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Simulating Social Emotion Regulation in Virtual Reality

Effect of Virtual Social Support Following Ostracism in a Cyberball Game

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Abstract—Virtual reality (VR) is a valuable research tool offering advantages in terms of high experimenter control and standardization in the simulation of vivid personal and social experiences. It has been used for assessments and training in social cognition with the use of virtual agents instead of face-to-face interactions – but its potential for the study of social emotion regulation has, perhaps surprisingly, largely remained untapped. The present study evaluates a novel immersive VR scenario designed to study the efficacy of social support by a virtual agent using a modified version of *Cyberball*, an established paradigm to induce the feeling of ostracism. Participants embodied a new pupil in a virtual school environment and played Cyberball, after which they either did or did not receive emotional support. Self-reports and psychophysiological markers demonstrated that the negative impact of social exclusion in Cyberball was successfully replicated, while participants also reported a significant improvement in emotional state after being supported by the virtual agent. These results indicate the potential of the developed scenario for research on social emotion regulation in immersive VR. Future studies could aim to test the efficacy of social support for people with difficulties in self-regulation, for example individuals with high social anxiety, with a view to developing training programs in VR.

Keywords—virtual reality, social emotion regulation, social support, agent, social exclusion, Cyberball

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1 Introduction

1.1 Virtual reality in psychological research

Almost 20 years ago, Blascovich et al. identified three major methodological problems of behavioral experiments in psychology which, they argued, could be addressed through the use of Virtual reality (VR) technology [1]: the loss of realism and ecological validity accompanying the increase in control over the experimental situation, the problems with the replication of exact scenarios, and the nonrepresentative participant samples used for many experiments out of convenience.

Virtual reality, and especially *immersive* VR, where the individual is surrounded by the virtual environment instead of seeing a representation of themselves in a world on a screen, allows for a vivid close-to-life experience while still offering a great amount of experimenter control, standardization and reliability [1], [2]. At the same time, the still-evident reduction in complexity and the more limited consequences of failure offered by VR compared to real life may be an advantage in themselves, since participants have reported more readily accepting the confrontation with challenging situations *in virtuo* [3], [4]. The third of the three problems Blascovich et al. identified, the nonrepresentative participant samples, could also be mitigated by virtual assessments thanks to the increasing availability of VR technology sets (see, for example, [5], where Zhang and Ho use the participant's smartphone for a combination of VR and therapy).

As such, immersive VR is used to assess human behavior in a comparatively natural setting that can be used to provide stable assessment and training contexts facilitating learning [6], as long as the person inside the environment feels guided in their learning process, rather than overwhelmed by the input [7]. Advances in hard- and software technology and in research on the medium itself have led to applications in a variety of fields, such as cognitive and motor rehabilitation after brain damage [8], [9], exposure therapy in the treatment of phobias and anxieties [3], [10], [11], vocational training for medical staff and other professionals [12], [13], and interventions for children with and without disabilities [14], [15].

1.2 Virtual reality and social situations

Standardization of another person's appearance and verbal and nonverbal behavior are difficult to achieve in real life experiments, even with extensive preparation. The use of a virtual environment makes it possible to create not only *virtual avatars* (representations of actual humans inside the virtual environment), but, even more standardized, *virtual agents* (representations of computer programs designed to give the impression of another virtual character). The potential to study social situations in more detail has long been recognized [16] and, since then, agents have gained much more visual and behavioral realism [17]. Indeed, the emotional expressions and nonverbal cues provided by agents have been included in recent studies in which participants are asked to identify their emotional states as part of an assessment of emotion recognition (for examples see [18], [19]). Furthermore, there have been a number of studies simulating social presence and interaction in VR, using it to assess and train social cognition and behavior. The nature of the medium has proven to be especially interesting for training social and communication skills with people on the autism spectrum, known to often have trouble with social interaction and understanding, and people with intellectual disabilities (for example, see [20]–[23]).

1.3 Why social emotion regulation?

One area in which VR has not yet been developed is that of social emotion regulation. Emotion regulation (ER), the management of one's response to an emotional experience, is an important part of a person's life and wellbeing [24]–[26]. Self-regulation is only one part of this, since other people's regulatory efforts to increase, maintain, or dampen our emotions are crucial in our daily life. Social or interpersonal ER either includes all intentional regulatory efforts by another person to impact our emotional states [27], and additionally perhaps, our own efforts to seek out regulation from the other person [28], or it is seen as a separate, relational approach to emotion [29].

Social ER remains underrepresented in the study of ER as yet [28], [30], [31], even though it has the potential to act as a valuable emotional buffer and help, particularly in situations in which one's own regulation attempts are not sufficient, e.g. when they are temporarily impaired [32], when positive resonance can increase satisfaction in partnerships [33], or when capacities to self-regulate are not yet developed, such as in young children [34], [35]. This underrepresentation is also reflected in VR research on ER, where there are a number of studies on the topic of self-regulation in adults and older adults, mainly focusing on how virtual elements can benefit the individual's ER abilities (for a review, see [36]), but only relatively few studies of social ER. For example, Pacella and López-Pérez developed a game-like VR experience to train social regulative skills in which participants meet virtual agents and receive points when they successfully identify emotional problems and choose suitable regulatory advice [19]. More recently, Kothgassner et al. examined the effect of virtual social support on a subsequent stressful situation [37]. Meanwhile, Ip et al. and Yuan and Ip created several short virtual scenarios about the daily lives of children in Hongkong and incorporated a training session on emotional and social skills [38], [39]. While these studies are interesting, no systematic approach to social ER in VR has been developed to date. This present article sets out a new virtual environment specifically designed to assess social ER in terms of whether participants' regulation can benefit from social support provided by virtual agents. Developing a virtual environment with a social scenario able to elicit a negative emotional reaction in participants which includes a virtual agent that can be emotionally supportive would provide an important starting point for future training programs by demonstrating the acceptance and efficacy of social support from virtual agents, and ultimately from other people in real life. Since there are many ways to provide social emotional support as a form of social ER [28], [32], we would like to specify here that we operationalized social emotional support as the approach and verbal utterance of the virtual agent (the regulator), who offers a reframing of the situation to assist the participant (the regulatee or target) in cognitively reappraising the situation in order to feel better, a well-studied and socially relevant regulation strategy [27].

