A Self-administered Virtual Reality Intervention Increases COVID-19 Vaccination Intention

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Summary

Background

Effective interventions for increasing people's intention to get vaccinated are crucial for global health. Considering COVID-19 vaccination, ending the pandemic requires that billions of people are willing to get vaccinated to protect themselves but also to protect others through community immunity. We devised a novel intervention using virtual reality (VR) consisting of a consultation with an animated general practitioner for communicating the benefits of COVID-19 vaccination and, in turn, increasing the intention to get vaccinated against COVID-19.

Methods

We conducted a preregistered online intervention study where people with eligible VR headsets were invited to install our experimental application and complete the study at their own discretion. In this 2×2 between-participant design experiment, participants were randomly assigned across two age conditions (young or old self-body) and two communication conditions (with provision of personal benefit of vaccination only, or collective and personal benefit). Participants experienced a ten minute virtual consultation about COVID-19 vaccination. The primary outcome was vaccination intention (score range 1-100) measured three times: immediately before and after the study, as well as one week later.

Findings

From April 14 to May 14, 2021, 507 adults who were not vaccinated against COVID-19 were recruited, of which 282 had less than perfect vaccination intention (< 100) prior to participating. Among those participants with imperfect vaccination intentions, the VR intervention increased pre-to-post intentions to get vaccinated across intervention conditions (mean difference $8{\cdot}6$, 95% CI $6{\cdot}1$ to $11{\cdot}1$, $p < 0{\cdot}0001$). The pre-to-post difference significantly correlated with the vaccination intention one week later, $\rho = 0{\cdot}20,\ p < 0{\cdot}002$.

Interpretation

The VR intervention was effective in increasing COVID-19 vaccination intentions both when only personal benefits and personal and collective benefits of vaccination were communicated, with significant retention one week after the intervention. Utilizing recent evidence from health psychology and embodiment research to develop immersive environments with customized and salient communication efforts could be an effective tool to complement public health campaigns.

Funding

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Introduction

The World Health Organization (WHO) has identified vaccine hesitancy as one of the ten biggest threats to global health[23]. Accordingly, effective interventions for decreasing vaccine hesitancy and, thus, increasing vaccination intentions are crucial for public health. Considering the COVID-19 pandemic, large-scale vaccination of all people is of utmost importance to end the pandemic and its associated social and economic costs. Most vaccinations

Research in Context

Evidence before this study

There is growing evidence that communicating the personal and collective benefit of vaccination increases participants' vaccination intentions. A recent study with more than $18,000$ participants from the UK found increased vaccination intentions, among those strongly hesitant, by providing text-based information about the personal benefit of vaccination, more so than when informing them about collective benefit or about both personal and collective benefit. A cross-national study with more than $2,000$ participants found that informing participants about community immunity improved participants' intention to get vaccinated in Western countries, whereas participants in Eastern countries had a priori higher collective responsibility with regard to vaccination. This study also reports an increased vaccination intention particularly after exposure to a more engaging interactive simulation compared to a text-based explanation. With regard to the latter finding, a review article from 2005 shows how immersive technology can induce illusory ownership of virtual bodies, and that implicit biases related to the body can be underpinned by such a multisensory experience via a process of self-association. Such immersive interventions, including body ownership illusions, are increasingly being used for behavior and attitude change interventions, as they create realistic and engaging learning environments. For example, a randomised controlled trial from 2018 reported encouraging results using virtual reality (VR) for treatment of fear of heights in participants from the UK.

On January 15th 2021, following the PRISMA guidelines, we searched PubMed, medRxiv, PsyArXiv, and arXiv with no date restrictions for publications in the English language on using VR to reduce vaccine hesitancy. The employed search terms were "virtual reality" AND ("vaccine" OR "vaccination"). We retrieved three empirical papers from our search.

One paper is about using VR for pain relief during vaccination of children and another one is about using VR for training of physicians. The third one reports on a study conducted with 171 US participants, of which 48 were immersed in a VR intervention that provided information about the collective benefits of influenza vaccination, whereas the others either received the same content via video or e-pamphlet, or received no information on community immunity at all. The VR intervention increased participants' presence compared to the other conditions, which in turn increased vaccination intentions. Yet, there was no direct effect of the VR intervention on vaccination intentions. Hence, there is no evidence of whether communicating the personal and/or collective benefit of vaccination using VR can increase vaccination intentions due to a lack of studies with sufficient statistical test power.

Added value of this study

The primary goal of this study was to investigate the effectiveness of a novel automated intervention strategy for decreasing vaccine hesitancy targeted at a young audience. We designed an immersive experience incorporating recent insights from health psychology and embodiment research, and carried out a VR study with a large number of participants recruited online. The results show that the VR intervention increased immediate vaccination intentions that sustained even one week after the study. As such, our study provides proof-of-concept of using VR as an effective tool for promoting vaccination intentions.

Implications of all the available evidence

Digital interventions delivered using VR consumer hardware can become an effective tool for vaccine advocacy, complementing more traditional communication channels. Combining health communication with experiential learning through bodily self-consciousness could be used in future health campaigns for tailoring communication efforts. Adopting novel technology in vaccine advocacy by relying on evidence-based intervention practices may thus help to decrease the spread of infectious diseases.

provide a personal benefit to the vaccinated individuals as well as a collective benefit due to reducing the spread of pathogens by increasing community immunity [7]. Previous research suggests that communicating the personal or collective benefit of vaccination increases people's vaccination intention [5,8,10,20].

Motivating people to participate in effective health interventions is challenging. Immersive virtual reality (VR) has the potential to increase access to state-of-the-art health interventions [8,22], and provides an opportunity to engage the audience on terrain salient to them [8]. Using novel technology, such as virtual reality, for vaccine advocacy may help by reaching particularly younger people, who are more likely to be hesitant against COVID-19 vaccination [15], potentially due to a lower likelihood to suffer from a severe course of the disease [6].

