Experiencing herd immunity in virtual reality increases COVID-19 vaccination intention: Evidence from a large-scale field intervention study

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ABSTRACT

This study investigates the impact of an immersive virtual reality (VR) simulation of herd immunity on vaccination intentions and its potential underlying mechanisms. In this preregistered field study, $N = 654$ participants were randomly assigned to one of the three VR conditions: (1) Gamified Herd Immunity; (2) Gamified Herd Immunity + Empathy (with additional narrative elements); (3) Control (gamified with no vaccination-related content). In the Gamified Herd Immunity simulation, participants embodied a vulnerable person and navigated a wedding venue trying to avoid getting infected. A total of 455 participants with below maximum intentions to take a novel vaccine and without severe cybersickness were analyzed. The Gamified Herd Immunity + Empathy and the Gamified Herd Immunity conditions increased vaccination intentions by 6.68 and 7.06 points on a 0–100 scale, respectively, compared to 1.91 for the Control condition. The Gamified Herd Immunity + Empathy condition enhanced empathy significantly more than the Gamified Herd Immunity condition but did not result in higher vaccination intentions. Experienced presence was related to the change in vaccination intentions. The results suggest that VR vaccination communication can effectively increase vaccination intentions; the effect is not solely due to the technological novelty and does not depend on empathy.

1. Introduction

The COVID-19 global pandemic declared in March 2020 is still a threat to public health, and increasing vaccine uptake is crucial to decrease hospitalization and death (Bozio et al., 2021; Haas et al., 2021). Yet, vaccine hesitancy poses a major obstacle to decreasing the number and severity of infections (Edwards et al., 2021; Luo et al., 2022; Neumann-Böhme et al., 2020). Moreover, the current situation indicates that additional booster shots are necessary for long-lasting protection

and immunity against new strains, for example, the Omicron variant and its various sublineages (Dolgin, 2021). As the standard approach to communicating the collective public health benefit of vaccination (Böhm & Betsch, 2022), such as reduced infection risks to vulnerable persons, might fail to reach desired effects (Freeman et al., 2021), developing and testing novel and effective ways to communicate the significance of vaccination is important, now and in the future.

There is emerging evidence that immersive Virtual Reality (VR) may be a promising tool in vaccination communication as it enables an

interactive and embodied experience of the vaccination's social benefit and, therefore, increases users' vaccination intention (Mottelson et al., 2021; Nowak et al., 2020; Vandeweerdt et al., 2022). However, previous research is silent about the psychological mechanisms underlying increased vaccination intentions after an interactive VR experience. Several mechanisms are possible. First, VR could have positive effects solely due to users' enjoyment of and excitement about the novel technology experience, potentially leading participants to more favorable or socially desirable ratings even in an unrelated domain (i.e., vaccination intention; Koch et al., 2018; Tsay et al., 2018). Second, positive effects could be due to the factual learning experience provided by the intervention's content (i.e., the value of vaccination for oneself and others; Betsch et al., 2017). Lastly, it could also be that the intervention's effectiveness is not primarily due to the learning content but rather due to the emotional responses elicited by the intervention's narrative (i.e., empathy toward vulnerable persons who may benefit from high vaccine uptake; Pfattheicher et al., 2021).

In the present research, we aimed to disentangle these potential mechanisms underlying the positive effect of communicating the social benefit of vaccination using VR on users' vaccination intention. To shed further light on why and when VR may be an effective tool in vaccination communication, we conducted a large-scale field intervention study where participants navigated social life from the perspective of a vulnerable person. By applying a VR control condition without any vaccine-related content but an otherwise similar user experience, we studied the potential novelty effect of the VR experience with the technology on vaccination intention. Additionally, we investigated whether adding an emotional narrative to the VR simulation would increase empathy and enhance the intervention's effectiveness. To address the importance of using immersive VR, we investigated the impact of psychological factors linked to a more immersive environment: presence and embodiment. Importantly, following the call for more methodologically sound VR studies with larger sample sizes (Lanier et al., 2019), we present a preregistered VR study that is, to the best of our knowledge, the largest VR intervention study ever conducted, yielding sufficient power to precisely estimate the effects on participants' vaccination intention. Before describing the present research in more detail, we provide reviews of the relevant literature on (i) communicating the benefit of vaccination, (ii) VR in health communication, and (iii) previous work on using VR in vaccination communication, (iv) to eventually derive our hypotheses.

1.1. Communication of the social benefit of vaccination

Vaccination does not only provide a personal benefit to the vaccinating person but also a social benefit due to three partly related effects: vaccination (i) increases herd immunity, (ii) protects vulnerable others from infection, and (iii) allows reducing the burden of behavioral restrictions in case of a pandemic (Betsch et al., 2013; Böhm & Betsch, 2022; Fine et al., 2011). For instance, in the case of COVID-19, it has been shown that vaccinated individuals are less likely to get infected (Lopez Bernal et al., 2021) and, therefore, also less likely to infect others; and even when getting infected, vaccinated individuals are less likely to transmit the disease than unvaccinated ones (Eyre et al., 2022). While the degree to which transmission is reduced varies between vaccination schemes, vaccines, and circulating variants of SARS-CoV-2, it can still be assumed that higher vaccine uptake in society has protective effects on the vulnerable (Shoukat et al., 2022). Thus, assuming that people care about others' welfare (Betsch et al., 2013; Böhm & Betsch, 2022), communicating the social benefit of vaccination could increase their vaccination intention. Indeed, communicating the social benefit of vaccination by educating individuals about herd immunity has been shown to positively impact the intention to get vaccinated, both for fictitious and real diseases, including COVID-19 (Betsch et al., 2017; Hakim et al., 2019; Pfattheicher et al., 2021). Moreover, it has been shown that informing people that particularly vulnerable others will