1.4 Developing scenarios to assess social emotion regulation

Cyberball is an established and inherently social paradigm, originally designed to elicit strong negative emotional feelings about being excluded [40]. This traditionally minimalistic 2-D computer task of playing ball with two or three other players was first adapted from a face-to-face ball game task and has been reliably used to create a feeling of social ostracism for over twenty years, the original study having been cited over 2700 times [40]–[42]. Cyberball is such a robust paradigm that studies have found the effect to occur even if there was no communication or visual contact between the players [43], if there was almost no graphical representation of the game on the screen [44], and even if, although to a lesser extent, participants knew that their co-players were controlled by a computer rather than by an actual person [45].

In terms of ER, the Cyberball paradigm has been used as a trigger situation for attempts at self-regulation [46], [47], and for assessing the readiness of participants to regulate a person's sadness after that person had been excluded from the game [48], [49]. Attempts to recreate the task in VR have been scarce, although some work has been done [50]–[52]. Kassner et al. first implemented the Cyberball paradigm into immersive VR, with participants being asked to remember as much as possible about the environment while playing ball with virtual agents, and succeeded in recreating an effect of exclusion, assessed by using retrospective self-report questionnaires [53]. In a study by Kothgassner et al., participants reported similar feelings in a similar environment [54]. In this experiment, heart rate (variability) was also assessed. While the results showed higher arousal during exclusion than during inclusion conditions in VR, arousal was higher in face-to-face interactions with people in real life than with the virtual characters.

Cyberball was adapted again in the present study in order to assess social ER with virtual agents in a new environment. After a few rounds of ball play in which the participant is excluded, one of the agents present in the virtual environment subsequently tries to act as a source of social support, the latter being a commonly used method for the regulation of other people's emotions [28]. It was thus important to ensure that negative emotions were indeed elicited with the Cyberball paradigm in the novel environment before assessing whether or not people benefited from the agent's attempts at social support. As such, we aim here to address two main questions: (i) Does our VR environment and experimental design provoke the desired negative emotional impact of ostracism, and (ii) Do participants benefit from the attempt at emotional support provided by a virtual agent as social ER?

In order to assess both in-game and retrospective reports of ER, psychophysiological and self-report measures were used. Skin conductance and heart rate variability were chosen as established physiological measures for arousal and distress (see, for example, [55]). While a decrease in heart rate variability is usually connected to heightened arousal and stress levels [56], there are conflicting results about the connection between skin conductance and ostracism. Some studies show a positive correlation [57], some none at all [58]. This study represents an opportunity to further investigate the link between the two.

In 2022, Stallmann et al. published a methods article elaborating in more detail on an experiment including a further developed version of the paradigm presented here [59].

1.5 Hypotheses

First, given the results on exclusion in immersive VR found by Kassner et al. [53] and Kothgassner et al. [54], we expected participants to react negatively to being excluded from our VR ball games:

1a) Participants should report more negative (and less positive) emotions when being excluded than when being included. Self-reports during two separate experiences of exclusion (one with social support afterwards and one without) should not differ significantly.

1b) Participants should show a heightened psychophysiological distress response when being excluded, compared to when being included. This would result in lower heart rate variability.
1c) Although this was exploratory, we also expected that the outcomes for skin conductance would be different between inclusion and exclusion.

Second, considering the well-established chosen regulation strategy and results on the social relevance of characters in VR [17], [20]–[22], we expected participants to benefit from the support given by a virtual agent.

2a) There should be a more pronounced improvement of reported emotions after the game when receiving social support than when not receiving social support.
2b) After being excluded, participants should show a lower physical stress response when receiving social support than when not receiving that support.

2 Method

2.1 Participants

Twenty-nine German-speaking adults (26 female), either currently enrolled at university or with an academic background, took part in this study, with a mean age of 23.7 years (SD = 3.9, age range from 18 to 32). Participants were recruited through online study advertising and university bulletin boards and were required to have normal or corrected-to-normal vision. Approval was granted by the Cantonal Commission for Ethics and Research of Geneva. Written informed consent to participate in this study was provided by the participants.

