Human Interaction in Multi-User Virtual Reality

Stephan Streuber, Astros Chatziastros
Max Planck Institute for Biological Cybernetics
Spemannstrasse 38
72076 Tuebingen
Germany
voice: [+49](7071)601-216; fax: [+49](7071)601-616
e-mail: `Stephan.Streuber@Tuebingen.MPG.de`
www: `http://www.kyb.mpg.de/~stst`

Abstract

In this paper we will present an immersive multi-user environment for studying joint action and social interaction. Besides the technical challenges of immersing multiple persons into a single virtual environment, additional research questions arise: Which parameters are coordinated during a joint action transportation task? In what way does the visual absence of the interaction partner affect the coordination task? What role does haptic feedback play in a transportation task? To answer these questions and to test the new experimental environment we instructed pairs of subjects to perform a classical joint action transportation task: carrying a stretcher through an obstacle course. With this behavioral experiment we demonstrated that joint action behavior (resulting from the coordination task) is a stable process. Even though visual and haptic information about the interaction partner were reduced, humans quickly compensated for the lack of information. After a short time they did not perform significantly differently from normal joint action behavior.

Keywords: Multi-User Virtual Reality; Joint Action Transportation Task; Collaborative Virtual Environment; Human Interaction

1 Introduction

In the first part of this paper we will compare two technical environments (immersive virtual reality and non-immersive multi-user environments) for their eligibility to perform behavioral experiments in the domain of joint action and spatial coordination. We propose that a combination of the advantages of both technologies can be used effectively to study proximal, physical interaction behavior in real-time (joint action). In the second part of this paper we will describe an experiment in which we investigated how a reduction of visual and/or haptic information effects interpersonal coordination.

2 IVR in Behavioral Sciences

Advanced developments in the field of media technology, including improvement of computational power, display technologies and tracking systems, led towards an intense usage of immersive virtual reality (IVR) systems in various fields such as research, simulation, training, rehabilitation and entertainment [BC03] [TW02]. These progressions extended the perceptual and technical limits of this media in terms of feeling present (defined as the sense of being in the computer-generated environment) and immersed (amount of sensory input provided by the technology) [Sch02][HD92]. These advantages of IVR are utilized in behavioral sciences to investigate human behavior under controlled conditions, where subjects' perceptions and actions are linked through the virtual environment [vdHB00][LBB99]. This experimental paradigm is effective when it comes to the investigation of isolated humans and their interaction with the physical world. However, it can be insufficient for studying real life situations, in which individuals have to coordinate their actions with those of others consistently. For example, researchers in the domain of applied perception investigate human car driving behavior by using driving simulators [KP03]. The driving simulator transforms user's interaction with the virtual environment (e.g. acceleration, navigation) into a realistic visual stimulus projected on a screen device. Other traffic members (e.g. cars, pedestrians) are represented as computer-controlled, non-interactive 3D-models. This reduced social environment denies the social component of driving: in the real world, each driver's behavior is strongly interconnected with the behavior of others. Therefore driving - in a social context - can not simply be seen as an obstacle avoidance navigation task, but rather as a dynamic feedback system (=traffic) in which the individual behavior is a result of the interaction with other single drivers and with the environment. Since many every-day behaviors take place in a social environment, a thorough investigation of human behavior requires also the inclusion of social information. However, most of the current IVR systems are not designed for multi-user simulations and therefore they are not qualified for the integration of social elements in the form of group interaction.