benefit from herd immunity (Böhm et al., 2019) and increasing empathy for such individuals (Pfattheicher et al., 2021) further promote vaccination intentions. However, it has also been shown that the method of communication matters. Specifically, interactive simulations can provide a better understanding of herd immunity compared to standard textual explanations, leading to a higher increase in vaccination intention (Betsch et al., 2017). In summary, the more people engage with the educational content related to the social benefit of vaccination, the more likely they will increase prosocial intentions to get vaccinated, either because they better understand what herd immunity actually means and how it works or because they feel more attachment to the beneficiaries of herd immunity.

1.2. Virtual reality and health communication

Immersive VR has been previously identified as a suitable tool for promoting healthy behavior (Riva et al., 2016). Immersion is defined as the objective quality of the media with a superior quality resulting in higher fidelity and the ability to shut out the outside world (Slater et al., 2009); thus, simulations accessed through a head-mounted display (HMD) offer higher immersion than simulations presented on a desktop monitor. Immersion facilitates the sense of *presence* (Cummings & Bailenson, 2015), defined as the psychological feeling of "being there" in the virtual environment (Lee, 2004).

Protection Motivation Theory (PMT; Rogers, 1975), has been proposed as especially suitable to explain how immersive VR can facilitate health-related behavior change (Plechatá et al., 2022). According to PMT, successful health communication should aim to increase threat appraisal together with coping appraisal. *Threat appraisal* constitutes threat severity, i.e., how severe the threat is to one's health, and vulnerability, i.e., how susceptible one is to this threat (Rogers, 1975). *Coping appraisal* consists of self-efficacy, one's belief in his/her ability to perform coping behavior, and response efficacy, one's belief that the coping behavior will effectively reduce the threat (Bandura, 1977). In the following paragraphs, we outline how higher immersion in virtual environments can facilitate threat appraisal via presence and how embodied perspective-taking can elicit empathy and threat appraisal for others.

The level of presence—and thus, perceived realism of the experience—can improve the persuasiveness of simulation and increase threat appraisal by making the consequences of unhealthy behavior more imminent (Plechatá et al., 2022). This has been supported by previous research showing that higher presence can intensify risk perception related to a threat and increase intentions to engage in healthy behavior (Ahn et al., 2019; Choi & Noh, 2020; Fox et al., 2020). Immersive technology has been successfully applied in health communication before. For example, it has been shown that watching an avatar gain weight in VR because of unhealthy eating or drinking habits can promote healthier eating habits by increasing risk perception (Ahn, 2015; Fox & Bailenson, 2009; Fox et al., 2009). In terms of smoking-related risks, projecting smoking lungs on a user's body using augmented reality has resulted in more negative emotions toward smoking (Jung et al., 2019).

Besides the feeling of being present in the virtual environment, immersive VR allows users to experience the world from someone else's perspective. The effect of embodiment, i.e., the feelings connected to having, being in, and controlling a virtual body (Kilteni et al., 2012), can be used to create intense experiences of a scenario from another person's perspective (Herrera et al., 2018). The embodiment allows for a first-person vivid perspective taking which might be more effective in eliciting empathy (the ability to understand another person's feelings and mental states) compared to standard imaginative approaches. A recent meta-analysis confirmed that VR is suitable for fostering affective empathy (Martingano et al., 2021); for example, witnessing social suffering in VR enhanced feelings of compassion (Cohen et al., 2021), and becoming homeless in VR can result in long-lasting positive

attitudes towards homeless people (Herrera et al., 2018). In the domain of health communication, embodying someone vulnerable to disease can help elicit empathy toward vulnerable people while also increasing threat appraisal for them (Plechatá et al., 2022).

Furthermore, in terms of learning, embodiment plays a crucial part in Embodied Cognition which emphasizes the role of the human body in cognitive processing and suggests that our sensorimotor system and our interactions with the environment influence our representation of the world (Wilson, 2002). Higher embodiment is associated with high degrees of increased knowledge and skill (Beilock et al., 2008). Research in immersive VR confirms that perceived embodiment (together with presence) leads to higher engagement in a story (Shin, 2018) and higher learning gains (Petersen et al., 2022; Slater, 2017). Furthermore, by providing embodied interactive direct experience immersive VR is suitable to facilitate experiential learning (Kwon, 2019; Plechatá et al., 2022).

Based on the theory and experimental findings summarized above, affordances of presence and embodiment might play a crucial role in the effectiveness of immersive VR in health communication.

1.3. Virtual reality and vaccination communication

Only recently has research started to exploit the features of VR in vaccination communication. Besides research investigating the potential of immersive VR to distract children from pain and reduce anxiety from the vaccination procedure (Althumairi et al., 2021; Arane et al., 2017), we are only aware of three studies that made use of VR in the communication of vaccine-relevant information—including the individual and social benefit of vaccination—to help people making an informed vaccination decision (Mottelson et al., 2021; Nowak et al., 2020; Vandeweerdt et al., 2022).