2.2 Apparatus

The experiment was programmed using Unity3D and C# and run using SteamVR and Unity3D game engine. For the creation of the virtual world, some assets were obtained for free and two packages of VR avatars, Toon kids [60] and Toon people [61], were purchased from the Unity Asset Store. The VR hardware belonged to the HTC VIVE© Pro line and consisted of a head-mounted display (HMD) with built-in headphones and microphone, one wireless hand-held controller and two base stations 2.0. At the start of the session, the HMD was always calibrated at the same starting position in the experimental room, so that participants would always begin and move around from the same starting point. Participants sat on a revolving chair and were free to turn and move their arms in every direction. Having participants stay seated was both beneficial in terms of quality of the psychophysiological recording and as a way to reduce the workload on the participant when confronted with this new experience. The sessions were recorded both in-game and externally, using a Canon Legria HF R806 camcorder in the corner of the room. For more details on the hard- and software used, please refer to the Materials and Equipment section of the article by Stallmann et al. on a subsequent version of the experiment [59], or directly to the source code, binary and 3D assets freely available via the online repository of the Open Science Foundation [62].

Psychophysiological signals, including pulse (PPG), electrodermal activity (EDA), using exosomatic recording with direct current, respiration (RSP) and a three-lead electrocardiogram for heart rate (ECG), were recorded using the software Acqknowledge 5.0.2 and hardware by Biopac© Bionomadix 2-CH Wireless. Only EDA and ECG are presented here. For skin conductance, one-way adhesive gel electrodes on the middle and fourth finger were used to connect to a PPG-EDA transmitter. For heart rate, one-way adhesive electrodes were connected to an ECG-RSP transmitter. Trigger points signifying relevant events were included in the recording. Afterwards, the data was processed (values for time points and epochs were extracted) by Python scripts. In addition, Kubios 2.2 was used to calculate heart-rate values while allowing for artifact correction.

2.3 Materials

Self-reported emotional state. For the participants' self-report on the emotions they experienced, two 5-point smiley scales on the experienced emotion intensity were created to appear as rows of three-dimensional objects inside the virtual environment one after the other, one of positive and one of negative valence. They appeared at critical points during the experiment (see below in section 2.4 for the timeline in Figure 3) and could be answered by grabbing the respective smiley with the VR controller (see Figure 1). The popping up of the scales was accompanied by an audio message asking participants to give feedback on how they were feeling at that moment ("Bitte gib an, wie (negativ/positiv) du dich gerade fühlst. [Please state how (negatively/positively) you are feeling right now.]") and there was no time limit for the response. The choice to separate positive and negative valence was in line with other tasks conducted during a larger overarching study, since the goal was to use the same scales throughout.

Fig. 1. Self-report on emotional state with two 5-point smiley scales

Physiological measurements. Skin conductance (from the EDA) and heart rate variability (from the ECG) were chosen as established physiological measurements for arousal and distress and data was collected for critical epochs throughout the experiment. (See section 2.2 for more details)

Post-experiment self-report measures. In a VR questionnaire (VRQ) administered post-experiment, participants were asked about demographic information (age, gender, study course, and year), whether they had already experienced immersive VR, and three open questions about their experience of the VR experiment. The three items focused on how they found the VR experience in general ("Wie fanden Sie das VR-Erlebnis insgesamt? [How did you like the VR experience in general?]"), whether they noticed anything about the experiment ("Ist Ihnen irgendetwas an dem Experiment aufgefallen? [Did you notice anything about the experiment?]") and whether they would change anything about the experiment ("Würden Sie irgendetwas am Experiment ändern? [Would you change something about the experiment?]").

2.4 Procedure

Participants were seated in a revolving chair in the middle of the room. Although clear instruction was provided in the information sheet, the four points of physiological measurements (PPG, EDA, ECG, RSP) were explained again. Participants were asked to lay their non-dominant hand down on the armrest of the chair, palm-side up, for the remainder of the experiment, and PPG and EDA were attached. The rest position of the hand was chosen to reduce motion-induced artifacts during the acquisition. Once they were attached, they were checked for functioning. The HMD was placed on the participant's head and adjusted to their liking, as they watched a SteamVR starting room to identify the correct position for the sharpest vision possible. Participants were advised that VR might make them feel dizzy or nauseous and that they could ask to stop the experiment at any time. After they had received a controller for their dominant hand, the experimenter started the experiment.

The experiment took place in an immersive school environment consisting of a school building with several classrooms, the schoolgrounds (including a pond), a hot-air balloon and a backdrop of woods, houses and a mountain range in the distance. First, a virtual tutorial about how to use the controller to grab objects and teleport a couple of meters was conducted by a robot called Marvin. See Figure 2 for an example of controller usage. Once the participant had demonstrated that they understood Marvin's instructions, they were invited to relax for three minutes while looking at a map of the earth on an easel. This relaxation time was used to create a baseline for the psychological measurements.

Fig. 2. Screenshot depicting in-game interaction with the handheld controller

The experiment presented here was part of a larger study that included two experimental paradigms in different parts of the school. Only the social ER paradigm based on the Cyberball paradigm will be featured here. This paradigm was always played on the schoolgrounds and was the last to feature in the sequence of paradigms of the larger study.

After certain tasks were accomplished during the experiment, floating stars appeared that participants were asked to collect. At the end of the experiment, the collected stars were included in a reward sequence, as the participant went on a hot-air balloon ride with the stars dancing around it. Following this, participants could remove the HMD and physiological electrodes and, after a brief rest, were asked to fill in the VRQ. For an overview of the sequence of events, see Figure 3.

