Social Presence and Cooperation in Large-Scale Multi-User Virtual Reality – The Relevance of Social Interdependence for Location-Based Environments

Wienrich, C.[1], Schindler, K.[2], Döllinger, N.[2], Kock, S.[2], Traupe, O.[2]

[1]University of Würzburg Team for Human-Technique-Systems

[2]Technische Universität Berlin Department of Psychology and Ergonomics

ABSTRACT

Introduction. An increasing number of location-based entertainment centers offers the possibility of entering multi-user virtual reality (VR) scenarios. Until now, neither cognition and emotions of users nor team experience have been scientifically evaluated in such an application. The present study investigated the gain of positive social interdependence while experiencing an adventure on the Immersive Deck of Illusion Walk (Berlin, Germany).

Method. The preliminary version of a VR group adventure of the company was enriched by a task establishing social interdependence (IDP condition). The impact of IDP on social presence and cooperation (i.e., mutual importance) was evaluated relative to a control task without interdependence (nIDP condition).

Results. Social IDP increased social presence and cooperation among participants. Additionally, behavioral involvement (part of presence), certain aspects of the adventure experience, and the affective evaluation during the experience were positively influenced by IDP.

Discussion. The present study showed that interdependence can substantially enhance social presence and cooperation (i.e., mutual importance) in a VR setting already characterized by social co-experience. Thus, it revealed one design option (social IDP) to improve the experience, particularly the social experience, of location-based entertainment.

Conclusion. The present research addressed one goal of location-based VR hosts to scientifically established design principles for social and collective adventures by supporting the impact of "collectively mastering an adventurous challenge". In addition, our evaluation demonstrated that the multi-modal tracking, the free movement, as well as the multi-user features enabled natural interaction with other users and the environment, and thereby engendered a comfortable social experience.

Keywords: Multi-user VR, Location-based Entertainment, Interdependence, Social Presence, Cooperation, Evaluation

Index Terms: [HCI]: Collaborative interaction, Virtual Reality; Empirical studies in interaction design; [Human Centered Computing]: Mobile computing; [Hardware]: Haptic devices; [Computing Methodologies]: Tracking

1 INTRODUCTION

Large-scale virtual reality (VR) experiences have gained importance for location-based entertainment [1]. Companies like Zero Latency [2], the Void [3], or the IMAX Experience Center [4] offer immersive multi-user adventures, which easily supersede the capabilities of typical home VR installations. Preliminary inquiries among VR companies revealed that satisfaction with the experience, and word-of-mouth advertising, could depend on the customers' notion of experiencing and mastering enjoyable challenges in interaction with others.

Commercial large-scale virtual reality is one of the most promising VR applications and its success highly depends on the quality of the user's experience. However, neither cognition and emotions of users in general, nor certain social aspects (e.g., team experience), have been scientifically evaluated before in this context. Such experiential aspects could lead to a sustained customer motivation beyond the often-reported initial high appraisal of modern virtual reality. The present study addresses these shortcomings by applying knowledge from the fields of social psychology and human-computer interaction. In particular, the impact of positive social interdependence was investigated while experiencing an adventure on the Immersive Deck of Illusion Walk (Berlin, Germany) [5, 6]. The experience of the adventure itself as well as team experience were assessed. In addition, the effects of the multi-modal tracking, the free movement, as well as the multi-user features on social experience were monitored. This line of research can contribute to establishing design principles for social and collective VR experiences.

2 RELATED WORK

2.1 Teams – object of research in the field of social psychology

Many game mechanisms correspond to core motives of human beings. Multiplayer games are geared towards the motive of *relatedness* from the *Self-Determination Theory* [*SDT*; 7] characterizing the meaning of others for own actions as well as the importance of own actions for others. In social psychology, several factors inducing mutual importance (e.g., team formation, cooperation) have been investigated. Besides social identity [e.g., 8, 9], social interdependence has reliably been shown to facilitate team formation and cooperation [e.g., 10, 11, 8, 12, 13]. Social interdependence implies shared common goals and actions between individuals and is categorized by outcome as well as means interdependence [14, 15]. Outcome interdependence occurs when individuals orient toward a desired outcome, goal, or reward. Means interdependence entails the means through which the outcome should be achieved (e.g., resources, tasks). The

[1]carolin.wienrich@uni-wuerzburg.de
[2]ole.traupe@tu-berlin.de

connotation of social interdependence determines the interaction pattern between individuals [14]. While positive social interdependence results in promotive interaction, negative social interdependence leads to oppositional interaction and no social interdependence results in an absence of interaction. Hence, positive social interdependence is a key factor for inducing mutual importance (corresponding to the relatedness motive), which in turn results in other valuable outcomes, such as significantly higher achievement and retention (e.g., in learning contexts see meta study of [15]). In addition, social relatedness was shown to potentially increase computer game enjoyment, played hours per week, and future game play in (massive) multiplayer online games [16]. Thus, it might also impact positively on the experience and future attendance of a location-based social VR environment.

2.2 Teams – object of research in the field of human-computer-interaction

The *media equation* is based on the idea that people respond socially to computers [e.g., 17]. The CASA paradigm (Computers Are Social) adapts scientific approaches to human-human interaction to the study of human-computer interaction and demonstrates that the social rules and dynamics guiding human-human interaction similarly apply to human-computer interaction [e.g., 18, 19, 20]. In consequence, many social phenomena have been confirmed for human-computer interaction [17].

