Co-Located vs. Remote Gameplay: The Role of Physical Co-Presence in Multiplayer Room-Scale VR

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***Abstract*—Our research investigates the role of physical co-presence for the experience of multiplayer cooperation in virtual reality (VR). We developed and compared a shared-room (co-located) and separated-room (remote) version of a cooperative two-player VR game. In an extensive study (N=92) we assessed measures of task awareness and spatial presence, as well as player communication, interaction, and performance. Our results indicate that players sharing the same physical space tend to neglect the cooperative task. Moreover, our results indicate that being physically separated can beneficially impact the perceived cooperative social presence, quality of communication, and performance in contrast to sharing a physical space. The role of physical co-location in room-scale VR and potential confounding effects caused by it, as well as implications for further research, are discussed.**

***Index Terms*—Virtual Reality, VR, Co-Location, Co-Presence, Collaboration, Cooperation, Shared Space, Multiplayer**

I. Introduction

Modern VR technology enables people in professional as well as entertainment domains to interact simultaneously in those worlds, even if they are physically apart. However, technological advancements in the development of head-mounted displays (e.g., standalone devices) eventually lead to a growing number of use cases, that easily allow multiple co-located users to interact in a shared virtual world. Such use cases include games for entertainment (e.g., The VOID) and serious applications for teams alike. Thus, knowledge of the psychological and behavioral consequences of being virtually and physically co-located at the same time would enhance the design of such applications.

The role of physical co-presence was previously investigated in the context of digital multiplayer games as a component of the overall social setting, [4], [8], [11]. Although in traditional co-located hardware setups player focus should rather be on the shared screen than on each other, the physical co-presence of others seems to beneficially impact the overall player experience, either due to the mere fact of being co-located or due to social interaction as a consequence of sharing a physical space (see [4] for review on this topic). Compared to remote multiplayer games, co-located games are assumed to provide a higher sense of social presence ("the sense of being together with another" [3]), and thus, increase enjoyment under certain circumstances [8]. Furthermore, persons playing in co-located settings tend to report greater involvement, engagement, competence, and positive affect, as well as lower tension, [4], [7], [8].

In VR settings the question arises whether the same tendency for remote and co-located gameplay is observable since modern HMDs can fade out the real surrounding and thus the other player. Gómez and Verbeek [1] addressed this question using cardboards which do not support room-scale. Their results indicate that cardboard VR technology can equalize the experiences of playing co-located and remotely. However, sharing the same physical space in modern room-scale VR systems enables new ways of experiencing the other player (i.e., colliding). Podkosova and Kaufmann [14] examined in a more recent work the impact of a multi-user navigation task in room scale VR. Their results indicate that sharing the same physical space can lead to undesirable effects such as a reduced focus on the task.

To shed more light on the relationship between physical co-location and player experience in VR contexts, we extended previous research and compared a co-located and remote version of a two-player VR game. We conducted a study with 92 participants in a between-group design and collected several player experience related constructs. Our results indicate that the perceived cooperative social presence, performance measures, and the perceived quality of communication are higher in the remote setting than in the co-located setting. Hence, playing in the same space in multi-user VR can be disadvantageous if not considered carefully. Our work contributes to the understanding and future design of multi-user VR applications. We address game designers and researchers alike who seek to create multiplayer VR applications by pointing out benefits and limitations which result from multiplayer room-scale VR.

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II. Related Work

A. Designing Multiplayer VR

Physical co-location introduces specific challenges to the design of VR multiplayer games. Therefore, the specific approaches to overcome those challenges determine how the player experience is affected.

As long as wired HMDs are the common hardware, cable management should be considered in general and specifically in co-located settings as a potential source of interference for gameplay. To a certain degree the tangling up of cables can be prevented by construction-based characteristics of the play space (e.g., placement of computers the HMDs are connected to, trusses). However, as long as the interactions within the virtual world require players to move around in various directions, these approaches are not sufficient. Therefore, the characteristics of the virtual world should be thoroughly considered in the game design process.