Nowak et al. (2020) investigated the effect of three different modalities of communicating vaccine benefits: e-pamphlet, video, and VR on influenza vaccination intake intentions. However, none of the interventions led to a significant increase in vaccination intentions compared to the control condition, similarly to other VR studies (Lanier et al., 2019), the study was underpowered to detect more subtle effects ($n = 48$ in the VR condition) which are usually reported in the studies investigating vaccination communication (Freeman et al., 2021), indicating the necessity for more large-scale testing.

A more recent study conducted as an online experiment (Mottelson et al., 2021) investigated whether a VR intervention can increase COVID-19 vaccination intentions in a sample of VR headset owners. The participants embodied a young vs. old virtual body and received information from a general practitioner (GP) about the vaccination's personal benefits vs. personal and social benefits. Across all conditions, the VR intervention significantly increased vaccination intentions immediately after the experiment, and the pre-post difference in intention correlated positively with the vaccination intention measured one week after the intervention, indicating at least some duration of the intervention effect. This study shows that a VR intervention administered in the field can influence vaccination intentions. Nevertheless, the missing control group did not allow to separate this effect from experimental demand characteristics. Furthermore, the applied VR intervention did not completely capitalize on the VR affordances to experience things that are not possible in the real world, e.g. visualizing the disease spread.

The third study, conducted by Vandeweerdt and colleagues (2021), tested a gamified VR intervention in which participants navigated through a public square in low and high-vaccination scenarios and tried not to get infected—or not infect others. The objective was to communicate the social benefit of herd immunity in the context of COVID-19 vaccination and compare it to the effectiveness of brief textual information with images. The results showed that the VR intervention increased the willingness to get vaccinated almost three times more than the standard textual information. Nevertheless, the psychological mechanisms behind the intervention's effectiveness remain unclear.

According to Makransky and Petersen (2021), immersive VR can increase participants' interest and enjoyment which can consequently increase the learning outcome. Indeed a recent study (Vandeweerdt et al., 2022) confirmed that participants had more fun during VR intervention compared to text-and-image intervention. Another mechanism can be the increased feeling of being present in the virtual environment, which was linked to higher threat appraisal for oneself (Fox et al., 2009; Nowak et al., 2020) but also for others (Nowak et al., 2020). Another mechanism that can be crucial, especially in health-related behavior involving negative externalities for others, e.g., vaccination behavior, is feelings of empathy towards vulnerable others (Pfattheicher et al., 2021), which can be supported by higher levels of presence and embodiment (Plechatá et al., 2022; Ventura et al., 2020). Finally, it has been proposed that the novelty of VR technology (Koch et al., 2018) is partially responsible for the engagement and motivational aspects of immersive technology and therefore for its reported effectiveness for learning (Tsay et al., 2018).

Therefore, in this study, we experimentally investigated (i) whether the VR's ability to elicit empathy is the key mechanism behind its effectiveness to promote vaccination behavior, and (ii) whether the impact of vaccination communication in VR is greater than the effect of technological novelty alone.

1.4. Aim of the present research and hypotheses

Going beyond previous research by investigating different mechanisms that might be related to the effectiveness of VR interventions in vaccination communication, we aimed to separate the effect of the novelty of the technology on vaccination intention from the impact of the VR simulation's content on vaccine intention. This distinction is important because it has been claimed that the positive effects of VR interventions could be due to the novelty of the technology (Koch et al., 2018) and not due to more fundamental factors of how the VR affordances influence the user and thereby result in positive outcomes (Makransky & Petersen, 2021; Plechata et al., 2022). To this end, our study compared a VR simulation of a wedding scenario with educational content about herd immunity (Gamified Herd Immunity condition) to the same VR wedding experience but without any educational content related to herd immunity (Control condition). Our hypotheses were as follows:

H1. The vaccination intention will increase in the Gamified Herd Immunity condition (pre-versus post-VR intervention difference).

H2. Vaccination intention will increase more in the Gamified Herd Immunity condition than in the Control condition (larger pre-versus post-VR intervention difference).

Empathy is a natural affordance of VR. Yet, despite its relevance in increasing prosocial preventive behavior, including vaccination (Pfattheicher et al., 2020, 2021), previous research using VR in vaccination communication has not attempted to investigate the potential role of empathy. Here, we investigate whether adding an emotional storyline to the VR simulation (Gamified Herd Immunity + Empathy condition) can potentially enhance its impact on vaccination intention. Our hypotheses were as follows:

H3. .Vaccination intention will increase in the Gamified Herd Immunity + Empathy condition (pre-versus post-VR intervention difference).

H4. Vaccination intention will increase more in the Gamified Herd Immunity + Empathy condition than in the Control condition (larger pre-versus post-VR intervention difference).

H5. Vaccination intention will increase more in the Gamified Herd Immunity + Empathy condition than in the Gamified Herd Immunity condition (larger pre-versus post-VR intervention difference).

Furthermore, we also expected that higher levels of vaccination intention would spill over to larger (costly) donations to charities related to COVID-19 and other vaccines as assessed after the VR interventions (see below). Accordingly, we hypothesized:

H6. . Vaccine-related donations will be higher in the Gamified Herd Immunity + Empathy condition than in the Control condition.