3 Non-immersive Multi User Environments

Media which allows for social interaction include, for instance, non-immersive online multi-user environments (OMUE) like social networks, chat programs, trade fairs or computer games. Millions of users daily exchange information, sell or buy products, communicate or play against (or with) each other over the internet. In all these activities individuals have to coordinate their actions with others. Of course human interaction using internet technology is strongly limited compared to real life situations. For instance, the interaction quality is drastically reduced (usually occurs by clicking or typing), the sensory modalities are mostly limited to the visual sense and the user is represented only abstractly (responses affect only the virtual representation and not the user itself).Today's most realistic, real-time interaction over the internet takes place in massive multi-player online role games (MMORG). In that case, the user is represented as a human-like avatar which allows for the exploration of three dimensional landscapes, communication with other players, spatial coordination and physical interaction (e.g. fighting, manipulating objects, or operating vehicles). The huge number of users, advanced interaction possibilities, and the ability to track behavioral data of avatars makes OMUE an interesting tool for analyzing complex social behavior [DM04][NH06]. However, considering the limitations of interaction possibilities, we have to move from desktop virtual reality to immersive virtual reality in order to study close human interaction.

4 Immersive multi-user environment (IMUE)

We believe it is time to create a new experimental environment in which the advantages of IVR and OMUE are merged into a single framework in which several humans can interact, communicate and cooperate in a highly immersive virtual environment. In this experimental environment it will be possible to account for the social nature of perception and to perform experiments in which we can investigate real-time human interaction. For this immersive environment it is required that the standard technical setup is extended by three important features: synchronous real-time tracking of multiple rigid bodies, a distributed application to render one virtual world from different perspectives (for each user) and the usage of avatars to enable users to identify and localize each other. In this setup participants can interact with the world and with others from an egocentric perspective by using their physical body as an interaction device.

5 Setup

The setup was implemented within a large, fully-tracked, free-walking space: 12 by 15 meters in size and equipped with an optical tracking system (16 Vicon MX13 cameras). Participants' head positions and orientations were tracked through the monitoring of reflective markers attached to the participants' heads and to an additional interaction object (stretcher). Each Vicon camera has a resolution of 1280x1024 and the tracking system has a maximum frame rate of 484Hz. In addition to updating the visual environment as a function of participants' head movements, the tracking sys-

	IVR	OMUE	IMUE
Sensory Motor Integration	x		x
Large Field of View	x		x
Ego Perspective	x		x
Multi User Interaction		x	x
Interaction Quality (accuracy, realism)	x		x
User is visually represented		x	x
Somatosensory Interaction	x		x

Table 1: Selection of features that are important for a realistic simulation of the world, including real social interaction.

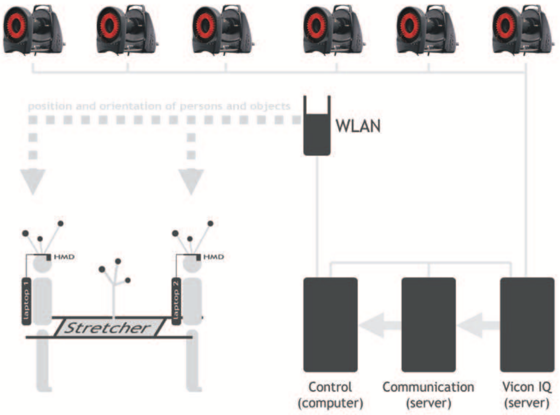

Figure 1: Overview of the hardware components used for the experimental setup. The two persons carry a stretcher which is used as an interaction device. Furthermore, each person carries a laptop for the visualization of the virtual environment.

tem also recorded walking trajectories (head position, head orientation) of both participants and the stretcher. Furthermore both participants wore lightweight HMD's (eMagin, Z800) with a resolution of 800x600 pixels and a 40-degree diagonal field of view (FOV) per eye (the software extended the FOV to 60 degree). We used a stereo projection to display the stimulus to both participants which saw the same virtual world from different perspectives, depending on their head position and facing direction. The HMD had a refresh rate of 60 Hz. Both the participants' and the stretchers' positional information was sent from the optical trackers (via a wireless network connection) to a backpack-mounted laptop worn by each participant. This information was then used to update participants' virtual viewing camera within the virtual environment. This setup allowed participants to move freely throughout the entire walking space without being constrained or tethered.