Inducing illusory ownership of a virtual body in virtual reality is an effective paradigm for changing people's attitudes and behavior [1,11,17]. Nowak et al. [16] used VR to communicate the collective benefit of vaccination and found only weak evidence of attitude change in a lab study. As their study had low statistical test power, the potential effectiveness of VR in vaccine advocacy in larger samples remains an open question. Addressing this problem, Freeman et al. [8] showed encouraging results in using self-administered embodied VR therapy for treatment of fear of heights.

Building on these insights from vaccine advocacy and immersive technology, we aimed to develop a VR intervention effective for increasing people's intention to get vaccinated against COVID-19, self-administered to a large online sample. We found the VR intervention indeed increased participants' vaccination intentions, immediately after study completion and one week later.

Methods

Study design

The study employed a 2×2 between-participant design. The two independent variables were **avatar age** with the levels *young* and *old*, and **vaccination communication** with the levels *personal benefit* and *personal + collective benefit*. The study design, procedures, hypotheses, and statistical analyses were preregistered and are available together with the data set via the Open Science Framework[a].

Deviation from preregistration

We preregistered to exclude participants with a negative mean embodiment, that is, participants who did not experience their avatar's body as theirs. We realized that excluding participants based on a post-intervention measure was not ideal because this could be influenced by the experimental condition. Therefore, we decided to apply a more conservative strategy by including participants irrespective of their self-reported embodiment. We report statistical analyses using the original preregistered criteria in the Supplementary Material.

Participants

We aimed at recruiting a final sample used for analyses of 200-300 adult participants. All participants had access to VR equipment to self-administer the intervention. After the preregistered exclusion of participants with a perfect vaccination intention prior to the intervention (i.e., 100 on a scale from 1 to 100), the final sample consisted of $n = 282$ participants, of which $n = 244$ participants also completed the follow-up survey one week later ($13{\cdot}5\%$ attrition; for sample characteristics, see Table 1).

The participants were recruited to participate in a VR study on COVID-19 vaccination via social media (most notably VR communities at Reddit[b] and Twitter[c]), and installed the VR application onto their own VR devices using the SideQuest[d] software. The call for participation clearly stated the eligibility criteria for study participation, namely (i) not previously vaccinated against COVID-19, (ii) at least 18 years of age, (iii) not having previously participated, (iv) and having access to a VR device of the type Oculus Quest (1st or 2nd generation). Participants received IRB-approved information describing the study, the data collection procedures, and information on informed consent.

Study recruitment took place from April 14 to May 14, 2021. Participants were reimbursed with a gift certificate of USD $10 of value (or the equivalent in their preferred currency), with an additional USD $5 for filling out a follow-up survey sent out one week following study participation.

[a] `https://osf.io/uyevs`
[b] http://reddit.com: /r/OculusQuest, /r/SideQuest, /r/oculus
[c] http://twitter.com
[d] http://sidequestvr.com

Randomisation and masking

The participants were randomly[e] assigned to either of four experimental conditions during application run-time (see Figure 1), after providing informed consent. Participants were unaware of the existence of any other conditions. As the research team had no contact with research participants (except for reimbursement after study completion), the research team can be considered as masked in relation to outcome assessments.

Procedures

The study was conducted as an online and unsupervised VR study following recent recommendations for running studies this way [14]. The study began as participants wore their headsets and launched the VR application. First, informed consent was acquired. Next, participants were asked if they had already received (any doses) of COVID-19 vaccine to verify participation eligibility. We then asked their gender identity, to match the sex of the virtual avatar with the sex of the participant. As a last step before the intervention initiated, pre-intervention measures were acquired (vaccination intention, vaccination recommendation, vaccination readiness, COVID-19 empathy).

Immersive Environment

The narrative of the immersive experience was situated around a visit to a virtual general practitioner (GP) in order to receive information about COVID-19 vaccination. The environment consisted of two virtual scenes. First, a bathroom scene (see Figure 2, left) where participants were directed to put on a face mask, wash hands, dry hands, and finally to enter the consultation room by activating a door. During these tasks a mirror rendered the participant's avatar in synchrony with the participant's movements. An inverse kinematics model predicted body posture using three stable tracking points (headset, left and right controllers). The purpose of this scene was to induce body ownership of the assigned virtual avatar in line with Maselli and Slater [13].

Afterwards, participants entered a consultation room (see Figure 2, right) where a standing female GP would greet the participant and continue with information about COVID-19 vaccination. Depending on the assigned experimental condition, the GP would either explain the personal benefit of vaccination, or both the personal and collective benefit of vaccination. Explanation of the collective benefit of vaccination entailed an animated

[e]The random assignment was allocated using `Random.Range` from the Unity SDK.