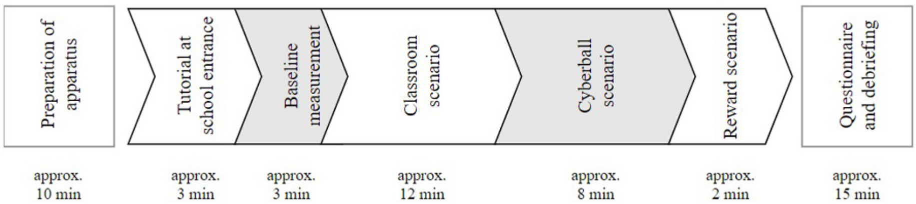

Fig. 3. Overview of sequence of events

Note: For the purpose of this paper, we focus on the social ER Cyberball scenario only.

Social Emotion Regulation Cyberball scenario. At the end of the previous paradigm in the larger study (not reported here), the students (including the participant and a number of virtual agents), were sent to the school grounds to play ball and a slingshot-like racket appeared on their controller. Pete, a classmate who accompanied the participant throughout the different scenarios and had been the friendly next-seat neighbor in the previous scenario in the classroom, explained to the participant how the game worked: there were three circles or play areas on the ground in which always three people could play. If a play area was ready to be joined, it started glowing blue. For the first condition, participants could participate immediately by walking into the area (Play area 1 in Figure 4). For the second and third condition, the participant needed to wait until one of the three players left.

While participants would receive and hold the ball automatically with their slingshot (see Figure 2), whenever they were targets of a ball toss, they would need to aim and throw it using their controller and a button below their index finger. No matter how far off their aim, the ball would always be caught by another player.

Three conditions were presented. In the first condition, the *inclusion* condition, participants received and threw the ball twice at the start and then each player got an equal share of the ball as it was passed between the three players. This was followed by two *exclusion* conditions, during which participants received and threw the ball twice, and then did not receive it anymore at all (with one or two ball tosses a commonly found number in Cyberball experiments, [41], [63], [64]). At the end of the second of the exclusion conditions, i.e., the last of the three conditions, a social support situation was included (see Figure 4). The order of the conditions stayed the same for each participant. It is not clear what effect this might have: a second exposure to exclusion could very well increase the level of negative emotions but could also decrease it due to habituation. Nonetheless it was necessary for experimental reasons to keep the order the same, since a different one may have enabled participants to draw from previous support, our operationalization (the agent's offer of a reframing of the situation) being especially sensitive to this.

Every ongoing game was accompanied by sound effects of children uttering simple phrases like "Ich hab ihn! [I got it!]" and "Ha!" As a pupil left a game, they would verbally explain that they were stopping. None of the students was responsive to attempts at interaction by the participant. While it had been explained to the participants before the beginning of the experiment that they would be able to use the microphone incorporated into the HMD throughout the experience if they wished to, it was not specifically asked during the paradigm. The participants were free to move around the virtual environment, not affecting the way the others played and always automatically receiving the ball whenever they were the recipient of a ball toss. The interaction was thus restricted to the passing of the ball. Every time the participants passed the ball, a celebratory sound effect was played.

Subjects took part in each condition for 60 seconds of playtime plus unlimited time for self-reports. After 50 seconds (t1 in Figure 4), the positive and negative smiley scales appeared one after the other (see Figure 1) and disappeared again when a response was registered. After this, the game continued for another 10 seconds before the two students would leave the game and run away (t2 in Figure 4). Participants then had a waiting or "recovery" period of 15 s (t3 in Figure 4). In the inclusion and first exclusion condition (i.e., without social support), nothing happened during this period although the participants could move freely on the school grounds, perhaps towards the area of the next condition. For the last condition (the second exclusion condition, this time with support), classmate Pete returned to offer support to the participants by saying that they did not need to feel bad since the students excluding them were known to never play with anyone else and it was not personal, thus offering a new appraisal of the situation.

In the inclusion condition, participants were asked for self-reports only once (during the game). In the exclusion conditions, another round of positive and negative smiley scales popped up after the recovery period. The self-report after the inclusion condition was omitted, in order to minimize the time and effort required to complete the task.

At the end of the paradigm, the participants received a star as a reward and were asked by the robot, Marvin, to come to the hot-air balloon on the schoolgrounds, where the reward sequence would start, as the students and teacher would applaud their efforts and they were offered a balloon ride together with fellow pupil Pete. As they were lifted into the air and the collected stars started dancing around the balloon basket, the experiment would end.