Two challenges in the design of co-located multiplayer VR interaction are the phenomenon of spatial desynchronization (when players are in physical proximity but virtual distance) and techniques for collision avoidance. If co-located players share a limited physical space but explore a larger virtual world, spatial desynchronization could occur [13]. This desynchronization threatens the general spatial orientation, and thus player safety, by provoking physical collisions. The issue of spatial desynchronization is based on the general possibility of physical collisions in co-located multi-user VR and its impact on user interaction. The authors of [14] compared a co-located and remote setting of a navigation task regarding users collision avoidance behavior. Results indicate that physical co-location impacts user behavior and user attention processes. Specifically, being co-located during interaction in VR led to a reduced focus on the task and an increased focus on collision avoidance, which is also reflected in greater clearance distances between users [14]. In summary, if applications do not implement a specific strategy against collisions, users tend to actively focus on it by themselves, eventually reducing the focus on the actual task of the interaction. Nevertheless, merely limiting the individual movement to smaller spaces may lead to dissatisfaction with the overall experience as reported in [13], and thus seems not a desirable approach. Although the findings in [14] regarding the shift in user focus are comprehensible, further work must verify if this shift applies in other, more engaging interactions. Based on their research question, the authors of [14] implemented path crossing, thus collision avoidance behavior, as an integral part in their experimental design. However, VR games are not limited to navigating through physical space, as they can have a variety of objectives and challenges. Therefore, it has yet to be validated, if VR multiplayer is affected by potential physical collisions, if the mere navigation is not the central objective.

In contrast to this rather negative perspective on body contact during VR interaction, providing remote VR users with additional sensory information cues (e.g., tactile cues of proximity) has found beneficially impact mutual awareness and certain aspects of cooperation [17], [18]. Whereas [17], [18] did not directly compare co-located and remote interaction in VR, their work indicates, that co-located settings may have certain advantages over remote settings.

An approach to investigate physical co-presence in multiplayer VR independent from collisions is described in [1]. The authors investigated the impact of physical co-location on game experience and social presence in a two-player VR game. In contrast to [14], they used a seated VR experience with cardboard HMDs. Referring to research on social presence in digital games, they argue that information cues like sounds of physical movement might enhance social presence in a co-located setting, although users are immersed visually and auditory. Interestingly, the two settings did not differ regarding the social experience. The authors conclude that the visual immersion of the cardboards, as well as the possibility to speak with each other (directly or via voice chat), equalize the experience and thus limit the potential impact of other consequences of physical co-presence [1].

B. Researching Multi-User VR

If the physical presence or absence of a co-user impacts aspects of interaction experience and behavior in VR contexts differently, then research in this domain should consider the spatial setting as a potential confounding factor in experimental designs. Review of related work indicates that the decision of co-location or separation of users in experimental settings is influenced by various factors, that are not always explained in detail or reported at all (e.g., confounding effects by meeting of participants before the actual interaction in VR [2], [9], technical setups or hardware limitations [20], not reported [5]). Therefore, we also review previous work, where authors discuss the role of physical co-presence or work that could benefit from considering it as a potential confounding factor.

The role of physical co-presence was previously partly discussed in the context of research on approaches to advance virtual interaction [16], [20]. In [20] the authors compared different techniques of gaze simulation behavior for user avatars. They investigated a two-user co-located VR setting and assessed various measures of the interaction experience (i.a. involvement, co-presence). In their discussion, they identify the awareness of being co-located as a potential confounding factor for involvement and suggest to compare presence-related aspects and quality of communication between co-located and remote users in future research. They support their discussion by comparing their findings to previous related work [9] that examined gaze behavior in a remote setting.

The work of [16] is another example for the discussion of the spatial relationship of VR users as a potential influencing factor. The authors investigated how they could visualize social behavior cues (i.e., joint attention, eye contact, and grouping) in a large-scale co-located VR setting, where participants were asked to explore a virtual museum. The comparison of an augmented and a non-augmented condition indicates that social augmentations enhance social perception and behavior. However, the authors did not find differences regarding certain measures of co-presence. Since users could hear each other in the physical space, and thus could estimate their physical social surrounding, the physical co-location in the setting is discussed as a potential confounding factor for potential effects of social augmentations.

The review of related work on multi-user VR should highlight two aspects. First, the role of physical co-presence has not been consistently considered as a potential influencing factor regarding various research questions. Second, previous studies directly comparing co-located and remote settings are either limited in the hardware they used when compared to current consumer devices [1] or limited regarding the complexity and engagement of interaction [14]. Therefore, we extend these approaches by comparing a co-located and a remote version of a self-developed multiplayer VR game as described in the following sections. Thus, our work contributes to the general research on multi-user VR, as well as to the design of multiplayer VR games.