Regarding mutual importance, the impact of identity and interdependence on the perception of team dynamics was investigated in human-computer interaction [21]. Interdependence was manipulated by either giving the participants the perception of receiving the same evaluation as the computer they interacted with (interdependence) or an individual evaluation (no interdependence). The results revealed that only interdependence had a significant effect on team affiliation and on the resulting attitude and behavior.

Social interdependence also was investigated in computer-mediated human-human interaction. In collaborative work settings, goal, task, and outcome interdependence correlated positively with motivation and team efficiency in virtual teams of two business companies [e.g., 22]. Other studies investigated interdependence regarding joint actions (e.g., shared object manipulation) [see 23 for a review]. The main findings were that the degree of spatial immersion (e.g., type of display [24]) and the degree of time-based immersion (e.g., symmetric interaction [25]) had the most impact on the performance in highly interdependent actions. Immersive and symmetric systems increased the feeling of co-presence and team efficiency stronger when performing an interdependent task as compared to a less interdependent task. Finally, in cooperative gaming settings, interdependence positively affected game enjoyment and the feeling of co-presence [e.g., 26; 27].

Location-based (large-scale) multi-user VR shares some features with more traditional collaborative or multiplayer VR applications. However, one main difference concerns the actual co-presence of the co-actors. While previously investigated VR settings were mostly remote- or online-based, in location-based virtual experiences the co-actors are also physically present. A specific manipulation of interdependence between multiple users in a large-scale VR (i.e., virtual, avatar-mediated, human-human interaction), as proposed by the CASA paradigm, has not been done before. Thus, it is unclear so far whether virtually mediated interdependence would actually increase the feeling of mutual importance in the co-presence of a real (physically attendant) person.

In summary, the degree and the connotation of social interdependence heavily influence the interaction and cooperation patterns between individuals. The media equation (often investigated by the CASA paradigm) presumes similar social processes in human-computer interactions, such as social VR environments. The present study applied the CASA paradigm in an immersive large-scale, multi-user VR, i.e., virtual, avatar-mediated, human-human interaction. In this context, users might be either purely co-existing with other users (no social interdependence) or dependent on playing or working together (social interdependence) for achieving a common goal. In detail, the gain of positive social interdependence was investigated while experiencing an adventure on the Immersive Deck [5, 6]. Two experimental conditions were distinguished. In the interdependence condition (IDP) participants had to solve a recurrent task together with their fellow participants, while in the non-interdependence condition (nIDP) participants had to solve a similar control task on their own. Based on the findings presented above, stronger team affiliation and more cooperation (i.e., mutual importance) were expected for participants in the interdependence (i.e., IPD) versus the control condition (i.e., nIPD).

In addition to effects on team experience one could also expect an increase of general presence due to the interdependence manipulation. Social relatedness can increase the enjoyment (i.e., positive affective evaluation) of virtual experiences [16]. Some authors argue, that the concepts of affect and presence are logically distinct [28], however they do not categorically rule out any relation between them [29]. Correspondingly, stronger affective responses have been shown to heighten the sense of presence in virtual environments [30, 31, 32, 33].

3 METHOD

3.1 Participants

Seventy-two volunteers (n = 12 female; mean age 32.11 years; sd = 8.68 years) with normal or corrected to normal vision participated in the study. Participants conducted the experiment in groups of three (n = 4 female experimental groups). No participants reported any health problems such as epilepsy or migraine. A screening questionnaire revealed that the sample was rather highly experienced with VR ($M = 3.35$, $SD = 1.49$; poles of scale 1 to 5) and video gaming ($M = 3.68$, $SD = 1.20$; poles of scale 1 to 5). Further, participants reported a high technical affinity ($M = 4.42$; $SD = .78$; poles of scale 1 to 5) and a good tolerance for simulator sickness ($M = 4.32$; $SD = .82$; poles of scale 1 to 6). As compensation, participants received a voucher from Illusion Walk for a free VR experience of the company.

3.2 Materials

3.2.1 VR installation and equipment

The experiment was conducted in the multi-user, multi-room VR installation Immersive Deck (Illusion Walk, KG), which is equipped with a marker-based inside-out tracking technology that allows for the continuous transition between adjacent rooms [5]. Participants wore Oculus Rift (Oculus VR, LLC) VR headsets powered by untethered backpack PCs (Intel Core i7 quad-core CPU, NVidia GTX 1070 GPU). The virtual environment was created and presented with Unity3D (Unity Technologies) running a client-server model over 802.11ac Wi-Fi connections. In addition, experimental data (in-experience questionnaires, event time stamps) were transmitted over this Wi-Fi network by means of the Labstreaminglayer, a multi-modal time-synched data transmission library [34]. Audio stimulation was provided via digital stereo headsets, voice communication was established by means of a custom TeamSpeak server (TeamSpeak Systems GmbH). VR hand interaction was achieved using Leap Motion (Leap Motion, Inc) sensors mounted on the front plate of the VR headsets.

The virtual environment contained a number of mixed-reality elements (MRE), in which properties of the real (shape, material, vibration) and the virtual (appearance, sound) world coincided (a buzzer-type start button, a door, etc.). The most prominent of these was given by the physical walls of the multi-room tracking space integrating into the walls of the mixed-reality environment.