The virtual world was rendered using Virtools Dev 3.5 and the Virtools VR-Pack and contained 3D-models of a labyrinth, a stretcher and two avatars. While the virtual maze was spatially fixed to the physical boundaries of the tracking space, both the avatars and the stretcher were rendered depending on their real world position and orientation. The participants carried a real stretcher, but what they perceived through the HMD was solely the visual representation of each other and the virtual stretcher.

6 Behavioral Experiment

6.1 Introduction

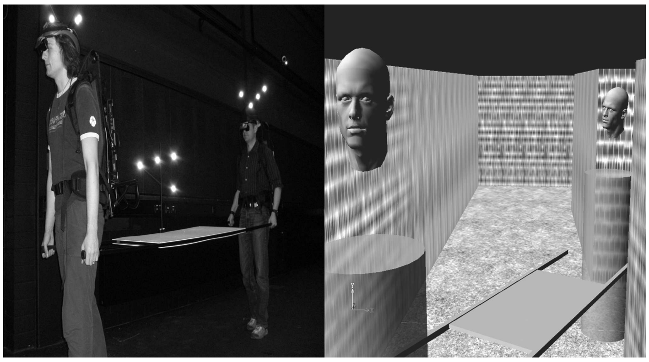

Figure 2: Two participants carrying a stretcher. Left: Subjects were equipped with laptops, head mounted displays and tracking helmets; Right: The visual stimulus which was projected in the HMD.

We tested 10 pairs of subjects performing a simple joint action task: to transport a stretcher through a virtual maze without colliding with the walls (if a collision occurred, an alarm sound was activated). Subjects were instructed to follow a corridor consisting of identical 90-degree corners. Furthermore, we told subjects to walk as naturally as possible and to not influence the behavior of the partner by pushing and pulling the stretcher. Analyzing walking trajectories of both subjects revealed information about the interpersonal coordination.

To perform the coordination task successfully, subjects were forced to coordinate their actions with each other. To perform the joint action task they could integrate different sources of information, such as:

- Visual and haptic information (information received through the physical contact with the stretcher) could be used to determine position, walking direction and velocity of the other person.
- Forces applied through the stretcher could communicate the preferred direction and velocity of the other person.
- Visual and haptic information could increase the continuous awareness of the presence of the other person. This awareness could result in a stronger activation of joint action behavior in individuals.

We hypothesized that the more information about partner and stretcher that is available, the better the dyad would perform the joint action task, resulting in a lower collision rate. Furthermore, we took the relative length of the walking trajectories of both partners as an indication about the amount of cooperation in this task. The absolute path length, however, characterizes the capability of the dyad to optimize its behavior. Specifically, we expected that integrated visual and haptic information will lead to a strong feeling of co-presence of the partner, which should influence the cooperation positively. This in turn should be reflected in shorter trajectories, less relative length differences and lower collision rates.

6.2 Methods

For the behavioral experiment we designed five conditions in which we selectively reduced visual and/or haptic information (see table 2).

Condition	Stretcher visible	physical Stretcher	Avatars visible
1. Baseline	x	x	x
2. No Haptic	x		x
3. No Visuals		x	
4. No Strecher		x	x
5. No Avatars	x	x	

Table 2: Overview of different experimental conditions. The marked fields display whether this sensory information is available during the particular condition.

In each condition pairs of subjects navigated through a virtual corridor transporting a stretcher (length = 2.5 m) together. As both subjects faced the walking direction, the person in the front (leader) was not able to see the person in the back (follower). In each condition the dyad performed two trials (first trial, second trial). In each trial subjects walked 10 corner segments (90-degree corners). After the first trial subjects switched leader and follower positions. Each experiment took approximately 1.5 hours with no breaks in between. We tested 10 pairs of subjects with the following gender combinations: 4 times female-male; 2 times male-male; 4 times female-female. All of the subjects were students within an age range of 23 to 37 years.

To compare the performance in different conditions, we analyzed the two dependent variables that revealed information about the joint action behavior and the coordination: collision rate (number of collisions that occurred during each trial) and the average path length (length of trajectories in each segment).