H7. Vaccine-related donations will be higher in the Gamified Herd Immunity + Empathy condition than in the Gamified Herd Immunity condition.

H8. Vaccine-related donations will be higher in the Gamified Herd Immunity condition than in the Control condition.

Finally, we explore how presence and embodiment—two fundamental affordances of using VR in health communication (Plechata et al., 2022)—influence the change in vaccination intentions. As previous research (Freeman et al., 2021) has shown that the effect of vaccination communication can be moderated by demographic characteristics, we also explore potential boundary conditions by investigating if our findings vary across participants' gender and age.

2. Method

The design, hypotheses, and analysis plan of this randomized control trial were preregistered on November 9, 2021, prior to data collection, via the Open Science Framework (https://bit.ly/3oImlnX). Unless otherwise noted, all steps below follow the preregistration plan. We provide open access to the data, analysis scripts, and supplementary materials via the Open Science Framework: https://bit.ly/3Bbn3PG. The full study procedure was approved by the Institutional Review Board at the Psychology Department, University of Copenhagen, approval number IP-IRB/02092021.

2.1. Participants and procedure

The participants were recruited from visitors to the Natural History Museum in Berlin (Museum für Naturkunde Berlin). The study was part of the museum's exhibition from November 11 to 28, 2021; participants were recruited via interactive screens and actively approached in person. Participants were compensated for taking part in the experiment with a small gift (a cup worth €4.50) and an additional €5 voucher for the museum's gift shop. Participants were given the option to donate the €5 voucher to charities of their choice in the post-treatment questionnaire.

The overall sample consisted of $N = 654$ participants who completed the experiment, of which $n = 124$ had a maximum vaccination intention, i.e., they indicated that they would definitely get vaccinated against COVID-19 with a novel vaccine (100 on a scale from 0 to 100, see below). Following the preregistration, we excluded those respondents (because there was no need and a possibility to further increase their vaccination intention), as well as participants who experienced high levels of cybersickness (4 and 5 on a scale from 1 to 5, see below), resulting in a final sample of $n = 455$ participants for the analyses. The final sample consisted of $n = 237$ (52%) males, $n = 211$ (46%) females, $n = 6$ (1.3%) and $n = 1$ (0.02%) participants who identified as non-binary or other, respectively. The average age of the participants was 29.42 years ($SD = 10.16$). The majority of the sample were German speakers, $n = 270$ (59%). The COVID-19 vaccination rate was very high, with 96% of participants reporting being fully vaccinated (2 jabs). A total of $n = 236$ (52%) participants had never tried VR before, $n = 181$ (40%) experienced VR 1–3 times, and $n = 38$ (8%) participants had used VR more than three times before. From November 11, the visit to the exhibition was only possible under the so-called 3G regulation. That is, visitors had to prove that they had recovered from COVID-19, had been vaccinated against COVID-19, or had a negative COVID-19 test. It was required to wear a medical mask or FFP2 mask and to maintain a minimum distance of 1.5 m from other people. From November 16, the 2G regulations (vaccinated or recovered) were applied in all museum's public areas. The regulations on wearing masks and keeping a distance remained.

Participants could choose to complete the simulation and questionnaires either in English or German. After filling out an informed consent form and a pre-treatment questionnaire, participants were randomly assigned to one of the three VR conditions: Control ($n = 138$), Gamified Herd Immunity ($n = 155$), and Gamified Herd Immunity + Empathy ($n = 162$). The randomization was embedded in the VR application. After completing the simulation, which lasted around 10–20 min, all participants filled out a post-treatment questionnaire. Participants spent on average 9.6, 10.9, and 14.9 min in the Control, Gamified Herd Immunity, and Gamified Herd Immunity + Empathy simulations, respectively.

2.2. Virtual wedding

The immersive VR application was developed using Unity[2] and was presented using Oculus Quest 2. The 3D avatar models were from the RocketBox library (Gonzalez-Franco et al., 2020).

In the VR application, each participant played an elderly character who could not get vaccinated against COVID-19 due to medical reasons. Both gamified conditions included a key scene where participants attended a wedding, trying to avoid getting infected by other wedding guests (in the Control condition, this scene featured no information about infections and indications of infected guests). The gamified simulation allowed participants to experience herd immunity from a first-person perspective in low and high-vaccination scenarios. Therefore, the participants could understand how easy it is to be exposed to infections when vaccination rates are low. We used voice recordings in either English or German by professional voice actors/actresses for all instructions and interactions with virtual avatars (for the full script, see supplementary materials here https://bit.ly/3Bbn3PG.).

In each of the three conditions, the VR experience began with a bathroom scene where the participant was embodied as an elderly person (of matching gender) and was instructed to wash and dry their hands to enhance the embodiment experience and to understand the game's mechanics (Fig. 1A). The following paragraphs describe the differences between the conditions in the rest of the simulation.