3.2.2 Questionnaires and behavioral observation

All text-based material for informing, screening, instructing, and assessing the participants outside the experience was presented on tablet devices. Mutual importance (i.e., team affiliation and cooperation) were operationalized by measuring social presence. The sense of being together in a multi-user VR influences the engagement of the individual with the game and the group [35]. A more general measurement of social presence is the *Social Presence Module* of the *Game Experience Questionnaire* [*GEQ*, 36]. It includes *psychological involvement*, *behavioral involvement*, and *negative feelings*. The cooperative module of the *Competitive and Cooperative Presence in Gaming Questionnaire [CCPIG*, 37] elaborates on cooperative social presence, the social presence felt towards teammates in cooperative digital games. It includes the scales *team identification*, *social action*, *motivation*, and *team value*. In addition to the subjective measurement of cooperation, each participant received an artificial bonus of 120 € after the experiment. No restrictions regarding the allocation were made. Thus, participants could for example retain the entire bonus or could fairly split it among each other.

The experience of the adventure was assessed by the *GEQ* including the *In-Game Module* with the subscales *competence*, *flow*, *immersion*, *challenge*, *tension*, *negative,* and *positive affect*. The *Post-Game Module* entails the subscales *positive* and *negative experiences*, *tiredness*, and *returning to reality*. In addition to the *GEQ*, the four *Curiosity* items of a shortened curiosity questionnaire gave insight into the evaluation of the adventure itself [38].

The VR experience in general was evaluated by measuring the state of presence with the German version of the *iGroup Presence Questionnaire* [*iPQ*; 39] entailing a *general presence* subscale, a *realism*, *involvement* and *spatial presence* subscale. Note, that we followed the view of Slater and Wilbur [40] who defined immersion as the extent to which the technological features of the device(s) and the setting are capable of providing the user with the illusion of reality. Presence, however, can be seen as a multi-dimensional psychological construct and focusses stronger on the experiential side.

To assess the participants' state during different parts of the experience, an in-experience questionnaire was set up. It primarily addressed the current mood on a German version of the *Positive And Negative Affect Schedule* [*PANAS*; 41]. Further, participants reported their level of simulator sickness on the *Fast Motion Sickness Scale* [*FMS*, 42]. Complementing the post-experience measures, the in-experience assessment additionally contained one team-based item concerning the importance of the other group members ("*At the moment, the experience with the other experts is important for me*.").

Since the present experiment was part of a bigger experimental cycle with additional research questions (see [43]), some further measures were assessed but not or very briefly presented here. These include the user experience (UX) appraised by the modular evaluation of key *Components of User Experience* [*meCUE*; 44], the discomfort that arises from the equipment [adapted from 45], as well as some open questions about the experience (e.g., *"What do you willing to pay for a similar experience lasting two hours?"*). Additionally, ratings of the mental and physical load during the experiment [adapted from 46], as well as some physiological parameters, were collected. Finally, behavioral observations were performed by a supervisor covertly following the group of participants throughout the tracking space.

3.3 Procedure

3.3.1 Overall structure of experimental sessions

The experimental sessions were structured into a preparation, an experience, and a post-experience phase. The preparation phase included usage instructions and safety warnings for the Immersive Deck as well as retrieving the participants' informed consent. Furthermore, demographic and health data were assessed by the screening questionnaire prior to the actual experience. In order to eliminate any interference due to pre-experimental exposure (e.g. effects of physical appearance), each of the three participants forming an experimental group were welcomed individually, seated in separate cubicles, and kept isolated from each other until fully equipped with the VR devices.

The experience phase began with the instruction (administered via headphones) to collectively explore the starting room, which virtually (MRE) resembled the physical starting room of the VR installation - a measure to facilitate immersion via a gradual transition into the virtual environment. Further exploration phases were interspersed at several points of the experience in order to broaden the data basis for assessing general experiential parameters such as comfort and presence ratings. The story line (see 3.3.3) of the experience could then be started by pressing a buzzer-type button (MRE). Participants could operate this and other mixed- and virtual-reality elements using their tracked, and virtually represented, hands. The basic theme of the story was a group repair job of a wind turbine in order to restore power to a couple of laser cannons sought to defend Earth's energy supplies against a hostile alien attack. The story required the participants to move through the VR installation on a predetermined path. It featured a repeating task with increasing difficulty, which conveyed the experimental manipulation and occurred at several key points within the experience. Additionally, included a recurrent in-experience short questionnaire provided in a pop-up style, also operated via the participants' tracked hands (see Figure 1). The in-experience questionnaire was disguised as a state evaluation within the suggested work context. The post-experience phase included the completion of the post-experimental questionnaires and a series of open questions.

3.3.2 Task description – manipulation of interdependence

The recurrent task was performed as a mini-game linked to a triangular pedestal with identical operating panels on its three side faces (see Figure 2). The pedestal appeared at pre-designed positions in the experience. Each participant's panel contained three differently shaped and colored buttons (red square, blue circle, green triangle), a graphical timer for the trial time, a numerical timer for the total task time, and a progress bar of stacked triangles on top of the pedestal. Its number representing the current sum of successful (positive) and failed (negative) trials. Across the task instances, the difficulty increased in order to keep the task interesting and challenging.

Figure 1: In-experience questionnaires presented in a pop-up style and operated via the participants' tracked hands; the example shows an item of the PANAS (German version).