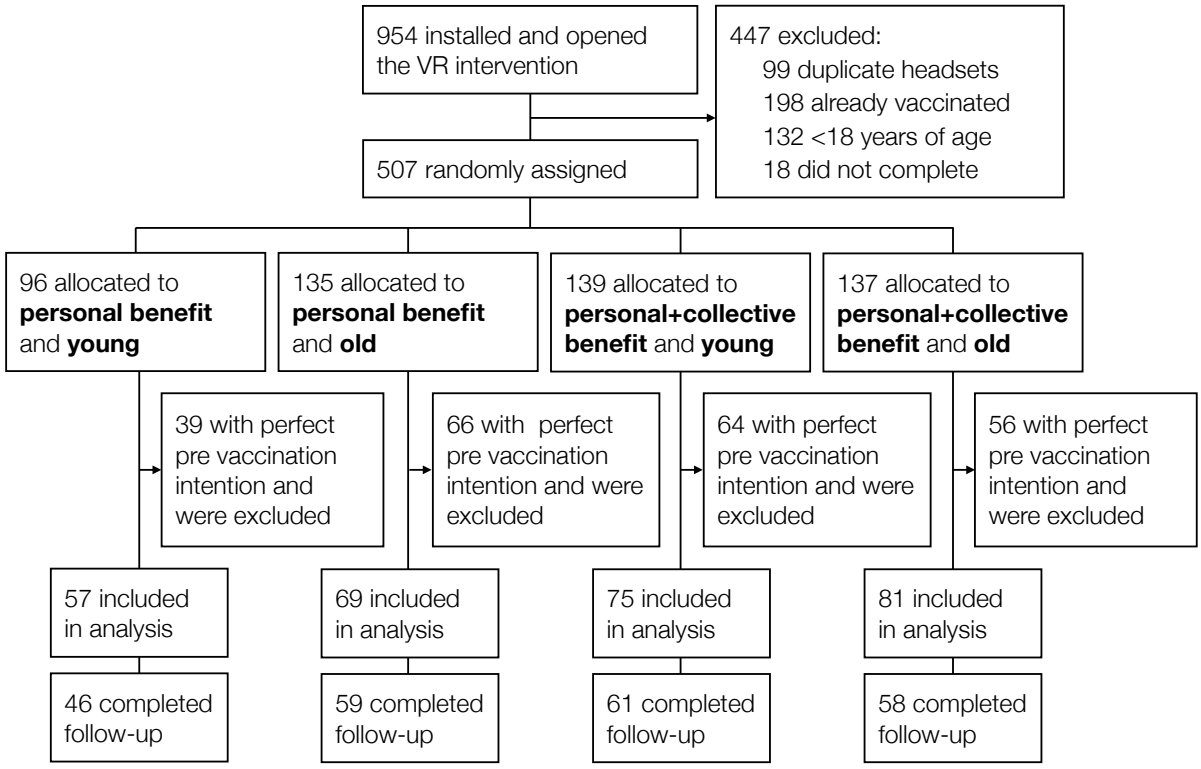

Figure 1: Trial profile

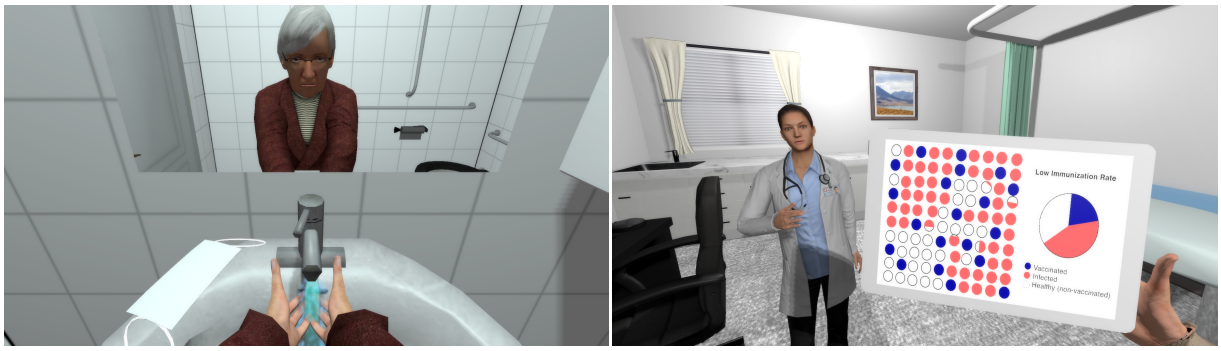

Figure 2: Screens from the immersive intervention: the first scene in a bathroom intended as embodiment phase where the participant washes hands under a faucet (left); and a tablet showing an animated visualization about the concept of community immunity in the doctor's office during counseling (right).

visualization shown on a tablet (see Figure 2, right) inspired by Betsch and Böhm [3], Betsch et al. [5]. The animation explained the concept of community projection, by showing the difference in spread of virus between high and low immunization populations. The GP made multiple remarks related to the assigned age condition to explain the heterogeneous risk profile regarding age [6] (e.g., 'young/old people, like you, are less/more vulnerable to the coronavirus').

Outcomes

The primary outcome was COVID-19 vaccination intention, as measured by Betsch et al. [5] on a 1-100 scale (1 = *"I would definitely not get vaccinated"*, 100 = *"I would definitely get vaccinated'*). This measure was collected in two contexts; while immersed in the virtual body (henceforth *as-avatar* vaccination intention), and during times without a self-avatar (henceforth *as-self* vaccination intention). The *as-self* vaccination intention was emphasized to relate to the participant's personal vaccination intention, and was measured a total of three times: before the intervention, after completing the intervention, and one week subsequent to completion. The first two were collected during the intervention, and the latter in an online survey sent to participants' email addresses.

For a secondary analysis we collected three additional measures related to vaccination: vaccination readiness [9], COVID-19 empathy [18], and vaccination recommendation. These were all collected on 5-point Likert-type scales. As part of the secondary analysis, we also investigated whether the effect of experimental condition was moderated by age, gender, country of residence, and experience with VR. We furthermore collected embodiment [2] and presence [12]. Finally, for exploratory purposes we collected objective measures related to movement and gaze. The complete list of measurements can be found in the Supplementary Material.

Statistical analysis

Differences in intervention effects by experimental condition on the primary outcome, i.e., vaccination intention, were analyzed using a two-way ANOVA on the pre-to-post difference in vaccination intention. Intervention effectiveness was tested by a t-test on participants' pre-to-post differences in vaccination intention against zero. We used Pearson's correlation coefficient for analyzing correlations.

