of VR applications and research simulations their use has been largely limited to single-user setups. Examples of applications where multiple users share the same IVE and interact with multiple virtual agents have not been demonstrated and social interactions in such mixed-agency scenarios (setups where each human user interacts with at least one other user and one virtual agent [19, 20]) have not been studied.

The presented experiment-in-progress contributes to the state-of-the-art research by approaching mixed-agency IVEs with our main question: will users treat other embodied users and agents differently when they interact with them within the same scenario? Specifically, we propose to investigate the impact of the perceived agency of virtual characters and their actual control (by a user or an algorithm) on behaviours and self-report of participants. Our planned study will take place in the simplest mixed-agency constellation with two human users and one agent.

Previous research has shown that agency of virtual others - the extent to which a virtual character is perceived as a representation of a real person [3] - influences user experience in social virtual environments [5, 16]. Social VR applications are a powerful collaboration medium because they can create a strong illusion of social presence, broadly defined as the perception that the virtual environment is shared with other individuals [14]. In analysing past research on social presence encompassing the results of more than 150 studies, Oh and colleagues found that in approximately half of the reviewed experiments participants felt higher social presence when virtual others were thought to be controlled by actual people than when they were thought to be controlled by a computer [16]. The reviewed studies used self-report as a measure of experienced social presence and virtual humans were generally introduced to participants as either avatars or agents. A meta-review of Fox and colleagues focuses specifically on agency and its influence on social influence in virtual environments [5] analysing the theory of social influence of Blascovich [3]. The latter posits that avatars produce greater social influence than agents; however, it also suggests that the more perceptually realistic the agent is the less a user will be influenced by the fact that it is controlled by an algorithm. The meta-analysis examined the results of 32 previous experiments (until 2015), selecting specifically studies that manipulated perceived agency prior to the experiment by telling participants whether they would interact with avatars or agents. The results show that virtual characters believed to be avatars indeed produced stronger responses than those believed to be agents in accordance with the social influence theory of Blascovich. The meta-review also analysed the actual control of virtual humans as a moderator, finding that stronger agency effects were found when virtual characters were actually avatars than when they were actually agents. While perceived agency can be directly manipulated by biasing participants prior to the experiment analysing the effect of actual character control is less straightforward. Participants need to be given some information about the virtual characters before the experiment and this information inevitably produces bias of one or another type. A frequent experimental procedure is to task participants with determining whether they interact with an avatar or an agent. For example, a recent study investigated the possibility of increasing human-likeness of agents by introducing social touch [11]. When the virtual character in the study was human-controlled it received higher ratings in perceived agency, co-presence and likeability; adding touch interaction improved agent's

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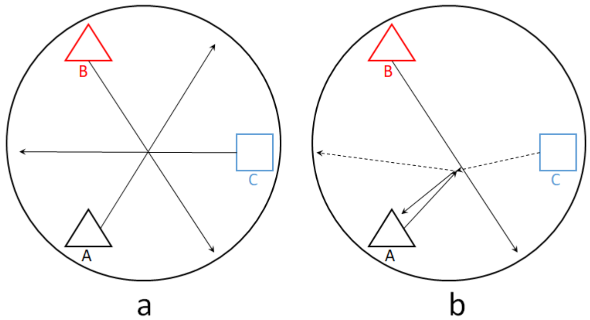

Figure 1: A scheme of the virtual arena and users A and B (triangular shapes) and agent C (rectangular shape) in it. Arrows indicate walking directions. a: All players cross the game area. b: A walks to C to hand an object and walks back, C modifies its path to receive the object.

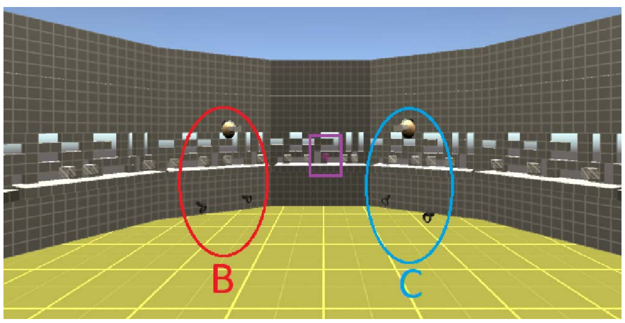

Figure 2: A work-in-progress version of the environment and the characters, showing the view of player A (cropped) looking at players B and C. The purple rectangle highlights the next target object for A.

ratings in perceived agency and co-presence in accordance with the assumption that behavioural realism of agents improves social interactions [3, 9]. In another experiment, users displayed more prosocial behaviour and social avoidance towards avatars [4] although levels of social presence and enjoyment were similar. Only few published studies manipulate perceived agency (with prior instruction) and actual control at the same time, as for example a desktop game-based study which found that although users humanized non-player characters they counted on them as a resource [24].