III. VR Multiplayer Testbed Game

We developed a testbed game to investigate the role of physical co-presence in multiplayer VR. It is a cooperative two-player game, in which players are wizards that defend their tower of knowledge from being plundered by monsters. Those monsters try to steal the books that are inside the tower by sneaking in and bringing them in the surrounding forest (see figure 1). The players are positioned on the top of the tower, whose virtual size corresponds to the available physical play space. The walkable virtual area is limited to this space. Thus, players can freely move around based on natural walking without worrying about spatial desynchronization [13]. In order to not provoke virtual and physical collisions, the gameplay does not require extensive movements around the play area. Thus, we purposefully decided against dividing the play area into two individual parts in line with [13]. Therefore, we deliberately decided that collisions between the players are possible to evaluate which impact collisions and potential collision behavior have on the player experience and cooperative social presence. Players are represented by the same virtual model, consisting of an HMD wearing a wizard hat, indicating their heads positions in physical space. Additionally, one hand of each player is represented by a wand, whose position corresponds to the Vive controller movement of a player in physical space (see Figure 2).

On top of the tower, the players see waves of monsters approaching from the surrounding forest. Monsters belong to one of three types, that differ in their movement, size, speed, defense, and their ability to swim. Small enemies are faster but withstand fewer hits than bigger ones. Additionally, blue enemies can swim through the moat to reach the tower. When a monster reaches the tower by one of the bridges or by the moat, it turns around and heads back to a random position in the forest. Once it reaches the forest, the books it stole are lost. The players have to stop them by shooting magic projectiles on them. This is done by pressing the trigger button on the Vive controller. If a player defeats a monster that carries books, the books are dropped at the position of its defeat. To recollect dropped books players can command an owl that rests in a cage underneath the top of the tower. By pressing the controller trigger while pointing at the cage, the owl flies to the battlefield and randomly collects up to ten books. Once returned, and after a 30 seconds cool-down the players can command the owl again.

Additional to individually shooting the enemies, players can coordinate two types of cooperative attacks. The first is triggered by hitting a monster with two successive hits from both players within a time frame of two seconds and quintuples the damage. The second cooperative attack is a thundercloud, that deals area damage and can defeat several enemies at once. A control panel for generating the cloud is attached on the back wall of the playing area (see Figure 2). Thus, the players are required to decide when they should use individual, that are fast or cooperative attacks, that require them to coordinate their actions but are more effective in certain situations.

Each game lasts nine minutes. In total 193 monsters are spawned in waves at predefined points in time. If players defeat a wave before the next one is spawned, they must wait and can recollect lost books. The number of stolen books and defeated enemies are displayed on the back wall of the playing area.

Due to hardware and performance limitations, it is common that only one HMD can be connected to a VR computer at a time. Therefore, multi-user VR applications are generally networked applications, independent of the spatial setting. Thus, it was not required to design the game specifically for co-located or remote players. The described game was played either in a shared physical space or in different rooms, without any further specific adaptations of the game design. We defined tracking areas identical in size in both scenarios with the *Steam VR Room Setup*, to ensure comparability as well as congruency between the position in virtual and physical space.

IV. Evaluation

We conducted a comprehensive user study to explore the impact of physical co-presence in a room-scale VR multiplayer game on cooperative social presence, spatial presence, performance, as wells as quality and quantity of communication, and the number of cooperative interactions. Hence, we compared a co-located and a remote session of gameplay of the same game.