Further analyses were conducted to ascertain if effects of the intervention varied by individual characteristics (age, gender, region, education, experience with VR). These analyses were conducted by including demographics variables as main and interaction terms in the regression models, or simply a correlation test for non-categorical variables.

All the analyses on the pre-to-post differences are based on $n = 282$ participants, whereas analyses including the follow-up measures are based on $n = 244$ who completed all three measurement occasions. Analyses were conducted in R (version 4.0.4).

Results

Successful embodiment was indicated by a significant interaction effect of the two experimental factors on the as-avatar vaccination intention. Specifically, vaccination intention when embodied as a young avatar, but not as an old avatar, increased when both the personal and collective benefit of COVID-19 vaccination was communicated, relative to the personal benefit only condition. This is in line with previous research, showing that people at

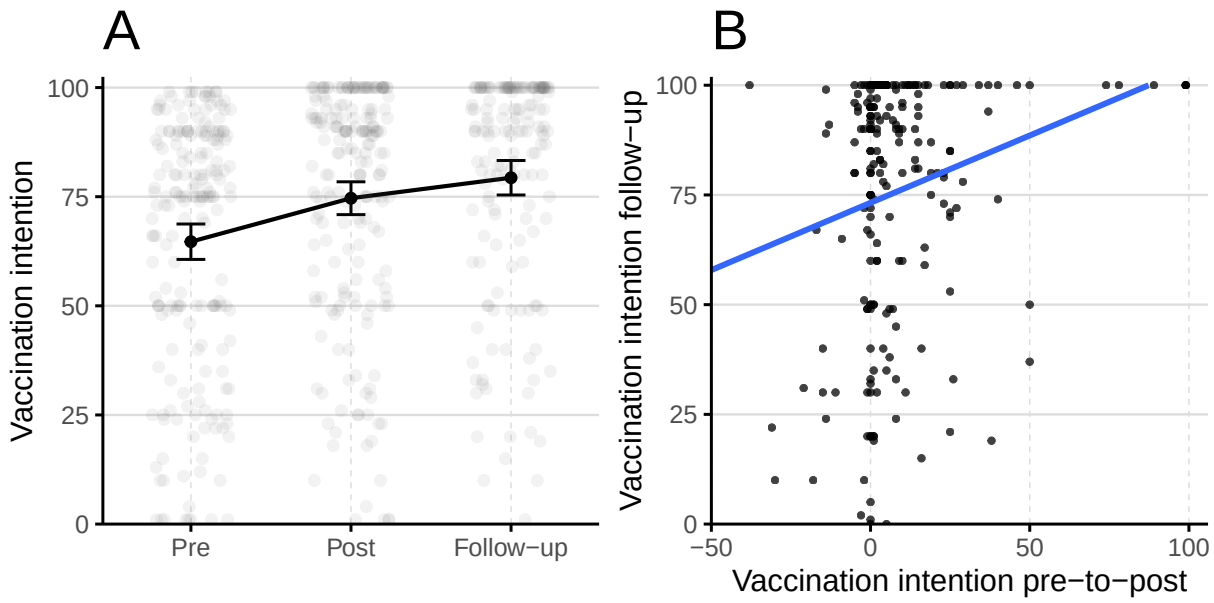

Figure 3: Mean vaccination intention as measured directly before (pre) and after (post) the VR intervention, and in follow-up survey one week later with error bars indicating 95% CIs (A), and correlation of vaccination intention as measured pre-to-post and in follow-up, $\rho = 0{\cdot}20$ (B).

lower personal risk increase their vaccination intention when they are informed about the collective benefit of vaccination[5].

More importantly and as expected, the VR intervention also increased participants own (as-self) vaccination intention, regardless of the experimental condition, measured as the pre-to-post intervention difference, $t(281) = 6{\cdot}8,\ p < 0{\cdot}0001$, Cohen's $d = 0{\cdot}29$ (see Figure 3A). The intervention caused a substantial mean increase in vaccination intention of $8{\cdot}6$, 95% CI $6{\cdot}1$ to $11{\cdot}1$.

Further exploratory analyses suggested retention of the positive intervention effect even one week after the study (i.e., intervention-based increase in vaccination intention causes subsequent higher vaccination intention). In detail, we found that the pre-to-post difference in vaccination intention due to the intervention is significantly correlated with the vaccination intention measured in the follow-up survey, $\rho = 0{\cdot}20,\ p < 0{\cdot}0001$ (see Figure 3B).

In addition to the intervention-based increases in vaccination intention, secondary analyses also revealed significant pre-to-post increases in COVID-19 empathy ($p = 0{\cdot}0001$), vaccination recommendation ($p = 0{\cdot}0001$), and vaccination readiness ($p < 0{\cdot}0001$), further supporting the intervention's effectiveness.

	Data (n = 282)
Age, years	28·9 (9·7)
Age group, years	
18-21	50 (25·3)
22-25	44 (22·2)
26-29	29 (14·7)
30-34	25 (12·6)
35-39	18 (9·1)
40-44	14 (7·1)
45-49	5 (2·5)
50-59	11 (5·6)
60-99	2 (1·0)
Gender	
Female	20 (7·1)
Male	255 (90·4)
Non-binary	7 (2·5)
Country	
United States	89 (31·6)
United Kingdom	22 (7·8)
Germany	21 (7·4)
Canada	20 (7·1)
France	19 (6·7)
Spain	14 (5·0)
Poland	10 (3·5)
Netherlands	9 (3·2)
Italy	8 (2·8)
Sweden	7 (2·5)
Mexico	5 (1·8)
Denmark	4 (1·4)
Ireland	4 (1·4)
Turkey	4 (1·4)
Argentina	3 (1·1)
Brazil	3 (1·1)
Japan	3 (1·1)
Educational level	
Bachelor's	84 (29·8)
High school/GED	82 (29·1)
Associate/2-year college	50 (17·7)
Master's	36 (12·8)
Professional degree	14 (5·0)
PhD	8 (2·8)
Primary/middle school	8 (2·8)
Prior VR experience	
More than 100 times	118 (41·8)
51-100 times	67 (23·8)
21-50 times	55 (19·5)
11-20 times	28 (9·9)
4-10 times	9 (3·1)
1-3 times	5 (1·8)

Table 1: Participant characteristics. Data are n (%) or mean (SD).