6.3 Results and Discussion

As expected, we observed a higher collision rate in the first trial of the No Haptic Condition (see figure 4). This result can partially be explained by an increase in task difficulty, because subjects additionally had to control their distance (in all other conditions interpersonal distance was easily maintained through the physical stretcher). After the first trial, however the collision rate dropped down to baseline, which suggests that sufficient coordination in this task can be achieved without a physical connection providing haptic and tactile information. However the physical stretcher simplifies the task by keeping subjects at a con-

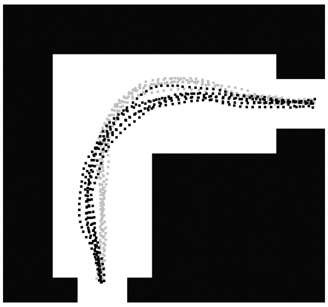

Figure 3: Top view of C-Segment (90-degree corner). The black and the grey dots represent walking trajectories of subjects that were connected via stretcher. Subjects walked from right-top to left-bottom (black=leader; grey=follower).

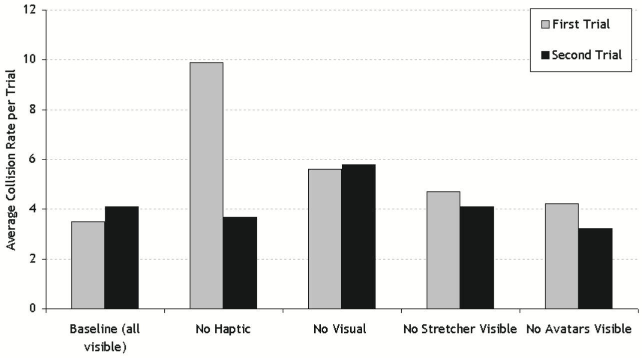

Figure 4: The average number of collisions for each condition over all subjects (N=10).

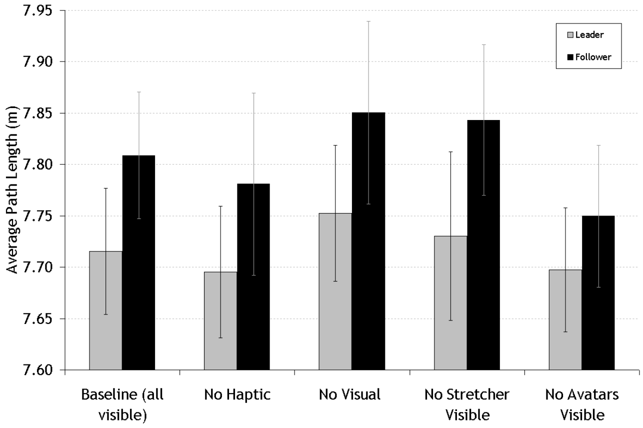

Figure 5: The average path length per corner in each condition for all subjects for leader (grey) and follower (black). In all conditions the follower walks a longer trajectory than the leader.The error bars show the standard error of the mean (N=10).

stant distance. The path length indicator supports these results (see figure 5): there were no significant differences in the path length in either condition (Path Length in No Haptic Condition is similar to Path Length in the Baseline Condition).

Surprisingly, there was no significant difference in the collision rate between Baseline Condition (3.8 collisions), No Stretcher Condition (4.4 collisions), and No Avatar Condition (3.7 collisions). This indicates that the subjects could accommodate to the missing visual information, possibly because in these conditions the position of the non-visible elements could have been inferred from the available visual information (if only the stretcher is visible, the follower knows were the leader is located; if only the avatars are visible, the follower knows were the stretcher is located). In accordance with this interpretation, we observed that the collision rate was slightly increased in the No Visual Condition, where visual information about the stretcher and partner was completely absent. Thus, in this experiment, we did not find an improvement of coordination by the visual (co-)presence of the interaction partner.