The interdependence (IDP) condition was meant to establish interdependence between participants by providing a task only solvable in a common effort. This condition also created the need for communication and coordination, further strengthening the notion of cooperation. All three participants repeatedly and simultaneously had to press one of three different buttons, until a final score of 10 was reached or the total time for the task had elapsed. Within a single trial, one participant (the announcer) would receive information about which of the group members (actors) would have to press a certain button. This button was signaled to the announcer by lighting up and additional small arrows on the panel of the announcer indicated the actors. The selection of the announcer, the actor(s), and the target button was randomized. The joint button press had to occur within a 800 ms time window. The maximum trial duration (group response time) from announcement to the button press was 20 s, 10 s, and 7 s for the three levels of difficulty (expiration rated as failure). The total time for completing a task was 120 s, 120 s, and 90 s, respectively. The number of actors increased from one, over two, to all three participants, in which case the announcer was also an actor. Each participant could only see his/her panel with the associated buttons and gauges. This task design ensured the need for communication of target button and actors, as well as the coordination of the joint button press.

The non-interdependence (nIDP) condition acted as a closely matched control condition not establishing any interdependence, nor the need for communication or coordination. The three participants had to press the different buttons on their panel in a given order signalled by the sequence in which they lit up, basically following the children's game "Simon" (Milton Bradley, US). Again, reaching a score of 10 was needed for solving the task, with the score being counted separately for each participant. In contrast to the IDP condition, it was sufficient for one participant to succeed. There were no restrictions on temporal regularity or proximity of button presses in this condition. The maximum trial duration was 10 s, 10 s, and 8 s for the three levels of difficulty (expiration again rated as failure). The total time for completing a task was 160 s, 160 s, and 150 s, respectively. The length of button sequences increased from four, over five, to six with increasing difficulty. Trial and task parameters were chosen carefully based on preliminary tests in order to achieve a moderate and linear increase in difficulty.

Figure 2: Operating panels for performing the recurrent minigame task (IDP condition); due to limitations of the capture software, the push-buttons appear without color.

3.3.3 Storyline and timestamps of in-experience assessment

The experience began with the first in-experience assessment (pop-up questionnaire) establishing a baseline measurement. The following story line was structured into three sections, each of them leading to an instance of the task in either the IDP or the nIDP version, followed by a repetition of the in-experience assessment. To ensure the participants' motivation, the story seemingly depended on task success. However, small storytelling workarounds (not detailed here) allowed the story to progress to the next section in case of a failure.

The first story section addressed entering the "story world" through a portal onto the outside bottom platform of the wind turbine site, to be opened by solving the first task on difficulty level 1. Participants then entered the wind turbine tower through a door (MRE) and proceeded to an elevator (MRE), where an in-experience questionnaire was administered. The second story section comprised the elevator ride to the top of the wind turbine, stepping outside through a door operated via a hand scanner (MRE), a period of free exploration of the maritime view of the windy (MRE) top platform, the second task (cannon repair) on difficulty level 2, and another in-experience questionnaire. The third story section led in with a devastating attack of a number of alien space ships. Then participants being particle-transported to an alien mother ship, where they were allowed to explore a windowed room with view onto Earth. The third task (disabling energy shields to escape the ship) was then performed on difficulty level 3. After briefly encountering a hostile alien specimen, participants were transported back to earth and fulfilled the final in-experience questionnaire back in the starting room.

3.4 Data Analyses

Firstly, the data of the post-experience questionnaires was aggregated according to the manuals of the questionnaires. Due to its robustness against any potential violations of the assumption of multivariate normal distribution and of homogeneity of covariance matrices, multivariate testing was performed by means of Hotelling's T^2 [47]. Significant results were followed up by one sided two sample t-tests with Bonferroni corrected p-values [47].

To analyze the in-experience questionnaires two independent variables were used: IDP/nIDP and time of measurement (t1 - t4). In a first step, the *PANAS* dimensions, positive and negative affection, were summed up as advised. Positive Affection (PA) was analyzed using a 2 x 4 mixed design ANOVA. Regarding negative affect the examination of assumptions for this model showed violations in normal distribution of residuals, variance homogeneity and sphericity. Therefore, a nonparametric rank transform test was calculated. Also the ordinally scaled variables, importance of others and motion sickness, required non-parametric analysis [48].

4 Results

Due to technical problems in some in-experiment questionnaires, the sample size for in-experience analysis was reduced to N = 38 (9 female, 29 male) participants. This smaller sample contained 17 participants in the IDP and 21 in the nIDP condition. For the statistical analysis of the post-experience questionnaires, no participant had to be excluded. Table 1 shows the results of the T^2-test.

Table 1
Multivariate results of the post experience questionnaire

Dependent Variables	Two Sample Hotelling T² Test				
	df_1	df_2	T^2	F	p
Social Presence (GEQ)	3	68	9.86	3.19	0.03
Cooperative Social Presence (CCPIG)	4	67	21.74	5.20	0.00
Presence (iPQ)	4	67	5.97	1.43	0.23
Game Experience (GEQ)	11	60	27.30	2.13	0.03
Curiosity	2	69	2.91	1.43	0.25
Overall UX Evaluation	10	61	13.27	1.16	0.34
Distribution of Bonus	2	69	1.42	0.70	0.50

In line with the expectations, general *social presence* received higher average scores in the IDP condition compared to the nIDP one. The one-sided post-hoc t-Tests with Bonferroni-corrected p-values ($\alpha_{Presence} = 0.0491$) revealed significance for the *behavioral involvement* subscale, but not for the *psychological involvement* or *negative feelings* (see Figure 3). The impact of interdependence was also confirmed by the results of the *cooperative social presence* (*CCPIG*). Participants in the IDP condition reported significantly higher feelings of *team identification*, *social action*, *motivation*, and *team value* compared to the participants in the nIDP condition (see Figure 4).