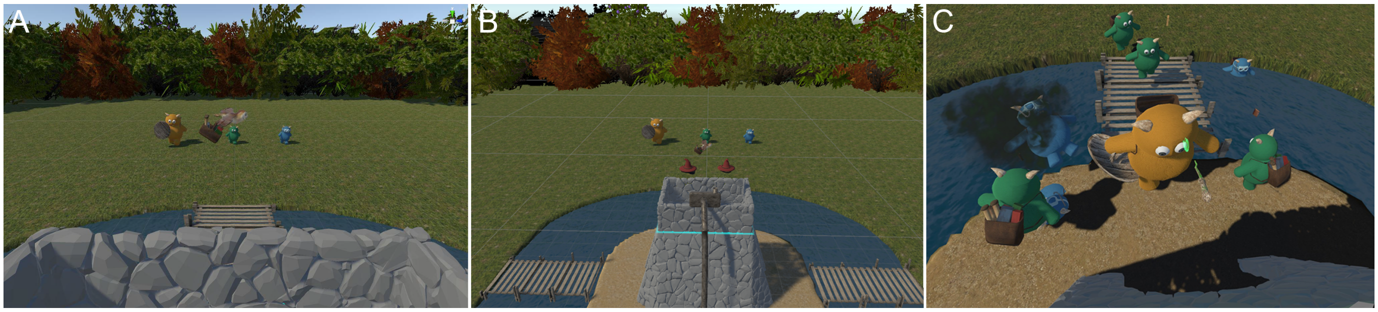

Fig. 1. **(A)** Three different enemies are approaching the tower as seen from a player's perspective- **(B)** The tower the players are standing on is surrounded by a moat which only the blue enemies can pass. The others must cross the bridges. **(C)** A player's perspective during the actual gameplay shows several enemies which are approaching the tower to steal books.

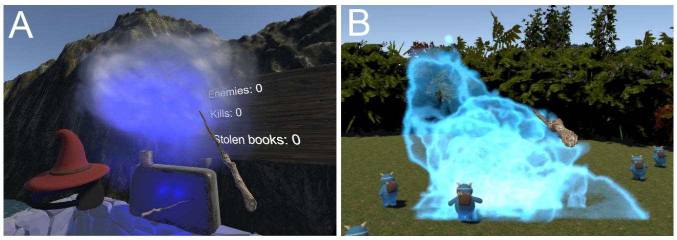

Fig. 2. **(A)** One player creates a cloud by sliding over the control panel with his wand. The other player can now move the cloud to the desired location on the battlefield by pointing her/his wand correspondingly. **(B)** After the second player has moved the cloud to the desired position, the first player can shoot the cloud to detonate it, defeating all monsters in a certain radius.

Based on the literature research we hypothesize the following:

I *Playing in a co-located space leads to a reduced task awareness than playing in a remote setting*

We further assume that a shift in the task focus might lead to reduced performance and additionally lowers the perceived quality and quantity of communication as well as the number of cooperative interactions in the co-located condition. We, therefore, further hypothesize the following:

II *Playing in a co-located space leads to lower*
  a) *Communication quality*
  b) *Communication quantity*
  c) *Performance*
  d) *Number of cooperative interactions*

A. Measurements

1) Cooperative Social Presence and Spatial Presence: Since our game is a cooperative, team-based game, with cooperation as the main task and objective, we assessed task awareness among teammates during gameplay, with the Co-operative Social Presence (CSP) sub-scale of the *competitive and cooperative presence in gaming questionnaire version 1.2* (CCPIG) [10]. It is designed for the evaluation of team-based digital games and is divided into the two dimensions *Perceived Team Cohesion* and *Team Involvement*. Team cohesion represents the level of perceived effectiveness and successful cooperation of the team. Team involvement refers to the degree of team involvement, team investment, and dependency on a team. Playing with other persons has an impact on the experience of spatial presence [15], and in the CLS condition, a mismatch between the virtual and physical representation of the other player could be possible and hence break the illusion of being located in a virtual environment. We therefore observed the experience of spatial presence using the *igroup presence questionnaire* (IPQ) [19]. The IPQ consists of four subscales: *spatial presence, involvement, experienced realism, and general presence*.

To evaluate the experience of collision avoidance behavior, we formulated the following three questions that were required to be rated on a five-point Likert scale:

- *Did the presence of your teammate restrict your freedom of movement?*
- *Did you deliberately avoid physical contact with your teammate?*
- *How much did you pay attention to where your teammate was and what she/he was doing?*

2) Communication and Interaction: We assessed two aspects of player communication - quality and quantity. To examine the quality of communication, we formulated five items which should be rated on a five-point Likert scale. The questions covered the subjective experience regarding the efficiency of the communication, e.g., *(My teammate directly understood what I was trying to tell her/him)*. We calculated one resulting *qualitative communication score* by adding all scores of the items. To assess the quantity of communication, we used an objective approach by recording the verbal communication of each game session and saving them in individual audio files. We then cut out passages beneath a certain threshold using the tool *Audacity*. Thus, the remaining files implicitly included various verbal social interaction cues that previously were used to analyze co-located multiplayer games [6]. Eventually, the length of each audio file was used as a measure for communication quantity. To assess the number of cooperative interactions, we logged the number of cooperative shots (consecutive shots and thunderstorm clouds). The resulting value represents the amount of cooperation of the team.