Interestingly, we observed that subjects walked longer trajectories in conditions where the stretcher was not visible (No Visual Condition and No Stretcher Visible Condition). This observation could be explained in that subjects could not easily control the visual distance between stretcher and corner and therefore they preferred to walk a longer trajectory than to risk a collision with the corner.

7 Conclusions

We showed that humans can quickly compensate for a lack of haptic and tactile feedback if they are immersed into the VE. Nevertheless, the haptic feedback seems to be important in that it decreases the task difficulty. Our prediction of an increased collision rate due to the reduction of visual information was only partially confirmed.

In all conditions subjects showed very similar path length which indicates a robust coordination behavior relatively independent from the immediate feedback cues about the partner.

We have presented an approach to utilize immersive multi-user virtual environment for the behavioral investigation of human interaction and spatial coordination in a social context. Our approach within the behavioral science represents only one area of application for incorporation for the future development of IMUE. Also in other areas an interest and demand for incorporation of social interaction into immersive environments exist. First implementations and prototypes have been developed in the field of architecture [KBP+00], learning and education [JF00], as well as, entertainment [SFK+03], that are expected to identify interesting areas of investigation also for the behavioral sciences.

Acknowledgments

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References

[BC03] Grigore C. Burdea and Philippe Coiffet, *Virtual reality technology*, John Wiley & Sons, Inc., New York, NY, USA, 2003.

[DM04] Nicolas Ducheneaut and Robert J. Moore, *The social side of gaming: a study of interaction patterns in a massively multiplayer online game*, CSCW '04: Proceedings of the 2004 ACM conference on Computer supported cooperative work (New York, NY, USA), ACM, 2004, pp. 360–369.

[HD92] Richard H. Held and Nathaniel I. Durlach, *Telepresence*, Presence **1** (1992), no. 1, 109–112.

[JF00] Randolph L. Jackson and Eileen Fagan, *Collaboration and learning within immersive virtual reality*, CVE '00: Proceedings of the third international conference on Collaborative virtual environments (New York, NY, USA), ACM, 2000, pp. 83–92.

[KBP+00] H. Kato, M. Billinghurst, I. Poupyrev, K. Imamoto, and K. Tachibana, *Virtual object manipulation on a table-top ar environment*, Augmented Reality, 2000. (ISAR 2000). Proceedings. IEEE and ACM International Symposium, 2000, pp. 111–119.

[KP03] A. Kemeny and F. Panerai, *Evaluating perception in driving simulation experiments*, TRENDS IN COGNITIVE SCIENCES **7** (2003), 31–37.

[LBB99] J. M. Loomis, J. J. Blascovich, and A. C. Beall, *Immersive virtual environment technology as a basic research tool in psychology.*, Behav Res Methods Instrum Comput **31** (1999), no. 4, 557–564.

[NH06] Bonnie Nardi and Justin Harris, *Strangers and friends: collaborative play in world of warcraft*, CSCW '06: Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work (New York, NY, USA), ACM, 2006, pp. 149–158.

[Sch02] R. Schroeder, *Copresence and interaction in virtual environments: An overview of the range of issues.*, Presence 2002: Fifth International Workshop, 274-295., Presence 2002: Fifth International Workshop, 274-295., 2002.

[SFK+03] Benjamin Schaeffer, Mark Flider, Hank Kaczmarski, Luc Vanier, Lance Chong, and Yu Hasegawa-Johnson, *Tele-sports and tele-dance: full-body network interaction*, VRST '03: Proceedings of the ACM symposium on Virtual reality software and technology (New York, NY, USA), ACM, 2003, pp. 108–116.

[TW02] Michael J Tarr and William H Warren, *Virtual reality in behavioral neuroscience and beyond.*, Nat Neurosci **5 Suppl** (2002), 1089–1092.

[vdHB00] M. von der Heyde and H.H. Buelthoff, *Perception and action in virtual environments.*, Max Planck Institute for Biological Cybernetics, Tbingen, Germany, 2000.