Discussion

Our findings from one of the largest randomised VR intervention studies ever conducted show that a self-administered psychological intervention delivered using immersive VR is effective in increasing intentions to get vaccinated against COVID-19. Although participants were sensitive to different experimental conditions when asked about their vaccination intention in the role of the avatar they were embodied as, we found that the intervention was successful in increasing their own vaccination intention across experimental conditions. This suggests that even a very short but highly immersive and engaging VR intervention has the potential to increase vaccination intentions.

Our study has some limitations. Firstly, despite the effectiveness of a one-time VR intervention that lasted only approximately 10 minutes to balance discomfort of immersion and clear communication, the intervention effect might be even larger by extending the time or number of intervention exposures. Secondly, our main dependent variable was vaccination intention (using an established measure[5]). Although psychological or structural barriers may create an intention-behaviour gap[4,21], intentions are still considered to be an important predictor of actual preventive behaviors[19]. Further, we present anecdotal evidence for the causal effect of exposure to our intervention and subsequent vaccination against COVID-19 (see panel below). Thirdly, we did not compare the VR intervention's effectiveness with other, more traditional communication methods (e.g., via text). However, we argue that immersive VR may be a viable intervention method to complement other communication channels as long as it is effective per se (as demonstrated here) because it allows to attract and therefore target different target populations to engage with vaccination information in the first place. Lastly, our study focused on vaccination against COVID-19. Future research should aim to extent and adapt our VR intervention to promote other vaccinations, too (e.g., measles, influenza).

More generally, our study shows the potential of using immersive VR in health communication. People with access to a VR headset could self-administer our intervention, which caused younger and male participants to be over-represented in our sample. At the same time, however, this procedure allows targeting population groups who are otherwise difficult to reach with traditional health communication. Moreover, VR interventions could also be administered differently, such as in medical practices (targeting patients) or in medical education (targeting health care professionals).

Comments from participants about the VR intervention

Although we did not inquire direct feedback from participants, several participants sent us emails with anecdotal evidence of the positive user experience as well as the effectiveness of the VR intervention in changing vaccination intention and behavior. Examples are shown here.

"The questions inside the game made me think more about whether or not to get vaccinated. In the end, 'The Vaccine' felt good because I felt like I was part of the solution to the world and in short I really liked the study."

"I enjoyed the study, and I had hard time deciding if I should get the vaccine or not. And as short as it was, it encouraged me a little bit and I felt more safe with my decision."

"I'd like to say what a cool experience 'The Vaccine' application was, I could see huge applications for things like this in the future."

"I did get my vaccine after participating in your study. You guys are awesome. Thank you!"

"First of all wow! This study let me think about the coronavirus for a month! And I did my first coronavirus vaccine two days ago and I felt like I saved the world or am part of the solution against the coronavirus."

"The game was amazing. I just love how you can teach more people about the situation and how you can help others. I played the game more than a week ago, and right after I finished the study I booked an appointment for coronavirus vaccination! And I wanted to share with you that it was because of you because last time I was afraid of the vaccine and its side effects and the game made me think more about the vaccine and I ended up doing the vaccine."

Contributors

AM, GM, and RB conceived the study idea. AM led the design, and drafted the paper. CV, RB, and GM contributed to the design. All authors reviewed the design. MA and AM implemented the VR application. AM and CV carried out the statistical analysis. AM produced figures. RB, CH, and GM secured study funding. All authors contributed to the interpretation of the results and the draft paper. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Data sharing

Anonymous participant data will be available at the project's Open Science Framework repository without undue reservation, following the publication of results. The analyses plan and full statistical report are available in the Supplementary Material. The source code and the employed 3D models are available upon request.

Declaration of interests

All authors declare no competing interests.

Acknowledgments

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References

1 Banakou D, Groten R, Slater M. Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. Proceedings of the National Academy of Sciences 2013;110(31):12846–12851.

2 Banakou D, Slater M. Body ownership causes illusory self-attribution of speaking and influences subsequent real speaking. Proceedings of the National Academy of Sciences 2014;111(49):17678–17683.

3 Betsch C, Böhm R. Moral values do not affect prosocial vaccination. Nature human behaviour 2018;2(12):881–882.

4 Betsch C, Böhm R, Chapman GB. Using behavioral insights to increase vaccination policy effectiveness. Policy Insights from the Behavioral and Brain Sciences 2015;2(1):61–73.

5 Betsch C, Böhm R, Korn L, Holtmann C. On the benefits of explaining herd immunity in vaccine advocacy. Nature human behaviour 2017;1(3):1–6.

6 Bhopal SS, Bagaria J, Olabi B, Bhopal R. Children and young people remain at low risk of COVID-19 mortality. The Lancet Child & Adolescent Health 2021;5(5):e12–e13.

7 Fine P, Eames K, Heymann DL. "Herd Immunity": A Rough Guide. Clinical Infectious Diseases 2011 04;52(7):911–916. https://doi.org/10.1093/cid/cir007.