In addition, the team based in-experience question revealed a marginal interaction effect between *time of measurement* and the *IDP* conditions ($F(3; 108) = 2.25$, $p = 0.09$, $\eta^2 = 0.01$). Starting with a lower rating in the beginning, the importance of others strongly increased in the IDP condition (first rating: $Mimportance_{IDP} = 2.65$, $SDimportance_{IDP} = 1.17$; last importance rating: $Mimportance_{IDP} = 3.24$, $SDimportance_{IDP} = 1.25$; poles of scale 1 to 5). In comparison, importance ratings in the nIDP condition started at a moderate level and did not change over time (first rating: $Mimportance_{nIDP} = 2.95$, $SDimportance_{nIDP} = 1.07$); last rating: $Mimportance_{nIDP} = 2.95$, $SDimportance_{nIDP} = 1.32$). Contrary to the expectations, the distribution of bonus was equally distributed between all participants in both conditions.

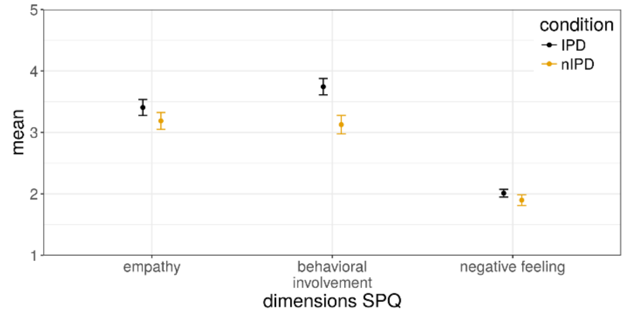

Figure 3: Means and standard errors of the social presence questionnaire subscales.

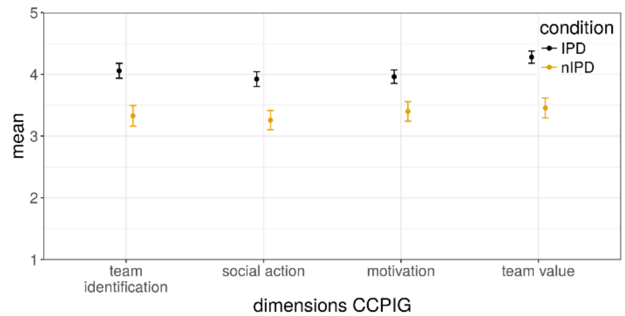

Figure 4: Means and standard errors of the cooperative social presence questionnaire subscales (CCPIG).

Interdependence significantly influenced the evaluation of the adventure measured by the GEQ. However, just some subscales were affected by the manipulation. Participants in the IPD condition reported significantly less challenge than participants in the nIDP condition. By trend, they also reported less tension, and less negative game experiences (see Figure 5).

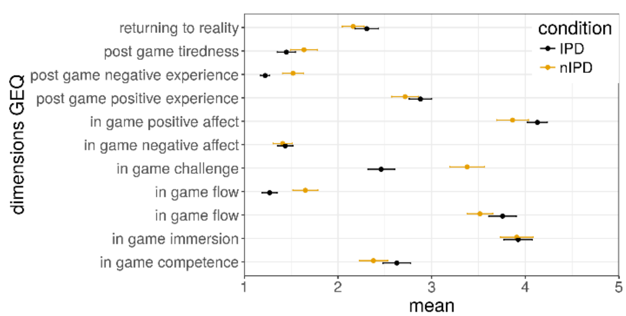

Figure 5: Means and standard errors of the game experience questionnaire subscales (GEQ).

The affect measure during the experience showed some influence of IDP. The positive affect changed significantly over time ($F(1; 108) = 19.33$, $p < 0.01$, $\eta^2 = 0.09$). Yet, participants in the nIDP condition reported a higher increase of positive affect in the middle of the experiment followed by similar decrease towards the final in-experience questionnaire. This is shown by a significant interaction effect (*F(3; 108)* = 3.03, $p < 0.05$, $\eta^2 = 0.02$). The analysis of negative affect revealed no significant differences but was rated low across all conditions ($M_{negative}$ = 1.29, $SD_{negative}$ = 0.36; poles of scale 1 to 5).

The adventure engendered positive presence ratings in both experimental conditions (e.g., $Mpresence_{IDP}$ = 6.00, $SDpresence_{IDP}$ = .73; $Mpresence_{nIDP}$ = 5.70, $SDpresence_{nIDP}$ = .77; poles of scale 0 to 7). Simultaneously, very low values of simulator sickness were reported in both conditions ($Msickness_{IDP}$ = 1.32, $SDsickness_{IDP}$ = 2.44; $Msickness_{nIDP}$ = .76, $SDsickness_{nIDP}$ = 2.11; poles of scale 0 to 20).

The overall UX evaluation was also very positive in both conditions (Mux_{IDP} = 9.56, $SDux_{IDP}$ = 1.35; Mux_{nIDP} = 8.88, $SDux_{nIDP}$ = 1.78; poles of scale 0 to 10). Participants showed a great willingness to pay for such or a similar adventure in both conditions ($Mpay_{IDP}$ = 30€, $SDpay_{IDP}$ = 19€; $Mpay_{nIDP}$ = 36€, $SDpay_{nIDP}$ = 26€).