Gamified Herd Immunity + Empathy: The Gamified Herd Immunity + Empathy condition aimed to increase empathy with those vulnerable to COVID-19 by including narrative elements. Participants started with a narrative scene, where they viewed a memory book with narration by the character's granddaughter, and then received a wedding invitation from her (Fig. 1B); the participants went to a general practitioner's (GP's) office, where the GP explained the risks associated with attending the wedding. Next, participants experienced a wedding, where only a few characters were vaccinated. They had to complete a task (signing the guestbook), which required moving around in a large ballroom filled with other guests. An exposure bar was displayed in the top-right corner of the participant's field of view, indicating how much accumulated exposure the participant had to infected avatars. The participant's exposure increased by getting too close to infected characters (Fig. 1D). In the next scene, their GP informed them that they probably got infected at the wedding and that the situation could have been different if more people had been vaccinated. After that, they played a second version of the wedding scene, where many characters were vaccinated; thus, it was easier to avoid exposure to infected characters while completing a new task (delivering a gift; Fig. 1E). A conversation with the bride and a final scene (receiving a postcard from the couple) aimed at creating a narrative and inducing empathy with the main characters: the player's own character and their newlywed granddaughter (Fig. 1F).

Gamified Herd Immunity: In the Gamified Herd Immunity condition, participants experienced the key scene of the VR simulation without the narrative elements (e.g., reading the memory book, receiving the invitation, speaking to the bride at the wedding). After the embodiment scene (Fig. 1A), participants went directly to the GP office (Fig. 1C). They also navigated the wedding venue while seeing the exposure bar, avoiding guests in a high- and low-vaccination world

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[2] https://unity.com.

Fig. 1. Screens from the Virtual Wedding simulation. The simulation started with an embodiment bathroom scene (A). In the Gamified Immunity + Empathy condition, participants experienced additional narrative elements, e.g., receiving an invitation (B) or conversing with the granddaughter (F). Except for the Control condition, all participants visited a doctor (C) and tried not to get infected during the wedding scene (D). The participants were instructed to actively move around the wedding scene using gamified elements, e.g., delivering a gift (E).

(Fig. 1D) while fulfilling the tasks (Fig. 1E).

Control (No vaccination content): Participants experienced the wedding storyline, including the narrative elements without vaccination content as a comparison condition. After the bathroom embodiment scene (Fig. 1A), participants read the memory book and received the invitation (Fig. 1B). They experienced only one wedding scene without the exposure bar, and there were no vaccinated or infected characters. They did not encounter any of the GP scenes.

2.3. Measures

Vaccination intention*.* Consistent with previous research (Vandeweerdt et al., 2022), the main outcome variable in the study was vaccination intention, measured as participants' intention to take up a hypothetical new COVID-19 vaccine. We chose a hypothetical new vaccine because we expected that many participants would have been already vaccinated at the time of the study; the measure thus mirrors the uptake intention of (future) COVID-19 booster vaccines. The item read: *Suppose that in the future, a new strain of COVID-19 spreads and that current vaccines are not effective against this strain. A new vaccine is developed against the new strain. The new vaccine seems effective and seems to have only mild side effects, but it has been tested on far fewer people. How likely would you be to get such a vaccine?* The response scale ranged from 0 = (definitely would not) to 100 (definitely would). This measure was assessed before (pre) and after (post) the VR experience.

COVID empathy*.* Affective empathy for people most vulnerable to the virus was measured with three items (Cronbach's $\alpha = 0.83$) adapted from Pfattheicher et al. (2020). The three items were: *I am very concerned about those most vulnerable to coronavirus (COVID-19)*; *I feel compassion for those most vulnerable to coronavirus (COVID-19)*; *I am quite moved by what can happen to those most vulnerable to coronavirus (COVID-19)*. The response scale ranged from 1 (strongly disagree) to 5 (strongly agree). This measure was assessed before (pre) and after (post) the VR experience.

Vaccine-related donations*.* This behavioral measure was based on a

question where participants indicated whether they would rather receive a gift shop voucher or donate the same amount to various charities, some of which are related to COVID-19 and vaccines (for detail, see the Supplemental materials). The outcome variable, vaccine-related donations, was calculated as the sum of donations to COVID-related charities. It was zero for participants who chose the voucher instead. This measure was assessed after (post) the VR experience.

Cybersickness*.* We used a one-item measure to assess possible cybersickness related to the VR simulation. The exact wording was: *How motion sick (nauseous or dizzy) did you feel during the wedding experience?* The response scale ranged from 1 (not at all) to 5 (extremely). This measure was assessed after (post) the VR experience.

Presence and Embodiment*.* To measure the sense of presence in the simulation, we adopted two items ($r_{SB} = 0.62$) from Makransky et al. (2017): *While I was at the wedding, I had a sense of "being there"*; *I had a sense that I was interacting with other people at the wedding rather than a computer simulation.* The response scale ranged from 1 (strongly disagree) to 5 (strongly agree). One item to measure embodiment was adapted from Gonzalez-Franco and Peck (2018): *I felt as if the virtual body I saw when I looked down was my body.* The response scale ranged from 1 (strongly disagree) to 7 (strongly agree). Both presence and embodiment were assessed in the post-treatment questionnaire.

3. Results

Prior to the main analyses, we checked whether the randomization procedure and the empathy induction had been successful. The groups did not differ in their demographic characteristics including age, $F(2, 452) = 0.90$, $MSE = 103.29$, $p = .406$; gender, χ^2 ($N = 455$) = 4.11, $p = .663$; and vaccination status, χ^2 ($N = 455$) = 5.55, $p = .235$. Using one-way ANOVA, we also found that the groups were evenly distributed in terms of pre-treatment vaccination intentions, $F(2,452) = 0.71$, $MSE = 550.18$, $p = .494$ and empathy $F(2,452) = 0.89$, $MSE = 0.47$, $p = .410$.