8 Freeman D, Haselton P, Freeman J, Spanlang B, Kishore S, Albery E, et al. Automated psychological therapy using immersive virtual reality for treatment of fear of heights: a single-blind, parallel-group, randomised controlled trial. The Lancet Psychiatry 2018;5(8):625–632.

9 Geiger M, Rees F, Lilleholt L, Santana A, Zettler I, Wilhelm O, et al. The 7Cs of vaccination readiness. European Journal of Psychological Assessment 2021;.

10 Hakim H, Provencher T, Chambers CT, Driedger SM, Dube E, Gavaruzzi T, et al. Interventions to help people understand community immunity: A systematic review. Vaccine 2019;37(2):235–247. https://www.sciencedirect.com/science/article/pii/S0264410X18315299.

11 Maister L, Slater M, Sanchez-Vives MV, Tsakiris M. Changing bodies changes minds: owning another body affects social cognition. Trends in cognitive sciences 2015;19(1):6–12.

12 Makransky G, Lilleholt L, Aaby A. Development and validation of the Multimodal Presence Scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. Computers in Human Behavior 2017;72:276–285.

13 Maselli A, Slater M. The building blocks of the full body ownership illusion. Frontiers in Human Neuroscience 2013;7:83.

14 Mottelson A, Petersen GB, Lilija K, Makransky G. Conducting Unsupervised Virtual Reality User Studies Online. Frontiers in Virtual Reality 2021;2:66.

15 Murphy J, Vallières F, Bentall RP, Shevlin M, McBride O, Hartman TK, et al. Psychological characteristics associated with COVID-19 vaccine hesitancy and resistance in Ireland and the United Kingdom. Nature communications 2021;12(1):1–15.

16 Nowak GJ, Evans NJ, Wojdynski BW, Ahn SJG, Len-Rios ME, Carera K, et al. Using immersive virtual reality to improve the beliefs and intentions of influenza vaccine avoidant 18-to-49-year-olds: Considerations, effects, and lessons learned. Vaccine 2020;38(5):1225–1233. https://www.sciencedirect.com/science/article/pii/S0264410X19315166.

17 Peck TC, Seinfeld S, Aglioti SM, Slater M. Putting yourself in the skin of a black avatar reduces implicit racial bias. Consciousness and Cognition 2013;22(3):779–787.

18 Pfattheicher S, Nockur L, Böhm R, Sassenrath C, Petersen MB. The emotional path to action: Empathy promotes physical distancing and wearing of face masks during the COVID-19 pandemic. Psychological Science 2020;31(11):1363–1373.

19 Rosenstock IM. The Health Belief Model and Preventive Health Behavior. Health Education Monographs 1974;2(4):354–386. https://doi.org/10.1177/109019817400200405.

20 Sääksvuori L, Betsch C, Nohynek H, Salo H, Sivelä J, Böhm R. Information nudges for influenza vaccination: Evidence from a large-scale cluster-randomized controlled trial. medRxiv 2021;.

21 Sheeran P. Intention—Behavior Relations: A Conceptual and Empirical Review. European Review of Social Psychology 2002;12(1):1–36. https://doi.org/10.1080/14792772143000003.

22 Singh RP, Javaid M, Kataria R, Tyagi M, Haleem A, Suman R. Significant applications of virtual reality for COVID-19 pandemic. Diabetes & Metabolic Syndrome: Clinical Research & Reviews 2020;14(4):661–664.

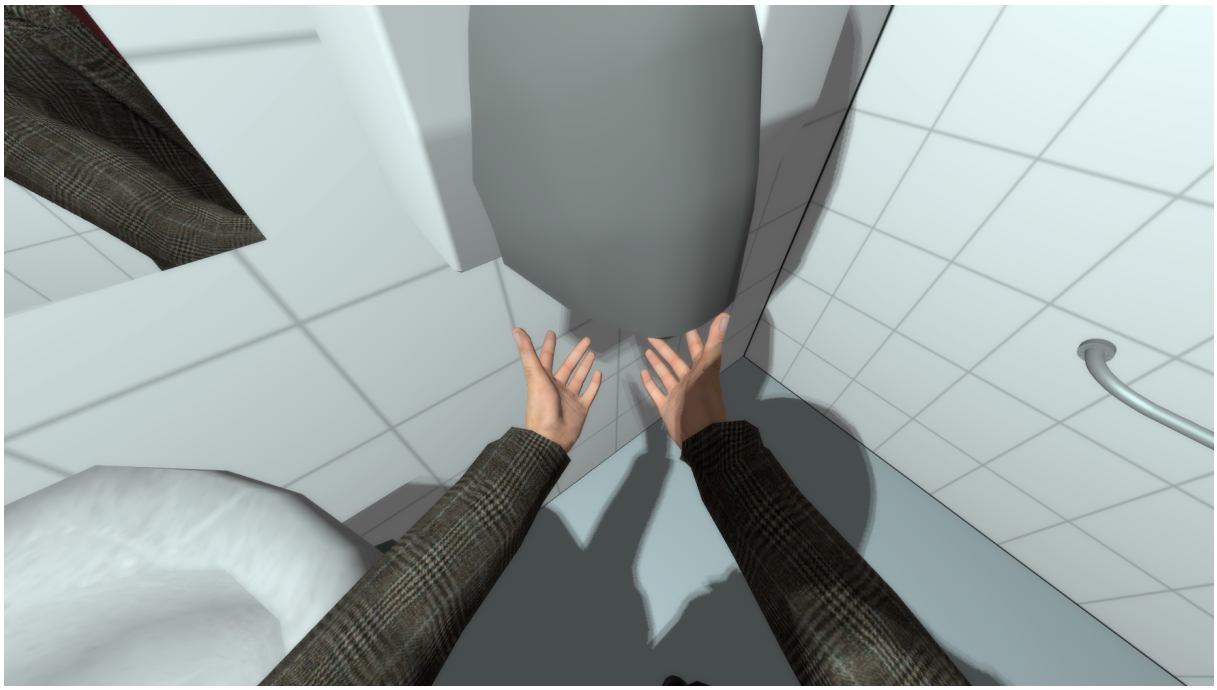
23 The World Health Organization, Ten threats to global health in 2019; 2019. https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019.