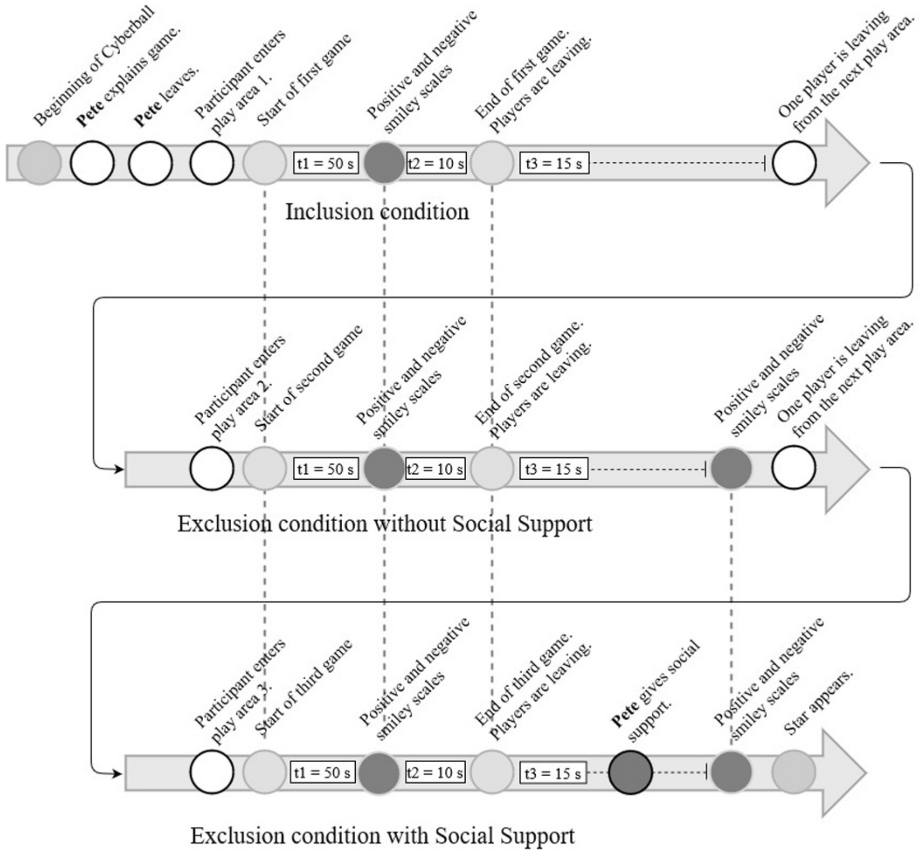

Fig. 4. Three conditions during the Social ER Cyberball scenario

Notes: Sequence of events happening with self-report measuring time points (in dark grey) and provided social support (on the bottom right). This is an altered version of a figure in the paper on the whole experiment [59].

2.5 Data preparation

Self-reports via answers to the smiley scales of positive and negative valences were coded as values from 0 to 4 and 0 to –4 respectively and analyzed separately. One single case was excluded from analysis of the self-reports as an extreme outlier, while one participant could not be included in the analysis on social support as they had not been able to hear the agent's voice.

In addition to the participants' self-reports at time points during the games and after, we computed skin conductance level and response (tonic and phasic components of the EDA) and heart rate for two time spans: from the start of the game to 50 seconds in and for the recovery period of 15 seconds after the game (t1 and t3 in Figure 4). To account for the time it took the agent giving support to arrive during the recovery period of the last exclusion condition, only the last 12 seconds of each recovery period were used. Between three and eight of the 29 participants were excluded from these analyses, since either the recording of physiological data had failed or because single cases were excluded as extreme outliers.

Individual skin conductance level (SCL) minimum and mean values were range-corrected via the formula provided by Lykken et al. [65]:

$$\varphi_\rho = (\rho_{ix} - \rho_{i(min)}) / (\rho_{i(max)} - \rho_{i(min)})$$

where ρ_{ix} is the raw value and $\rho_{i(max)}$ and $\rho_{i(min)}$ are the maximum and minimum overall value of the respective participant. Skin conductance response (SCR) was derived from the EDA signal using high-pass filtering [66]. It was recorded as mean and maximum values, as the peak count (non-specific SCR) and the cumulative peak amplitudes.

Heart rate was both collected as mean values and used to compute the root mean square of differences (RMSSD) between interbeat intervals as a measure of heart rate variability that can be used with ultra-short time spans [67], which in our case was the 50 seconds of game play (t1).

3 Results

All participants stated in the VRQ that they enjoyed the VR experience in general, and there were no apparent differences between participants who had already experienced VR and those who had not. No participants dropped out during the experiment. Results are reported for all 29 participants including the three men, since subsequent analyses with only the 26 women did not reveal any significant differences in the results.

3.1 Ostracism – emotions during the games (t1)

We expected participants to react negatively to the exclusion from the ball games.

A repeated-measures ANOVA on the negative self-reports during the three game conditions showed a significant effect of condition, $F(1.30, 35.16) = 46.98$, $p < .001$, $\eta^2 = .64$. One case was excluded from the analysis because of an extreme outlier value in the inclusion condition. Greenhouse-Geisser-corrected values are reported. As can be seen in Figure 5, participants reported the least negative emotion during the first game, when they were being included, and the most negative emotion after being excluded twice, during the third game. Effects were paralleled by the repeated-measures ANOVA on the positive self-reports, with again a significant effect of condition, $F(1.34, 37.38) = 52.52$, $p <. 001$, $\eta^2 = .65$. Detailed results, including means and standard deviations, are displayed in Table 1.

Paired-sample t-tests also showed significant differences between inclusion and first exclusion ($t(27) = 7.00$; $p < .001$), between inclusion and second exclusion ($t(27) = 7.29$, $p < .001$), and between first and second exclusion, $t(28) = 3.09$, $p = .005$.