Regarding the self-reported level of empathy, for participants who did not already feel maximum empathy ($n = 363$), the Gamified Herd

Immunity + Empathy increased empathy significantly more than the Control condition, $b = -0.19$, 95% CI $[-0.31, -0.07]$, $t(361) = -2.96$, $p = .003$ and more than the Gamified Herd Immunity condition, $b = -0.15$, 95% CI $[-0.27, -0.03]$, $t(361) = -2.37$, $p = .018$ (for a mean level comparison, see Fig. 2A). These results suggest that the Gamified Herd Immunity + Empathy successfully elicited higher levels of empathy toward people vulnerable to COVID-19 than any of the other conditions.

To test our hypotheses 1–5, we compared the absolute and relative effectiveness of the different VR interventions in increasing vaccination intention (for a mean-level comparison, see Fig. 2B). In detail, we tested the effectiveness of the Gamified Herd Immunity condition (H1 and H2) and the Gamified Herd Immunity + Empathy condition (H3 and H4) against the Control condition and finally compared their effects (H5). Supporting H1, the Gamified Herd Immunity condition ($n = 155$) significantly increased the vaccination intention from pre- ($M = 64.5$, $SD = 23.6$) to post-VR intervention ($M = 71.5$, $SD = 23.4$) by 7.06 points, 95% CI $[5.30, 8.82]$, $t(452) = 7.88$, $p < .001$. Furthermore, supporting H2, the Gamified Herd Immunity condition was significantly more effective than the Control condition ($n = 138$), $b = -5.15$, 95% CI $[-7.72, -2.57]$, $t(452) = -3.93$, $p < .001$, which increased the vaccination intention only by 1.91 points, still yielding a significant increase, 95% CI $[0.03, 3.79]$, $t(452) = 2.00$, $p = .046$.

When it comes to the Gamified Herd Immunity + Empathy intervention ($n = 161$), we also found a significant increase in vaccination intention from pre- ($M = 64.7$, $SD = 22.0$) to post-VR intervention ($M = 71.4$, $SD = 22.0$) by 6.68 points, 95% CI $[4.95, 8.41]$, $t(452) = 7.60$, $p < .001$, supporting H3. Additionally, the Gamified Herd Immunity + Empathy was more effective in increasing vaccination intention than the control treatment, $b = -4.77$, 95% CI $[-7.32, -2.21]$, $t(452) = -3.67$, $p < .001$, supporting H4.

Finally, we compared the vaccination intention before vs. after completing either the Gamified Herd Immunity + Empathy condition or the Gamified Herd Immunity condition. The results showed that the Gamified Herd Immunity + Empathy increased the vaccination intention to a similar extent as the Gamified Herd Immunity condition did, $b = 0.38$, 95% CI $[-2.09, 2.84]$, $t(452) = 0.30$, $p = .763$. Thus, H5 was not supported (see Fig. 2B).

Furthermore, we tested whether the different experiences in the VR interventions would also lead to differences in the willingness to donate money to vaccine-related charities. We found no evidence for such spillover effects. There was no difference in the amount of charity donations between the Gamified Herd Immunity + Empathy condition ($M = 1.51$, $SD = 1.99$) compared to the Control condition ($M = 1.54$, $SD = 1.94$), $b = 0.03$, 95% CI $[-0.42, 0.47]$, $t(452) = 0.12$, $p = .908$, nor the Gamified Herd Immunity condition ($M = 1.56$, $SD = 1.90$), $b = 0.04$, 95% CI $[-0.38, 0.47]$, $t(452) = 0.20$, $p = .838$. Similarly, there was no difference between the Gamified Herd Immunity condition and the Control condition, $b = -0.02$, 95% CI $[-0.47, 0.43]$, $t(452) = -0.08$, $p = .935$.

To further explore the mechanisms behind the effectiveness of the Gamified Herd Immunity and Gamified Herd Immunity + Empathy conditions ($n = 364$), we investigated the impact of presence and embodiment on vaccination intention using multiple regression analysis. The model using presence and embodiment as predictors of change in vaccination intentions showed that presence, $b = 1.69$, 95% CI $[0.88, 2.50]$, $t(315) = 4.10$, $p < .001$, but not embodiment, $b = 0.51$, 95% CI $[-0.39, 1.41]$, $t(315) = 1.11$, $p = .269$, significantly predicted the increase in vaccination intentions.

As the last step, we investigated whether age and gender moderated the effect of our treatment conditions on vaccination intentions. We did not find an interaction between age and treatment effects of Gamified Herd immunity, $b = -0.87$, 95% CI $[-3.39, 1.65]$, $t(449) = -0.68$, $p = .500$, or Gamified Herd immunity + Empathy condition, $b = 0.58$, 95% CI $[-1.92, 3.08]$, $t(449) = 0.46$, $p = .648$. Similarly, we did not find an interaction between gender and the effects of the Gamified Herd immunity condition, $b = 2.87$, 95% CI $[-1.84, 7.59]$, $t(449) = 1.20$, $p = .231$, or the Gamified Herd immunity + Empathy condition, $b = 3.11$, 95% CI $[-1.80, 8.02]$, $t(449) = 1.24$, $p = .214$, on changes in vaccination intention.