Supplementary Material

Avatars

Figure 4: Avatars embodied by participants: young female (top left), old female (top right), young male (bottom left), and old male (bottom right).

Screens



Registered Hypotheses and Primary Analyses

As-avatar refers to measuring vaccination intention as a participant is embodied in a virtual avatar (hence only post intervention).

As-self refers to collection vaccination intentions outside the context of virtual embodiment. As-self vaccination intention was measure before the study (pre), after the study (post), and a week later (follow-up).

We tested the following two hypotheses related to COVID-19 vaccination intention (measured during embodiment; 1-100 likelihood of getting vaccinated), compared between conditions:

> H1. Illusory ownership of an old body results in higher as-avatar COVID-19 vaccination intention, compared to a young body.

H1 was not supported ($p = 0{\cdot}86$).

> H2. Communicating individual and social benefits of vaccination results in higher as-avatar COVID-19 vaccination intention, compared to individual benefits only.

H2 was not supported ($p = 0{\cdot}61$).

Although H1 and H2 were not supported, secondary analyses revealed an interaction effect between the two independent variables for this measure, $F(1, 278) = 5{\cdot}0, p = 0{\cdot}026$ (see Figure 7). A similar result was found with the reduced sample of n = 198 using the pregeristered removal criteria: $F(1, 194) = 5{\cdot}7, p = 0{\cdot}018$. While embodied, vaccination intentions are higher when experiencing the provision of information about personal benefit of vaccination as a young individual, or respectively, information about collective benefit of vaccination in combination with an old virtual body.

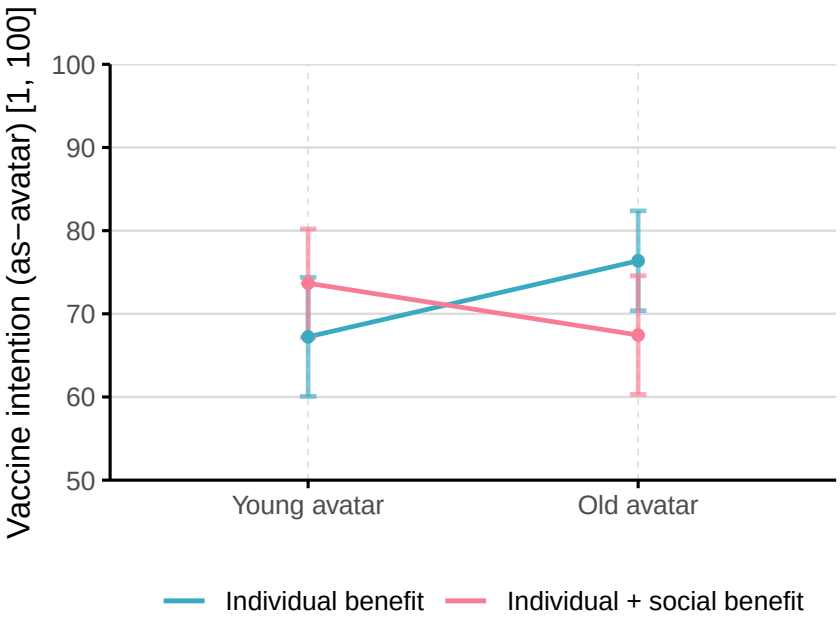


Figure 7: Vaccination intention as measured directly after the VR intervention while the participant is embodied in either a young or old avatar.

We also tested three hypotheses about COVID-19 vaccination intention, comparing pre- and post-intervention measurements:

> H3. As-self COVID-19 vaccination intention increases from pre- to post-intervention measurement, pooling all conditions.

H3 was supported ($p = 6 \times 10^{-6}$).

> H4. As-self COVID-19 vaccination intention increases more strongly from pre- to post-intervention measurement in conditions with old body ownership, compared to a young body.

H4 was not supported ($p = 0{\cdot}81$).

> H5. As-self COVID-19 vaccination intention increases more strongly from pre- to post-intervention measurement in conditions with individual and social benefits communication, compared to individual benefits communication only.

H5 was not supported ($p = 0{\cdot}81$).

Finally, we tested the following hypothesis about the connection between as-self and as-avatar vaccination intentions:

> H6. Post-treatment, as-self COVID-19 vaccination intention is positively correlated to the as-avatar COVID-19 vaccination intention.

H6 was supported ($p = 2 \times 10^{-16}$).

Using preregistered removal criteria

Analyses reported in the paper were conducted on $n = 282$, even if our preregistered criteria entailed $n = 192$ from removal of participants reporting a negative mean embodiment (across three items[1]). From rerunning the analyses with the reduced sample we report almost identical findings: H1 ($p = 0{\cdot}67$); H2 ($p = 0{\cdot}49$); H3 ($p = 4 \times 10^{-9}$); H4 ($p = 0{\cdot}57$); H5 ($p = 0{\cdot}47$); and H6 ($p = 2 \times 10^{-16}$).