To summarize, previous research shows that both actual control of a virtual character (by a human user or computer) and user beliefs about this control (whether they were induced by the experimental manipulation or formed by the user during the exposure) influence user experience of social interactions in IVEs. Although both factors are clearly important, there is not enough information on their exact interplay in IVEs. Taking this into account, we will vary the pre-study information on the agency of virtual characters within our mixed-agency context, establishing the extent to which user perceptions and behaviours will be influenced by their assumptions about the agency of their collaborators and by their actual control.

2 Methodology

2.1 Experiment design

2.1.1 Environment and task

In the experiment, three virtual characters (two avatars and one agent) are placed into a round virtual environment in the size of a large room where they need to accomplish a task together. The task resembles a tetris game - there are objects in the virtual scene that need to be placed into slots inside the walls surrounding the virtual arena. Each player is prompted to pick up one object at each moment of the game and bring it to one of the slots that are shown as suitable for this object. At specific moments, a participant is commanded to give the object to any of two other players instead of inserting it into a slot. This way, the participant is forced to initiate interaction with one of the two other virtual characters. The command is only given to one participant at a time. The player on the receiving side must always accept the object that is handed over to them.

Figure 1 shows a schematic of the virtual arena. The next available object and the next selection of suitable slots are always chosen on the opposite side of the game area prompting players to walk across it. This way we induce situations where participants need to perform collision avoidance. The game is designed in a way that each human participant can observe the virtual agent on both their left and right hand side at different moments during the game. Figure 2 shows a screenshot of the prototype game, at a moment where all three players are walking towards objects.

2.1.2 Technical setup

The experimental environment is developed with Unity 3D and designed to be conducted in physically separated tracking areas. Each user will be equipped with an HMD and a pair of controllers. We aim to use Oculus Quest due to its compact form-factor, absence of wires and large-scale tracking capabilities. However, the simulation can run on HTC Vive as well.

2.1.3 Visual representations

Previous research has shown that high behavioural realism of virtual characters increases social presence, while visual realism is only important in way that it should not exceed the level of behavioural realism [16]. A recent study confirms this finding showing that dyadic interactions in VR resulted in greater social presence when participants' avatars had accurately tracked head and hands as opposed to fuller representations with lower levels of behavioural realism [9]. Taking into account these findings, we opt for character representations consisting of head and hands, tracked by HMD and controllers for avatars and animated with pre-recorded motions for agents. In an experiment involving large amounts of walking, it is important for users to have a sufficient amount of visual interaction to be able to effectively share the walkable space with others. A study by Hessels and colleagues that analysed gazing behaviour of participants during their interactions with passing-by walkers in a real-life setting identified head and hands as the most important body parts [10]. Taking into account these findings, we opt for character representations consisting of head and hands, tracked by HMD and controllers for avatars and animated with pre-recorded motions for agents. All three virtual characters will be identical except for three different colours so that participants could distinguish between their two collaborators.

2.1.4 Behaviours of avatars and agents

Behavioural fidelity of virtual representations, whether they are controlled by humans or computer algorithms, is a strong predictor of social presence [16]. In our experiment, agents should be able to exhibit the same functional behaviours directly related to the experimental task as human users - walking around without colliding with others, manipulating objects and reacting on the interaction intentions displayed by users.

Walking For avatars (embodied users) walking is achieved naturally with the use of an HMD system with embedded tracking. To simulate walking of agents we use a crowd simulation framework previously developed in-house. The framework calculates motion trajectories of walking agents according to the set speeds, accelerations, goals etc. While an agent is in motion following its trajectory, a pre-recorded walking animation is applied.

Collision avoidance Experiments with virtual agents have shown that the ability to avoid collisions with each other and with human users is a type of interactive behaviour that strongly contributes to the perceived realism and human-likeness of agents [8, 12, 15, 23]. Collision avoidance behaviour of agents is achieved with the use of the crowd simulation framework that includes collision avoidance simulations that can be tailored to a specific scenario.

Manipulating objects In the course of the experimental task objects scattered in the environment need to be picked up, carried across the game area and inserted into indicated slots in the walls. For users, object interaction is achieved through the use of tracked controllers that make part of the HMD system. For agents, object manipulation animations were created by recording motions of users with the help of an Xsense motion capture suit [1].

Reactive behaviour Agents should be able to react appropriately when users try to interact with them - in our experimental task, by giving them an object. We were able to establish how these reactions unfold in several experimental runs with three human users. As a result we determined the reactive behaviour to contain the following elements - the agent should deviate from its trajectory and walk towards the user who is trying to interact, then slow down to a complete stop while extending the right arm to receive the object. After the object is placed in the agent's hand it resumes its walk towards the initial goal. The process is shown in Figure 1b. The user's intention to interact is recognized automatically - the agent registers an interaction attempt when a user looks and walks in the direction of the agent while also extending the hand with the object towards it. The direction of the gaze is approximated by the forward vector of the player's virtual camera.

2.2 Experimental manipulation

We will manipulate the agency of virtual characters in two ways: 1. by introducing virtual characters as avatars or agents and therefore biasing participants' belief about the agency directly; 2. by varying the amount of correct information on virtual characters' agency prior to the experiment. In one team with players A, B and C, A and B are human participants and C is agent. Following our experimental manipulation, all teams will be split into three instruction groups:

Group 1: A and B are both told that another user is avatar and C is agent.