4. Discussion

We tested whether communicating the social benefit of getting vaccinated using VR increases users' vaccination intention and, more importantly, what are the underlying processes of such an effect. The present study brings four major findings with important implications for vaccination communication via VR.

First, both gamified VR interventions increased users' vaccination intentions. This finding supports previous findings on the positive effects
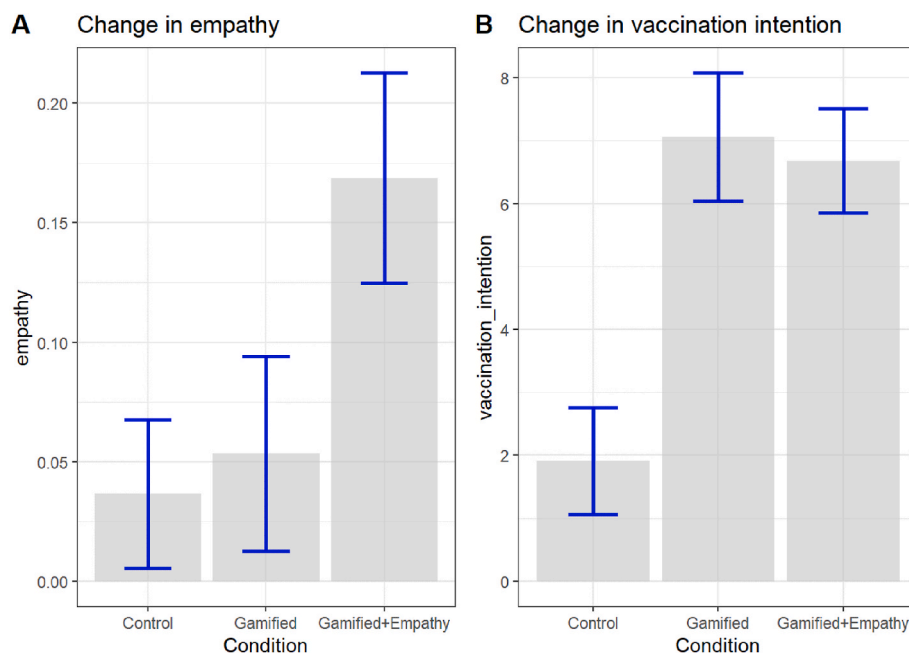

Fig. 2. Mean pre-vs. post-VR intervention difference in empathy (A) and vaccination intention (B) across the three conditions. Error bars show SEM.

of communicating the social benefit of vaccination in general (Betsch et al., 2013; Hakim et al., 2019) and using VR in particular (Mottelson et al., 2021; Vandeweerdt et al., 2022). The results thus strengthen the idea that using engaging communication methods such as VR is particularly appropriate to communicate even complex epidemiological phenomena (Böhm & Betsch, 2022).

Second, the effects of the gamified VR interventions were substantially larger than the effect of a Control condition without vaccine-related content. This indicates that the novelty and the potential excitement associated with the novel technology are not sufficient to explain the interventions' effectiveness.

Third, although the gamified VR intervention with an additional emotional narrative enhanced empathy toward people vulnerable to COVID-19, this did not lead to a further increase in vaccination intentions compared to the gamified VR intervention without an emotional narrative (and lower perceived empathy). This suggests that the vaccine-related content of the VR simulation, and not the elicited empathy, is likely to drive the intervention's effectiveness. One of the possible explanations could be that our treatment is aiming more at threat appraisal for the user but not for others. VR has been shown to be a powerful tool for increasing risk perception by making threats, which might be not only temporally but also socially distant, more imminent (Ahn, 2015). In the presented scenario, the user "becomes" the vulnerable person, and thanks to high immersion this experience feels like it is really happening to the user. Therefore the feelings of compassion towards others might be redundant as the users might feel at risk themselves (see also Sääksvuori et al., 2022).

Fourth, in line with the hypothesis mentioned above, the results show that the more present participants felt in the virtual environment, the more likely they were to increase their intentions to get vaccinated. The role of presence in behavioral change has been previously reported in studies focusing on health communication in VR (Ahn et al., 2019; Choi & Noh, 2020; Fox & Bailenson, 2009) and it supports the results of the previous media studies showing larger effects when using immersive VR compared to desktop interventions (Wu et al., 2020) or text-and-image interventions on a tablet (Vandeweerdt et al., 2022). One of the possible explanations would be the role of presence in reducing the perceived distance of the threat and therefore increasing threat appraisal (Ahn, 2015; Plechatá et al., 2022), an important factor in behavioral change according to PMT (Rogers, 1975). Indeed, there is evidence that higher immersion and increased feelings of presence can increase risk perception (Breves & Schramm, 2021). Experiencing the risk of being infected from a first-person perspective while perceiving the situation as realistic might increase threat appraisal (self- or other-oriented), which can be a potential mechanism of VR effectiveness. The embodiment, on the other hand, might be more crucial for eliciting empathy than the threat appraisal.