5 Discussion

The emerging public perception of VR leads to a growing number of location-based entertainment centers offering multi-user VR experiences (e.g. Zero Latency with currently 12 sites). Preliminary inquiries among VR companies revealed that satisfaction with the experience, and word-of-mouth advertising, could depend on the customers' notion of "having collectively mastered a challenging and enjoyable adventure". The present study aimed to reveal means of fostering such a notion by applying knowledge from the fields of social psychology and human-computer-interaction. In particular, the gain of positive social interdependence was investigated while experiencing an adventure on the Immersive Deck of Illusion Walk (Berlin, Germany) [5, 6]. The preliminary version of a VR group adventure of the company was enriched by a task establishing social interdependence (IDP condition). The IDP task was only solvable in a common effort and engendered a strong need for communication and coordination further strengthening the notion of cooperation. The impact of IDP on mutual importance (i.e., team affiliation and cooperation) was evaluated relative to a control task without interdependence (nIDP condition). The results revealed that positive social interdependence can substantially enhance team affiliation and cooperation (i.e., mutual importance) in a VR setting already characterized by social co-experience.

These results are in line with core findings from social psychology having reliably shown a gain of interdependence on team formation and cooperation [e.g., 10, 11, 8, 12, 13]. As the connotation of social interdependence determines the interaction pattern (promotive, negative or no interaction) between individuals [14], it appears crucial, however, to design interdependent interactions carefully, as well as to closely investigate the impact of the established interdependence on the experience of the users. Further, previous findings demonstrating that the social rules and dynamics guiding human-human interaction similarly apply to human-computer interaction (media equation or CASA paradigm with computers: e.g., [21], with virtual teams: [22]; with avatars: [26]) were applied (and confirmed) in a large-scale multi-user VR setting for the first time. More precisely, interdependence patterns appearing in the human-human and human-computer interaction also occur in a virtual, avatar-mediated, human-human interaction. Thus, on the one hand, the present study successfully incorporated basic principles from the field of social psychology and human-computer interaction into a commercial location-based entertainment setting. On the other hand, it revealed one design possibility (social IDP) to enhance the experience, particularly the social experience, of location-based entertainment. The latter, as investigated here, bears resemblance to the concept of *relatedness* from the *Self-Determination Theory* [*SDT*; 7], which was shown to potentially increase computer game enjoyment, played hours per week, and future game play in (massive) multiplayer online games [16]. It seems reasonable to assume that measures enhancing the team experience (corresponding to the relatedness motive) of location-based social VR entertainment are able to sustain customer motivation beyond the ubiquitous initial "wow effect" of modern virtual reality. In addition, the manipulation of interdependence in the present study had no negative effect on presence ratings or on the general enjoyment of the experience. These findings show that such measures can be included into multiplayer VR scenarios without any detrimental effects to their experiential quality in general.

On the other hand, the higher social relatedness did not increase the sense of presence, either. This is not surprising, however, as such an effect likely would have been mediated by stronger affective responses [30,33], which could not be found for the IDP condition. While the reasons for this could be manifold, the general enthusiasm of the experienced participants for this elaborate VR adventure potentially overshadowing a more differentiated affective evaluation seems to be a prominent one. In addition, the social component of presence (affected by the social manipulation) might be captured predominantly by the specific social presence assessments (CCPIG; Social Presence scale of the GEQ).

The general perception of the experience was very positive and the participants showed a high willingness to come back. The tracking and interaction technology of the Immersion Deck seems to have contributed to these findings. Visitors of the Immersive Deck are able to move around freely, even transition between rooms. They can see their team members and communicate with them in familiar ways (verbally and via gestures), while naturally using their hands to interact with the environment. High ratings of immersion and a low in-game negative affect support this notion while showing no signs of impediment by the equipped VR hardware. In addition, non-standardized post-experimental interviews revealed a high satisfaction of the (VR-experienced) participants with how to interact with their team members and the environment. These results all emphasize the comfort and adequacy of the VR installation and the way the experience was constructed (more details in [43]).

However, for location-based VR companies it might be beneficial to evaluate their experiences with a more representative client base. The present sample reported a high technical affinity, was rather VR experienced, and, most severely, the participants did not know each other prior the experiment. Steed et al. [49] showed that virtual collaboration was not impacted by the status of affiliation (friend or stranger). Nonetheless, newer and more immersive systems might provide stronger social cues and lead to a higher impact of affiliation, particularly in a more entertaining setting. In addition, the present study mainly incorporated means (task) interdependence, which led to strong effects on the behavioral involvement. Future studies might also address other kinds of interdependence (e.g., goal, reward) potentially leading to a stronger psychological involvement or longer lasting effects of cooperation (e.g., bonus distribution after the experiment). Another important contribution might be the assessment of VR-specific features (e.g., spatial aspects) and social effects as addressed by [50]. In this regard, the spatial, time, and role trajectories of participants according to [51] might give further insight into social behavior in multi-user environments (further discussion in [43]). Similarly, transferring the findings to other multi-user applications might also be interesting for future work (future classrooms, collaborative work spaces, or entertainment systems). Finally, future studies might also address the design of task difficulty. Even though difficulty was matched via pre-testing for the present study, observations revealed that the task in the nIDP condition was perceived as more challenging. However, general experience (presence) and negative affect assessed during the sessions were not impacted differently by the experimental conditions, showing participants to exhibit a certain robustness towards an imbalance of task difficulty. Altogether, it appears that the observed differences in team experience can be safely attributed to the experimental IDP manipulation.