Group 2: A and B are both told that another user is agent and C is avatar.

Group 3: A and B are both told that one of the other two virtual characters is an avatar and another one is an agent, without specific details.

Comparing the results of Group 1 and Group 2 will allow us to discriminate between the effect of prior agency bias and actual control, while comparing the results of Group 1 and Group 3 will allow to analyse effects due to the difference between introduced and self-deducted beliefs about agency.

2.3 Hypotheses and research questions

Previous research shows that explicit manipulation of perceived agency produces powerful bias in users' attitudes towards virtual characters [5,24]. When not tricked by pre-experiment biasing, users can usually correctly distinguish avatars from agents [11]. However, it is unclear how actual behaviour of users might be affected, especially taking into account high behavioural realism of avatars.

[1]https://www.xsens.com/motion-capture

We formulate the following research questions and hypotheses in respect to experimental manipulation.

RQ1 How will prior information on agency and actual control interact in the self-report results and in behavioural metrics?

H1 Participants will report lower perceived agency towards virtual characters introduced as agents than to those introduced as avatars.

RQ1 and H1 will be assessed by comparing the results of Group 1 and Group 2.

RQ2 Will participants exhibit different behaviour in their interactions with avatars and agents?

H2 If no false information on agency is introduced, self-report on agency and social presence will be stronger for avatars than agents but the level of details in instruction will moderate the effect.

RQ2 and H2 will be assessed by comparing the results of Group 1 and Group 3.

2.4 Measures

As recommended in previous research on social interactions in VR, we will use both behavioural metrics and self-report [1, 2, 17, 20] (details are provided in sections 2.4.1 and 2.4.2). While self-report measures help to understand user experience in full detail, we believe that certain behavioural metrics are important not only as predictors of social presence and but also in themselves, giving an indication of whether the examined setup would be useful for skills transfer to the real world. For example, if trainees would only interact with avatars but ignore agents a collaborative training scenario would not be successful. Similarly, if trainees would avoid avatars but walk through agents in a simulation of evacuating from a crowded place skill transfer would not be achieved.

2.4.1 Behavioural metrics

Choice of interaction partners We will record the number of times when each participant initiated object-based interaction with each of the two other players, to analyse whether the choice of interaction partners is influenced by their agency.

Collision avoidance behaviour Respecting accepted proximity rules is considered to be a sign of realistic social behaviour [1]. We will analyse collision avoidance behaviour of participants following the procedure used in a study with three walking users [17]. In addition, we will analyse the approaching distance when participants hand over an object to another player.

Gaze behaviour Gaze behaviour has been previously used to evaluate differences in attention paid to human and agent collaborators [20]; we will follow this approach as well.

2.4.2 Self-report

Perceived agency and social presence will be evaluated with questionnaires adapted from the work of Biocca and colleagues and Slater and colleagues [2, 22]. In addition, post-experiment interviews will be used to fully discuss participants' experience and impressions.

3 Discussion and Outlook

While implications of the presented experiment for real-world application scenarios can only be discussed when the experimental results become available, it is already clear that further comprehensive study of mixed-agency interactions is linked to the topic of scalability, of the results themselves as well as the experimental procedure. In particular, the question of validity of results and used metrics is relevant in context of scenarios with larger amount of avatars and agents as well as in systems where embodied users are co-located in the physical environment.

The review of social presence reveals positive correlation between physical co-location of embodied users and perceived social presence [16]. Indeed, physically co-located setups can be better suited for team training and location-based team games from a practical point of view. Especially when a specific and complex hardware setup is involved, such as a large-scale multi-camera tracking area providing full-body motion capture for realistic avatars, it does not seem feasible or reasonable to provide each user with an individual system. In a co-located setup, agents will inevitably differ from avatars more, not having co-located physical bodies and invisible in the real space. It is reasonable to believe that in this situation the effect on social presence with non-physically present collaborators (agents) will be negative, as it has been shown in a setup with three embodied users, one of whom was physically separated [17].

When a virtual environment is shared by three virtual characters it seems feasible to ask each user to evaluate their interaction experiences with each of two collaboration partners, and indeed self-report measures have been used in this modality [17,22]. However, if our experiment is expanded to include three embodied users and two virtual agents, would each user be able to remember the details of their interactions with all four virtual characters after the exposure? If they do, how reliable will the obtained metrics be, and is there a limit to amount of virtual characters interactions with whom can be evaluated with post-experiment questionnaires? One may argue that exclusively behavioural metrics could be used in scenarios with many virtual characters; however, it is clear that subjective impressions of users are a valuable resource. A potential solution is to use in-game questionnaires [21] that are presented to a user right after each interaction if the experimental task can be kept meaningful in presence of such interruptions. Finally, it is likely that increased number or embodied users and virtual agents would change interaction dynamics in IVEs, calling for further experiments on the topic of mixed-agency scenarios.

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