3) Control Variables: Since expertise in gaming and VR technology usage may impact the behavior, rating, and performance of players, we determined the player expertise using ten self-formulated items. Each question was required to be rated on a five-point Likert scale. Furthermore, we used the *immersive tendencies questionnaire* (ITQ) to determine the immersive tendency, which was evaluated to positively correlate with spatial presence [21]. To observe potential simulator sickness effects, we used the *simulator sickness questionnaire* (SSQ) [12]. The familiarity between teammates was assessed by self-report on a 5-point Likert scale.

B. Design and Procedure

We used a non-repeated measure between-subject design. Participants played the game in dyads. Each group either played in the remote space condition **(RS)** or in the co-located space condition **(CLS)**. The procedure regarding the questionnaires was the same for both conditions. Before the start of the experiment, participants were welcomed in a shared room and asked to gave their consent. Depending on which condition the group was randomly assigned to, the participants were then separated from each other or remained in the same room. In both conditions, a supervisor was present in each room (see figure 3).

First, participants were asked to report their gaming and VR expertise, and socio-demographic data, and fill out the ITQ, as well as the SSQ to assess whether potential high values of the SSQ after the gaming sessions were due to high values before the game play. After filling out the questionnaires, both players were introduced to the virtual world and played a simple tutorial for about three to five minutes. In the tutorial, they learned how to defeat enemies and how to use the cooperative mechanics of the game. Afterwards, both players played the game for nine minutes. In both conditions, the players communicated via *Discord*, wearing an HTC Vive audio headstrap, to equalize the mode of verbal communication (mediated). PCs were positioned at opposite sides of the play space to minimize the possibility of tangling up the HMDs' cables during gameplay in the CLS condition. After the game ended, participants were asked to fill out the SSQ, CCPIG, and IPQ. Afterwards, the players were asked to rate the perceived communication and whether the presence of the other player (virtual or physical) restricted the perceived freedom of movement and led to deliberate collision avoidance. In conclusion, participants were debriefed and handed certification of participation, which they need for certain university courses. The experiment took about 45 - 60 minutes to complete. The study was reviewed and approved by the university's ethics council.

Fig. 3. In the remote setting, the tracking areas of both rooms were identical, by visualizing the dimensions of one room on the floor of the second room. In both conditions, each HMD requires to be operated on individual PCs. The synchronization of the game is done via a broadband local area network.

C. Participants

Ninety-two participants were recruited and equally distributed to the two conditions - 46 to each group. Exclusion criteria were a history of neurological diseases such as epilepsy. Four participants were excluded from the statistical evaluation since the log files during the gaming session have not been saved correctly. Hence, 88 participants were included in the statistical analysis - 46 in the remote setting and 42 in the co-located setting.

D. Results

1) Sociodemographic Variables: The age of the 88 participants ranges from 18 - 56 ($M = 24.52, SD = 5.26$). 40 participants identified as female, 29 as male, and 19 did not give any information. Considering the general digital gaming behavior, 21% of the participants reported, to never play digital games, 41% reported to play several times a month, and 38% reported to play at least several times a week. The expertise with VR technology can be considered quite low, with 36 participants reporting to have no VR expertise at all and an additional 28 participants reporting to have not used VR more than two times.

2) Simulator Sickness: The SSQ results indicate very low simulator sickness scores for both conditions. The post-game SSQ values for the CLS condition ($M = 4.71, SD = 4.41$) and RS condition ($M = 3.76, SD = 3.84$) do not show significant differences between the pre-game SSQ values for the CLS ($M = 7.57, SD = 6.62$) and RS condition ($M = 6.22, SD = 5.72$), indicating that the VR game did not induce any simulator sickness.

3) Spatial and Cooperative Social Presence: No significant differences were found for the spatial presence and