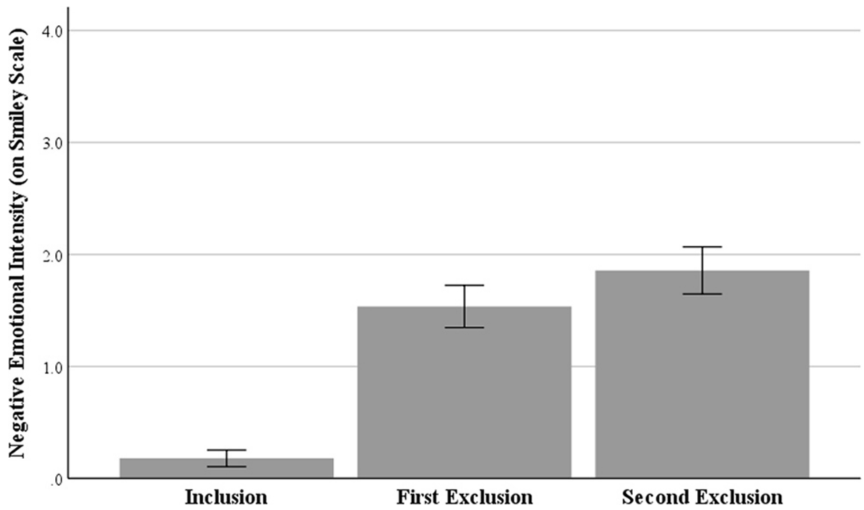

Fig. 5. Negative emotions within the three Cyberball conditions (after t1)

Note: Error bars: ± 1 SE

Table 1. Summary of results on ostracism

	Inclusion Condition		**1st Exclusion Condition**		**2nd Exclusion Condition**		**Main Effect of the Repeated-Measures ANOVA with the Factor Condition**			
	M	***SD***	***M***	***SD***	***M***	***SD***	***df***	***F***	***Sign.***	***η2***
Self-report: Negative emotion intensity smiley scale (0 to 4)	0.18	0.39	1.53	1.00	1.86	1.11	1.30, 35.16	46.98	***	.64
Self-report: Positive emotion intensity smiley scale (0 to 4)	2.83	0.97	1.00	0.96	0.69	0.97	1.33, 37.38	52.52	***	.65
Skin conductance level: Mean (of voltage, range-corrected)	0.67	0.22	0.54	0.21	0.41	0.25	1.55, 38.64	16.07	***	.39
Skin conductance level: Minimum (of voltage, range-corrected)	0.53	0.20	0.45	0.19	0.33	0.22	1.57, 39.24	13.13	***	.34
Skin conductance response: Mean (of voltage, in µS)	0.0016	0.0092	0.0018	0.0037	0.0003	0.0032	1.39, 29.10	0.36	ns	.02
Skin conductance response: Maximum (of voltage, in µS)	0.48	0.40	0.34	0.39	0.39	0.51	2, 48	1.84	ns	.17
Skin conductance response: Number of peaks	7.85	2.11	8.15	2.51	8.58	2.70	2, 50	0.79	ns	.03
Skin conductance response: Sum of amplitudes of peaks	1.72	1.58	0.90	1.04	1.17	1.57	1.56, 34.35	3.16	ns	.13
Heart rate: Mean (Beats Per Minute)	76.95	12.42	75.87	12.25	76.67	12.61	2, 44	2.09	ns	.09
Heart rate variability: RMSSD (Root Mean Square of Successive Differences, in ms)	46.67	29.40	38.24	16.72	33.27	18.30	2, 42	4.46	*	.18

Notes: Significance levels are coded: * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$.
Degrees of freedom are Greenhouse-Geisser-corrected, if sphericity could not be assumed.

A repeated-measures ANOVA on the mean SCL values of the time spans during the games (t1) revealed a significant decrease of skin conductance level over the three conditions ($F(1.55, 38.64) = 16.07$, $p < .001$; $\eta^2 = .39$; see Table 1 for reference), with it being highest in the inclusion condition and lowest in the second exclusion condition. The same procedure on the minimum values showed a parallel effect, $F(1.57, 39.24) = 13.13$, $p < .001$; $\eta^2 = .34$. Paired-sample t-tests on the mean values showed significant differences for all three pairs – between the inclusion and the first exclusion condition ($t(25) = 2.70$; $p = .012$), the inclusion and the second exclusion condition ($t(25) = 4.68$; $p < .001$), and the first and second exclusion condition, $t(25) = 4.08$, $p < .001$. Paired-sample t-tests on the minimum values again paralleled these results with the pair of inclusion and first exclusion condition being an exception ($t(25) = 2.17$; $p = .040$), since the significance level was lowered to .017 with a Bonferroni correction.

Repeated-measures ANOVAs with the factor condition on both the SCR maximum and mean of the time spans during the games revealed no significant effect. Repeated-measures ANOVAs on the number of SCR peaks during said time spans also showed no significant effect, nor did a repeated-measures ANOVA on the sum of amplitudes of peaks.

A repeated-measures ANOVA with the factor condition on the mean heart rate during the three games showed no significant effect. A repeated-measures ANOVA on the RMSSD did, however, reveal a significant effect, $F(2,42) = 4.46$, $p = .018$, $\eta^2 = .18$. The RMSSD was highest in the inclusion condition, compare Figure 6.

Paired t-tests on the differences between the game conditions revealed no significant difference between inclusion and first exclusion ($t(22) = 1.38$; $p = .18$) and first exclusion and second exclusion ($t(23) = 1.60$; $p = .123$), but there was a significant difference between inclusion and second exclusion, $t(21) = 2.68$; $p = .014$.