It is noteworthy that our study had an unusually large sample size, which is likely to increase the robustness of the conclusions drawn (Lanier et al., 2019). Potentially even more important, the current study had a particularly heterogeneous sample by recruiting visitors from a large museum. Besides, conducting a VR intervention study in a rather noisy field environment underlines the potential of using VR in vaccination communication, for instance, in schools, doctor's offices, or at public events. In such settings, the strong immersiveness of VR provides strong advantages over standard communication methods (e.g., reading a pamphlet; Vandeweerdt et al., 2022).

4.1. Limitations

The current study also has some important limitations. First, a major limitation is that we measured vaccination intention but not actual vaccination behavior. Intentions are considered antecedents of actual behavior (Ajzen, 1991); however, research has consistently shown that people do not always follow their intentions (Sheeran & Webb, 2016). Measuring actual vaccine uptake would bring some ethical and practical

issues; nevertheless, future research should attempt to investigate the impact of VR interventions on actual vaccine uptake. By assessing donation behavior, we added an alternative behavioral measure to our study to investigate potential behavioral spillover effects. Yet, we did not find any behavioral differences between the experimental conditions. This null finding could be due to a weak conceptual relationship between donation and vaccination behavior or the aforementioned intention-behavior gap (Sheeran & Webb, 2016).

Second, due to COVID-19 measures implemented shortly after the commencement of the study, which restricted non-vaccinated citizens from visiting the museum, only a small portion of the participants was not vaccinated against COVID-19. Nevertheless, hypothetical vaccination intentions regarding the uptake of a new future booster vaccine yielded some variance in intentions, which allowed us to study potential intervention effects even in a context with a rather high vaccine acceptance (Vandeweerdt et al., 2022).

Third, despite several advantages of recruiting participants from museum visitors, this also resulted in a context-specific sample, consisting of a mix of German and non-German speakers with an average age of 29 years, which is below the general population average (among other potential differences). While our results are in line with previous findings on VR vaccination communication in very different samples (Mottelson et al., 2021; Vandeweerdt et al., 2022), further research may be needed to verify whether the conclusions transfer to the general population.

Fourth, in order not to overburden participants, we used only short pre- and post-questionnaires. Therefore, we measured the sense of embodiment and presence with only one item (Gonzalez-Franco & Peck, 2018) and two items (Makransky et al., 2017), respectively. These items were adapted from longer standardized scales. Therefore, the results regarding the impact of presence and embodiment on vaccination intentions should be interpreted with caution and investigated in more detail using more reliable measures. Neither age nor gender moderated the effects of the intervention, nevertheless, as we did not collect other demographic data, we could not investigate the potential boundary conditions of VR intervention in more depth. For similar reasons, we did not measure participants' threat appraisal or coping appraisal, which should be considered as measures in future studies on health communication in immersive reality (Plechatá et al., 2022).

5. Conclusion

Despite these limitations, we conclude that VR is a powerful tool for vaccination communication, mainly because it allows for alternative and more effective ways to communicate vaccine-related content. This goes even beyond demonstrating complex microbiological mechanisms of the immune system but targets the large-scale societal impact of vaccination. In contrast, mere demand characteristics due to novelty or stronger emotional engagement due to induced empathy seem to play a less important role in the effectiveness of VR interventions in increasing vaccination intention than gamified educational content, if at all.

This research has implications for (the future of) vaccination communication. With the predicted arrival of the metaverse (Pimentel et al., 2022), we can expect more extensive use of immersive technology in daily life. As such, future health communication can and should make use of these new tools. Our results indicate that using an interactive first-person simulation to experience how viruses spread could be an effective way to increase vaccination intentions. More generally, immersive VR can facilitate the understanding of abstract and complex biological mechanisms (Plechatá et al., 2022). The role of presence as shown in this study underlines the importance of using immersive technology to elicit realistic reactions that may eventually support health behavior change (Blascovich & Bailenson, 2011). We do not propose replacing all standard vaccination communication with VR or related immersive technology, but rather suggest exploiting this tool as a complementary communication method when feasible.

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Author contribution

Adéla Plechatá: Conceptualization, Formal analysis, Data Curation, Investigation, Writing - Original Draft, Writing - Review & Editing, Project administration. **Clara Vandeweerdt:** Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing, Project administration. **Michael Atchapero:** Software, Data Curation, Investigation, Writing - Review & Editing. **Tiffany Luong:** Software, Writing - Review & Editing. **Christian Holz:** Funding acquisition, Conceptualization, Writing - Review & Editing. **Cornelia Betsch:** Conceptualization, Writing - Review & Editing. **Bonnie Dietermann:** Resources, Writing - Review & Editing. **Yori Schultka:** Resources, Writing - Review & Editing. **Robert Böhm:** Supervision, Funding acquisition, Conceptualization, Writing - Original Draft, Writing - Review & Editing, Methodology. **Guido Makransky:** Supervision, Funding acquisition, Conceptualization, Writing - Original Draft, Writing - Review & Editing, Methodology.

Declaration of competing interest

The authors declare the following financial interests/personal relationships, which may be considered as potential competing interests: [Robert Böhm is a member of the Technical Advisory Group on Behavioral and Cultural Insights at the World Health Organization/Regional Office for Europe, Copenhagen/Denmark.]

Data availability

We provide open access to the data, analysis scripts, and supplementary materials via the Open Science Framework: https://bit.ly/3Bbn3PG.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chb.2022.107533.

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