TABLE I
IPQ, CCPIG, AND COLLISION AVOIDANCE SCORES

Subscales	CLS M *(SD)*	RS M *(SD)*	*p*
IPQ			
General Presence	4.90 (*0.73*)	4.96 (*1.19*)	.808
Spatial Presence	4.88 (*0.79*)	4.88 (*0.92*)	.988
Involvement	4.18 (*1.03*)	4.40 (*1.28*)	.386
Realism	2.49 (*0.96*)	2.52 (*0.88*)	.996
CCPIG			
Total CCPIG Score	100.67 (*12.71*)	108.96 (*9.97*)	**.001**
Team Involvement	43.45 (*5.66*)	47.05 (*4.77*)	**.002**
Team Cohesion	57.22 (*5.66*)	61.91 (*6.12*)	**.002**
Collision Focus			
Movement Restriction	1.79 (*0.90*)	1.67 (*1.01*)	.587
Collision Avoidance	2.45 (*1.38*)	2.13 (*1.34*)	.271
Attentional Focus	3.12 (*1.09*)	3.22 (*0.99*)	.657

all subscales of the IPQ. One-way ANOVAs revealed significant differences for the experience of the total social presence CCPIG score between the CLS and RS condition $F(1,86) = 11.69, p = .001, \eta_p^2 = .12$. Furthermore, significant differences were found for the *Team Involvement* subscale $F(1,86) = 10.41, p = .002, \eta_p^2 = .11$ as well as the *Cohesion* subscale $F(1,86) = 10.08, p = .002, \eta_p^2 = .11$ between the conditions. The corresponding values can be found in table I. Since we used the cooperative social presence to assess the task awareness, our first hypothesis is confirmed. The scores regarding the questions assessing the freedom of movement and deliberate collision/contact avoidance are surprisingly low (see table I). We have found no significant difference for any question between the two conditions.

4) Communication, Interactions, and Performance: A one-way ANOVA revealed a significant higher qualitative communication score in the RS condition $(M = 21.84, SD = 2.19)$ than in the CLS condition $(M = 20.60, SD = 2.80)$ $F(1,86) = 5.14, p = 0.26, \eta_p^2 = .056$ and thus confirms our hypothesis *IIa*. No significant differences were found for the quantity of communication. Furthermore, no significant differences were found for the cooperative interactions, though a tendency is observable which indicates a slightly higher summed up value for all cooperative interactions for the RS setting $(M = 394.33, SD = 109.44)$ than for the CLS setting $(M = 363.60, SD = 111.02)$ with $F(1,86) = 1.71, p = .195$. Hence, we reject our hypotheses *IIb* and *IId*. Since the performance of the players can be assessed using the numbers of killed monsters and books stolen, we calculated two one-way ANOVAs to investigate a potential impact of the setting on the performance. A significant difference was found for the amount of killed monster between the CLS $(M = 107.38, SD = 26.11)$ and RS $(M = 119.78, SD = 26.00)$ condition $F(1,86) = 4.98, p = .028, \eta_p^2 = .055$. The number of stolen books did not differ between the groups. Since one performance indicator significantly differs between the groups, our hypothesis *IIc* is partly confirmed.

5) Confounding Variables: Since previous gaming and VR expertise, simulator sickness, immersion tendency, and familiarity of the players can influence the gaming experience and thus have a potential impact on our dependent variables, we calculated correlations between potential confounding variables and our dependent variables. We only found correlations between the familiarity of the players and several dependent variables. The familiarity between the player positively correlates with the total CCPIG Score $r(88) = .32, p = .002$, the team involvement $r(88) = .26, p = .015$ and team cohesion subscale $r(88) = .34, p = .001$, as well as with the quality $r(88) = .31, p = .004$ and quantity of communication $r(88) = .40, p < .001$. Hence, this indicates that the familiarity between the player might have impacted the findings of the one-way ANOVAs. Therefore, at first, we investigated whether the reported familiarity values of the players differ between the two conditions. No significant difference was found. Afterwards, multiple analyzes of covariance were conducted to detect differences between the game settings while controlling for player familiarity as covariate. Since only three participants reported familiarity values of 2 and 3, we excluded these cases for the multiple analyzes of covariance. The results of the multiple analyzes of covariance show no deviations from the one-way ANOVA results. This indicates that familiarity does not influence the significant differences between the RS and CLS condition for the experience of social presence, quality of communication, and amount of killed monsters.

V. DISCUSSION

The main results of our experiment reveal significant differences in the experience of cooperative social presence (team cohesion and involvement). Further, we found significant differences in the quality of communication and performance between the CLS and RS conditions. In consequence, we assume that the physical presence or absence of the players had an impact on player experience and behavior in our VR multiplayer game. Based on the assumption that the CCPIG is an adequate operationalization for cooperative task awareness, these results confirm our first hypothesis, that playing together co-located reduces the task awareness. Our second hypothesis is partly confirmed, in that co-located play leads to lower values of behavioral aspects of cooperation based on the shift of player focus.