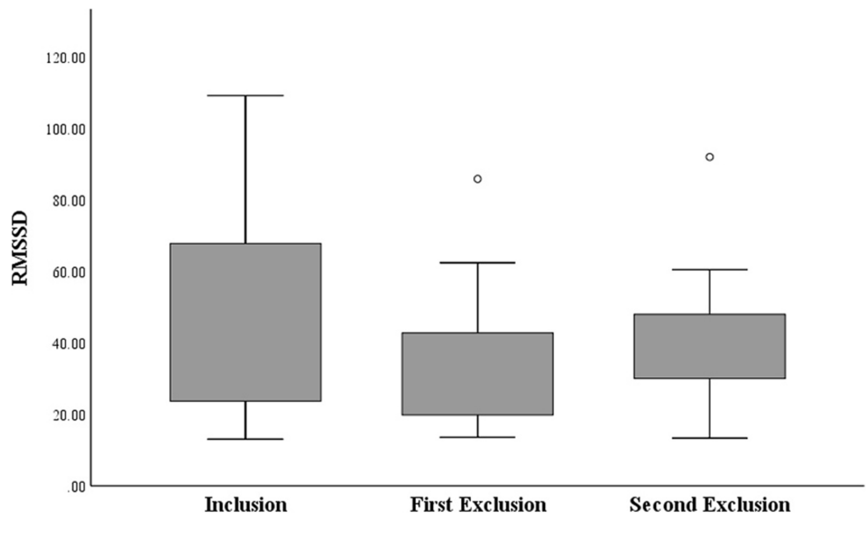

Fig. 6. Heart rate variability during the three conditions of the social ER Cyberball game

3.2 Effect of social support provided by the virtual agent (t1 – t3)

We expected participants to benefit from the social support provided by a virtual agent.

Looking at self-reports during and after the two exclusion conditions only, a 2×2 repeated-measures ANOVA with factors support condition (first exclusion without social support and second exclusion with social support) and timing (during game and after recovery phase) on the negative self-report scales revealed no main effect of support condition, but a main effect of timing ($F(1,27) = 8.59$; $p = .007$; $\eta_p^2 = 0.24$), with participants reporting less negative emotion after the recovery phase than during the game (see Figure 7). There was a significant interaction ($F(1,27) = 10.23$; $p = .004$; $\eta_p^2 = 0.28$) indicating a larger reduction in negative valence in the condition with social support than in the condition without (see Table 2 for an on overview). A repeated-measures ANOVA on the positive scales showed a similar pattern, with a main effect of timing ($F(1,27) = 19.02$; $p < .001$; $\eta_p^2 = 0.41$) and an interaction ($F(1,27) = 20.25$; $p < .001$; $\eta_p^2 = 0.43$), but with the addition of a main effect of support condition, $F(1,27) = 7.73$, $p = .010$; $\eta_p^2 = 0.22$.

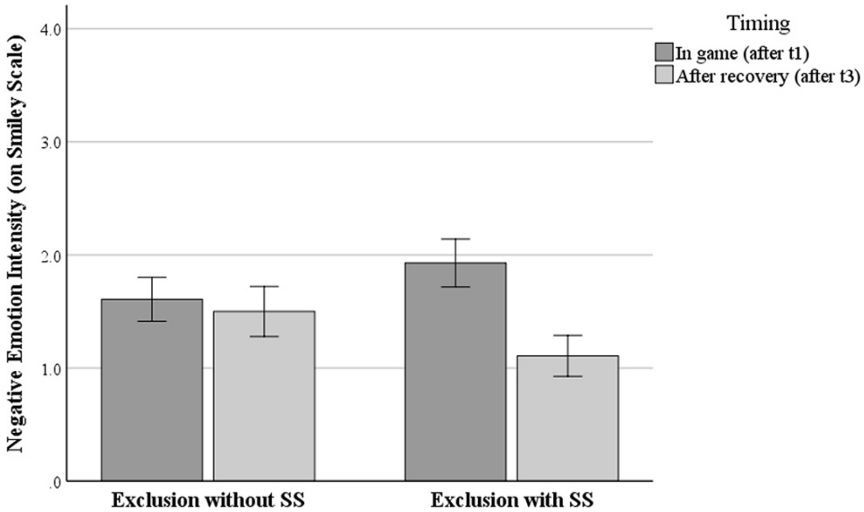

Fig. 7. Negative emotions in the two exclusion conditions with and without support

Note: Error bars: ± 1 SE.

Paired-sample t-tests confirmed that the time points differed significantly in the condition with social support ($t(27) = –3.87$, $p = .001$) but not in the condition without, $t(27) = –0.62$, $p = .54$. The difference between the two after-recovery reports was not significant, at a Bonferroni-corrected significance level of .017, $t(27) = –2.17$, $p = .039$.

Looking at the recovery periods (t3) after both exclusion conditions, one with and one without social support, paired-sample t-tests on SCL showed no significant difference for the minimum values ($t(24) = 1.45$, $p = .16$) and again none for the mean values, $t(24) = 1.53$, $p = .14$. There was also no significant difference for the two SCR maximum values ($t(24) = 0.28$, $p = .98$), nor for the mean, $t(24) = 1.11$, $p = .28$.

Table 2. Summary of results on social support

	1st Exclusion Condition without Support				**2nd Exclusion Condition with Support**				**Main Effects and Interaction of the 2 × 2 Repeated-Measures ANOVA with the Factors Support Condition and Timing**			
	In Game (After t1)		***After Recovery (After t3)***		***In Game (After t1)***		***After Recovery (After t3)***		***df = 1, 27***			
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***Effect***	***F***	***Sign.***	η_p^2
Self-report: Negative smiley scale (0 to 4)	1.61	1.03	1.50	1.17	1.93	1.12	1.11	0.96	Support	0.14	ns	0.01
									Timing	8.59	**	0.24
									Interaction	10.23	**	0.28
	1.04	0.96	1.04	0.92	0.71	0.98	2.00	1.05	Support	7.73	**	0.22
									Timing	19.02	***	0.41
									Interaction	20.25	***	0.43

Notes: Significance levels are coded: * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$; ns = $p > .05$.