6 Conclusion

The focus of the investigation was to scientifically support design decisions for social experiences in location-based VR. A strong feeling of social involvement and relation might be a key factor to sustain customer satisfaction in the long run, motivating them to revisit VR entertainment centers and recommend them by word-of-mouth advertising. The study supports the benefits of group tasks and social interdependence in solving such tasks. Basic findings from the field of social psychology and human-computer-interaction were incorporated and confirmed in the much-applied setting of a large-scale, multi-user VR. In addition, our evaluation demonstrated that the multi-modal tracking, the free movement, as well as the multi-user options enabled natural interaction with other users and the environment and, thus, a comfortable social experience.

Acknowledgment

The Illusion Walk KG strongly supported the study. In particular, Andrea Heuck, Julien Rüggeberg and Jim Rüggeberg contributed enormously to the successful conduction of the study.

7 References

[1] [Online]. Available: https://www.forbes.com/sites/charliefink/2017/03/07/the-future-of-virtual-reality-isnt-your-living-room-its-the-mall/#1e741bf3f36a.

[2] [Online]. Available: https://www.zerolatencyvr.com/.

[3] [Online]. Available: https://www.thevoid.com/.

[4] [Online]. Available: https://imaxvr.imax.com/.

[5] [Online]. Available: https://www.illusion-walk.com/.

[6] I. Podkosova, K. Vasylevska, C. Schönauer, E. Vonach, P. Fikar, E. Broneder, H. Kaufmann: "ImmersiveDeck: A large-scale wireless VR system for multiple users"; in: "Proceesings of the 9th Workshop on Software Engineering and Architectures for Realtime Interactive Systems SEARIS 2016", IEEE Xplore Digital Library, 2016.

[7] R. M. Ryan and E. L. Deci, “Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being.,” American psychologist, vol. 55, no. 1, p. 68, 2000.

[8] H. Tajfel, “Social psychology of intergroup relations,” *Annual review of psychology*, vol. 33, no. 1, pp. 1–39, 1982.

[9] J. C. Turner, “Towards a cognitive redefinition of the social group,” *Social identity and intergroup relations*, pp. 15–40, 1982.

[10] V. L. Allen, “Situational factors in conformity,” *Advances in experimental social psychology*, vol. 2, pp. 133–175, 1965.

[11] M. Deutsch and H. B. Gerard, “A study of normative and informational social influences upon individual judgment.,” *The journal of abnormal and social psychology*, vol. 51, no. 3, p. 629, 1955.

[12] D. M. Mackie, “Social identification effects in group polarization.,” *Journal of Personality and Social Psychology*, vol. 50, no. 4, p. 720, 1986.

[13] R. Spears and A. S. Manstead, “The social context of stereotyping and differentiation,” *European Journal of Social Psychology*, vol. 19, no. 2, pp. 101–121, 1989.

[14] M. Deutsch, “Cooperation and trust: Some theoretical notes.,” 1962.

[15] D. W. Johnson and R. T. Johnson, *Cooperation and competition: Theory and research.* Interaction Book Company, 1989.

[16] R. M. Ryan, C. S. Rigby, and A. Przybylski, “The motivational pull of video games: A self-determination theory approach,” Motivation and emotion, vol. 30, no. 4, pp. 344–360, 2006.

[17] C. Nass, J. Steuer, E. Tauber, and H. Reeder, “Anthropomorphism, agency, and ethopoeia: computers as social actors,” 1993, pp. 111–112.

[18] C. Nass, J. Steuer, and E. R. Tauber, “Computers are social actors,” 1994, pp. 72–78.

[19] C. Nass, B. Reeves, and G. Leshner, “Technology and roles: A tale of two TVs,” *Journal of Communication*, vol. 46, no. 2, pp. 121–128, 1996.

[20] D. Johnson and J. Gardner, “Effects of teams-based computer interaction: the media equation and game design considerations,” *Entertainment Computing - ICEC 2005, Lecture Notes in Computer Science*, vol. 3711, pp.468–479, 2005

[21] C. Nass, B. J. Fogg, and Y. Moon, “Can computers be teammates?,” *International Journal of Human-Computer Studies*, vol. 45, no. 6, pp. 669–678, 1996.

[22] G.P. Hertel, U. Konradt, and B. Orlikowski, “Managing distance by interdependence: Goal setting, task interdependence, and team-based rewards in virtual teams,” *European Journal of work and organizational psychology*, vol. 13, no. 1, pp. 1–28, 2004.

[23] R. Wolff, D. J. Roberts, A. Steed, and O. Otto, “A review of telecollaboration technologies with respect to closely coupled collaboration,” *Int. J. Comput. Appl. Technol.*, vol. 29, no. 1, pp. 11–26, 2007.

[24] I. Heldal, M. Spante, and M. Connell, “Are two heads better than one?: Object-focused work in physical and in virtual environments,” *Proc. ACM Symp. Virtual Real. Softw. Technol. VRST*, pp. 287–296, 2006.

[25] D. Roberts, R. Wolff, O. Otto, and A. Steed, “Constructing a Gazebo: supporting teamwork in a tightly coupled, distributed task in virtual reality,” *Presence Teleoperators Virtual Environ.*, vol. 12, no. 6, pp. 644–657, Dec. 2003.

[26] J. B. Ellis, K. Luther, K. Bessiere, and W. A. Kellogg, “Games for virtual team building,” 2008, pp. 295–304.

[27] M.-W. Hsu, T.-Y. Wu, Y.-C. Wu, Y.-A. Chen, Y.-C. Lin, and P.-S. Ku, “Party Animals: Creating Immersive Gaming Experience for Physically Co-present VR and Non-VR Players,” in *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’17*, 2017, pp. 222–225.