Referring to [14], one reason for a reduced task awareness could be a shift of focus to collision avoidance. However, we did not find any significant differences between our conditions regarding the perceived freedom of movement and avoidance of physical contact. Thus, we cannot confirm that a focus on collision avoidance did consciously interfere with the focus on task completion. Therefore, we would argue that unconscious processes may explain the constellation of our study results. We assume that our game provided a certain degree of engagement, that prevented players from consciously focusing on aspects that were related to the physical space surrounding them. Thus, we were not able to reveal these processes with the self-report instruments we used. Future work should consider assessing both, conscious (self-report) as well as subconscious measures (clearance distance as in [14]) of player focus to validate this assumption. Furthermore, we deliberately decided that collisions can occur to evaluate which impact collisions and collision avoidance behavior have. Preventing collisions by specific game design choices should be evaluated in future research to explore the role of potential collisions on the game experience and cooperative social presence.

In contrast to [14], we should consider the use of wired HMDs as a potential confounding aspect of our spatial setting and its influence on cooperative social presence. Participants in both conditions often reported the wires of the HMDs had restricted their perceived freedom of movement. Additionally, in the CLS setting, some participants reported they were afraid of the wires tangling up although the cable setup was carefully implemented and did not cause any actual problems during gameplay. However, this could have also caused a shift in player focus that we did not assess systematically.

Although we have found a significant difference in the quality of communication, we did not find a significant difference in the quantity of communication. Thus, we assume that the quality of communication was not based on the amount, but the contents of the communication. This indicates, that though both groups communicated a similar amount of time, the communication was more effective in the RS condition. This would align with the findings on cooperative social presence, in that a higher focus on the cooperative task facilitates effective communication about it. However, since we did not analyze the communication audio files content-wise, we cannot validate this interpretation ultimately. Another potential influencing factor for the reported differences in communication quality is the mediation of verbal communication via Discord in our study. In CLS condition setting, this led to situations, were players heard each other twice (non-mediated and mediated) with a short delay. Although we used the same mode of verbal communication in both settings to ensure comparability, this instance has been remarked by several players and thus, could have undermined the quality of communication.

In line with the previous argumentation, remote players performed significantly better than co-located. Thus, we explain this difference with a higher focus on the cooperation, and more effective communication. Similar to the differences in perceived communication quality, this difference appears not to be based on the number of cooperative attacks, but on their effectiveness. Based on the higher quality of communication, remote players might have coordinated and used cooperative as well as individual attacks more effectively.

Though our results are in line with [14], they are contrary to the results of [1] who also examined a multiplayer VR game with a similar research focus. This contrast can be seen as the results of the VR system, which was used in the studies (cardboard vs. room-scale VR). While cardboard systems seem to equalize potential benefits that result from co-located non-VR multiplayer settings, room-scale VR can shift them to the remote setting. This instance can be explained with regards to the potential physical influence the other player has while sharing the same physical space. For the design of future VR multiplayer, researches should therefore carefully consider which system should be used and which restrictions should be implemented to avoid unwanted side effects.

Future research should use validated methods to analyze the quality of communication. Further, it is interesting to investigate how modern wireless room-scale VR technology impacts the cooperation and to which degree our findings are influenced by the wired setup. Furthermore, in this context, it is interesting to track behavioral data to get a better insight into the player's collision avoidance and movement. This could also shed light on the question to which degree collision avoidance in multiplayer room-scale VR is conscious.

VI. Conclusion

Our study indicates that separating or co-locating two players physically in a multiplayer VR game can have a significant impact on the player experience. In line with our expectations and prior research, co-located play can undermine the experience of cooperative social presence, quality of communication, and performance. Thus, in extension to previous work, our results indicate that unconscious processes due to the physical co-presence of the other player and the technical properties of the setup influence the experience and effectiveness of cooperation. Nevertheless, our results should be interpreted with the discussed limitations in mind. Depending on the specific application domain (e.g., educational games, entertainment games), the objective of VR interaction could either be experience, or performance driven. To ensure better design decisions in such domains, future research should further investigate more facets of player experience and performance in multiplayer VR.

Our work contributes to the understanding of interaction in multiplayer VR and how it affects player experience and behavior and emphasizes the importance to carefully consider which physical spatial relationship between users should be used in future investigations. Since room-scale VR recently became an affordable technology for the consumer and business market, our results inform the growing number of developers and researchers alike that want to create multi-user content purposefully.

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