4 Discussion

A novel paradigm was designed to assess the efficacy of social ER in immersive VR by first demonstrating that the effects of a classic ostracism paradigm could successfully be reproduced, and then by providing social support through a virtual agent. As expected, self-reports indicated that the exclusion in the ball games had a negative impact on the participants' emotions, while the physiological results were less conclusive. This suggests that the Cyberball paradigm successfully translates to immersive VR environments. In terms of whether the social support helped, self-reports indicated that support by a virtual agent can have a positive impact on one's emotional state. These findings suggest that social ER can be successfully studied using our VR paradigm.

These results provide a number of options for future research and interventions. The demonstration that a virtual agent is sufficiently relevant for the participants to accept its role as a social regulator of the situation and implement its support into their own ER attempts, even though the agent is clearly computer generated, is an important step towards the wider application of this VR paradigm in interventions and training programs. There have already been a few attempts to use VR as a medium for the assessment and enhancement of social cognition [17], [20], but our study suggests this approach could be developed even further. Individuals who experience difficulty regulating their own emotions and who have the potential to benefit from social ER in their everyday life might learn to seek social support and integrate it *in virtuo* before applying related strategies and techniques in the outside world. This could enrich therapies and inspire serious games aimed at improving social ER. As a first step, these results motivate the use of the current paradigm for assessments regarding the efficacy of social ER in different populations (e.g., typically developing individuals and those with neurodevelopmental disorders who tend to have difficulties self-regulating their emotions [68]) and particularly children and adolescents, with those being potentially even more sensitive to a school environment.

In the current study, we focused on only one type of social support: providing a reframing of the situation to help the participant cognitively reappraise the situation. However, social ER also includes other ER strategies which are linked to selecting and modifying a situation, attentional deployment or response modulation, targeting not only the valuation of the situation by the regulatee (as done with an invitation to reappraise), but also the perception of said situation or the impulse to react in a particular way [69]. An avenue for future studies could be to investigate in more detail the effect of social support. A comparison with other potentially helpful instances, like the virtual agent joining the participant without talking (and just as a positive presence, also called social buffering [40], [70]), or talking about something else (as a distraction, [69], [71]), rather than providing a reframing to allow a reappraisal of the situation, would help ascertain which aspects of the support provided by the virtual agent are the most effective. This would help identify the most efficacious strategies to be adapted for potential intervention programs.

Another important point in social ER is the appropriateness of the regulator's offer in general and in the eyes of the regulatee. The latter will interpret the regulator's intentions and react accordingly, making the efficacy of the offered strategy only as good as their relationship with and opinion of the regulator and their goals [27]. Since in our experiment the social ER was offered regardless of the regulatee's individual emotions, there is a lot of potential in developing a more interactive version of the situation: for example, the agent's input could vary depending on the participant's self-reported emotions. This would be an important point for the development of interventions tailored to the individual's needs.

Other questions remain to be addressed in future studies. The difference in self-reports between the two exclusion conditions is not worrying in itself, since two distinct instances of exclusion one after the other could very well induce an even higher level of distress, or even a lower one, if the participant habituated to the paradigm. However, the fixed order, while making sense for our setup, also translates to possible other order effects, apparent, perhaps, in the skin conductance results. While the latter definitely do not seem to support those studies suggesting that ostracism in Cyberball results in higher skin conductance levels and response, the uncertainty about psychophysiological reactions to exclusion remains. This could be a general problem of the reliability of physiological measurements in this context. However, some research suggests a difference between low-stake and high-stake exclusion [72], whereby the former would result in emotional pain and the latter would result in a flattened affect, but a more likely explanation might be the difference in the immediacy of the threat, with quick reactions involving heightened sensitivity and slow reactions involving numbing [73], [74]. This could explain the lower skin conductance levels in the exclusion conditions. An important additional aspect to consider is the difference in movement between the conditions that results from the nature of the VR experience (with the controller and in extension one's arm and body being used to catch and throw balls) while this is not the case in traditional Cyberball tasks. Taking into account these points in the future, while randomizing the order of conditions, could give more insight into the sources of the effect. After all, skin conductance might not be a reliable measure for this immersive VR Cyberball scenario. Instead, future versions of the task could employ other markers to examine the psychophysiological impact of social support: For example, leaving longer periods of measurement after each game would make it possible to analyze heart rate variability. While not possible with the current task design, another option could be to equate the physical activity in each condition. An additional goal for future studies is to include a large-enough sample of male participants in order to explore possible gender effects.

In conclusion, the results of this newly created VR paradigm are promising and invite further research and development using this paradigm. The Cyberball paradigm was successfully adapted for immersive VR and able to elicit differentiated emotional responses, while social support by a virtual agent was effective, allowing a more thorough study of social ER in VR. Future studies could aim to assess the efficacy of social ER in individuals with difficulties in self-regulation. Should they be able to benefit from social ER in VR, this would pave the way to developing interventions and training programs in immersive VR.

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