[28] M. Slater, "A Note on Presence Terminology", PRESENCE—Connect [On-line], Available: http://presence.cs.ucl.ac.uk/presenceconnect/articles/Jan2003/melslaterJan27200391557/melslaterJan27200391557.html, 2003.

[29] M. Slater, "Presence and Emotions", CyberPsychology & Behavior, vol. 7, no. 1, 121-121, 2003.

[30] G. Robillard, S. Bouchard, T. Fournier, and P. Renaud, "Anxiety and Presence during VR Immersion: A Comparative Study of the Reactions of Phobic and Non-phobic Participants in Therapeutic Virtual Environments Derived from Computer Games", CyberPsychology & Behavior, vol. 6, no. 5, pp. 467-476, 2003.

[31] S. Bouchard, J. St-Jacques, G. Robillard, & P. Renaud, "Anxiety Increases the Feeling of Presence in Virtual Reality", Presence, vol. 17, no. 4, pp. 376-391, 2008.

[32] R.M. Baños, C. Botella, M. Alcañiz, et al., "Immersion and Emotion: Their Impact on the Sense of Presence", CyberPsychology & Behavior, vol. 7, no. 06, pp. 734–741, 2004.

[33] G. Riva, F. Mantovani, C.S. Capideville, et al., "Affective Interactions Using Virtual Reality: The Link between Presence and Emotions", CyberPsychology & Behavior, vol. 10, no. 1, pp. 45-56, 2007.

[34] [Online]. Available: https://github.com/sccn/labstreaminglayer/.

[35] A. L. Alexander, T. Brunyé, J. Sidman, and S. A. Weil, "From gaming to training: A review of studies on fidelity, immersion, presence, and buy-in and their effects on transfer in pc-based simulations and games," *DARWARS Training Impact Group*, vol. 5, pp. 1–14, 2005.

[36] W. IJsselsteijn, Y. De Kort, K. Poels, A. Jurgelionis, and F. Bellotti, "Characterising and measuring user experiences in digital games," 2007, vol. 2, p. 27.

[37] M. Hudson and P. Cairns, "Measuring social presence in team-based digital games," *Interacting with Presence: HCI and the Sense of Presence in Computer-mediated Environments*, p. 83, 2014.

[38] C. Moser, V. Fuchsberger, and M. Tscheligi, "Rapid assessment of game experiences in public settings," 2012, pp. 73–82.

[39] T. Schubert, F. Friedmann, and H. Regenbrecht, "The experience of presence: Factor analytic insights," *Presence: Teleoperators and virtual environments*, vol. 10, no. 3, pp. 266–281, 2001.

[40] M. Slater and S. Wilbur, "A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments," *Presence Teleoperators virtual Environ.*, vol. 6, no. 6, pp. 603–616, 1997.

[41] H. W. Krohne, B. Egloff, C.-W. Kohlmann, and A. Tausch, Untersuchungen mit einer deutschen Version der Positive and Negative Affect Schedule (PANAS), Diagnostica-Gottingen-, vol. 42, pp. 139–156, 1996.

[42] B. Keshavarz and H. Hecht, "Validating an efficient method to quantify motion sickness," *Human factors*, vol. 53, no. 4, pp. 415–426, 2011.

[43] C. Wienrich, N. Döllinger, S. Kock, K. Schindler, and O. Traupe, "Assessing User Experience in Virtual Reality – A comparison of different Measurements," in *International Conference, DUXU 2018, Held as Part of HCI International*, 2018, p. accepted for publication.

[44] M. Minge, L. Riedel, and M. Thüring, "Modulare Evaluation von Technik. Modulare Evaluation interaktiver Technik. Entwicklung und Validierung des meCue Fragebogens zur Messung der User Experience," *Grundlagen und Anwendungen der Mensch-Technik-Interaktion. Düsseldorf: VDI-Verlag*, pp. 28–36, 2013.

[45] L. Zhang, M. G. Helander, and C. G. Drury, "Identifying factors of comfort and discomfort in sitting," *Human factors*, vol. 38, no. 3, pp. 377–389, 1996.

[46] Eilers, K., Nachreiner, F. and Hänecke, K. (1986). Entwicklung und Überprüfung einer Skala zur Erfassung subjektiv erlebter Anstrengung. Zeitschrift für Arbeitswissenschaft, 40. (215-224).

[47] A. Field, J. Miles, and Z. Field, Discovering statistics using R (Reprint). Los Angeles, Calif.: Sage, 2013.

[48] H. Lüpsen and R. Rechenzentrum, Varianzanalysen-Prüfen der Voraussetzungen und nichtparametrische Methoden sowie praktische Anwendungen mit R und SPSS. Köln: Universitäts-und Stadtbibliothek, 2015.

[49] A. Steed *et al.*, "Strangers and friends in caves: an exploratory study of collaboration in networked IPT systems for extended periods of time," *Proc. 2003 Symp. Interact. 3D Graph.*, pp. 51–54, 2003.

[50] S. Streuber and A. Chatziastros, "Human interaction in multi-user virtual reality," in *Proceedings of the 10th International Conference on Humans and Computers. HC 2007*, 2007, pp. 1–6.

[51] S. Benford, G. Giannachi, B. Koleva, and T. Rodden, "From Interaction to Trajectories: Designing Coherent Journeys Through User Experiences," *Chi2009 Proc. 27th Annu. Chi Conf. Hum. Factors Comput. Syst. Vols 1-4*, pp. 709–718, 2009.