Secondary analyses

Embodiment

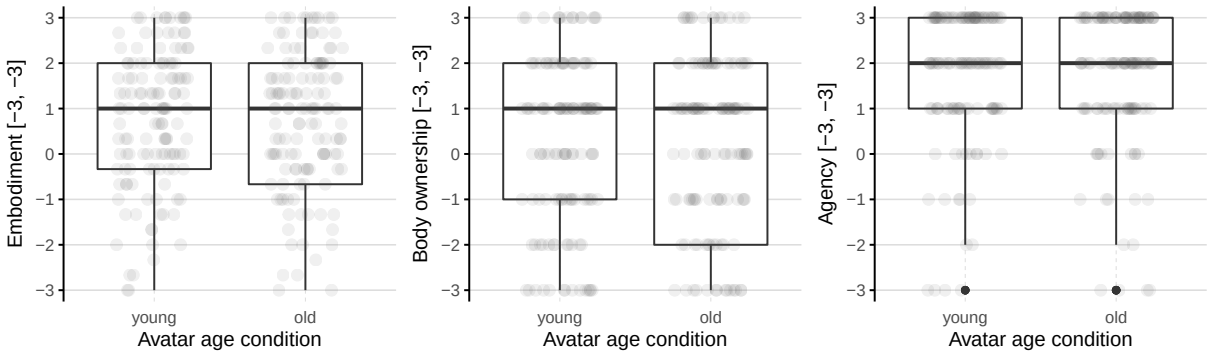


Figure 8: Boxplots of subjective embodiment scores showing medians and interquartile ranges. Mean embodiment of body ownership, agency, mirror body (left); body ownership (middle); and agency (right). See-through circles denote regular observations, black circles denote outliers.

The reported embodiment scores (see Figure 8) are comparable to previous studies employing even more sophisticated technical tracking equipment[1,2]. These measures are encouraging for deploying self-administered embodied VR interventions, where the position of virtual body's limbs are computed using an inverse-kinematics model of three stable points (HMD and both controllers).

Presence

We measured presence (social and physical) using the inventory by Makransky et al.[12]. The collected data shows comparable levels of presence across conditions.

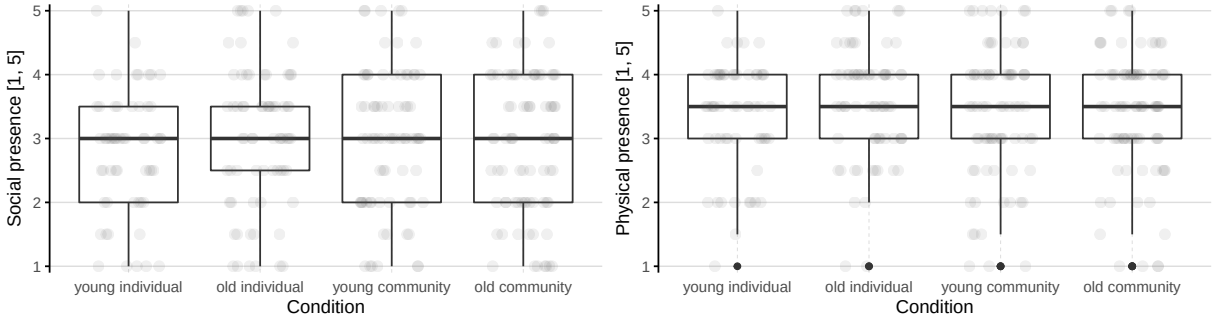


Figure 9: Boxplots of subjective presence scores: social presence (left); physical presence (right).

Effects of individual characteristics

Age

Participant age and their pre-to-post vaccination intention were not correlated, $\rho = 0{\cdot}01$.

Gender

Female participants accounted for a higher pre-to-post vaccination intention than males, however not significantly (see Table 2). We did not find a main effect on vaccination intention for gender, but including gender as an interaction term revealed a significant effect between gender and avatar age ($p = 0{\cdot}006$). A post-hoc Tukey's HSD revealed differences between female and other gender ($p = 0{\cdot}04$), likely caused by reduced self-association with the binary gendered avatars. The 'other gender' group account for less than 3% of the sample.

	n	Pre	Post	Follow-up
Male	255	63·1 (3·6)	71·0 (3·6)	75·1 (3·9)
Female	20	63·0 (14·3)	80·3 (10·8)	84·1 (13·1)
Other gender	7	31·3 (34·5)	42·1 (32·2)	34·5

Table 2: Mean vaccination intention divided between genders. Parentheses showing 95% CIs.

Country

We did not find any significant main or interaction effects for participants' country of origin.

Education

We did not find any significant main or interaction effects for participants' education.

VR Experience

We did not find any significant main or interaction effects for participants' VR experience.

Survey item wordings

Vaccination intention, from 1 (I would definitely not get vaccinated) to 100 (I would definitely get vaccinated):

- What is the likelihood of you being vaccinated when the Covid-19 vaccine is available to you?

Vaccination recommendation, from 1 (I would definitely not recommend getting vaccinated) to 100 (I would definitely recommend getting vaccinated):

- What is the likelihood of you recommending a friend getting vaccinated against COVID-19?

Vaccination readiness, Likert-type scales from 1 (strongly disagree) to 5 (strongly agree):

- **Confidence,** I am convinced that authorities only allow effective and safe vaccines against COVID-19.
- **Complacency**, I get vaccinated against COVID-19 because it is too risky to get infected.
- **Constraints**, Vaccination against COVID-19 is so important to me that I prioritize getting vaccinated over other things.
- **Calculation** (reverse-coded), I only get vaccinated against COVID-19 when the benefits clearly outweigh the risks.
- **Collective Responsibility**, I see COVID-19 vaccination as a collective task against the spread of COVID-19.
- **Compliance**, It should be possible to sanction people who do not follow the COVID-19 vaccination recommendation by health authorities.
- **Conspiracy** (reverse-coded), COVID-19 vaccinations cause diseases and allergies that are more serious than COVID-19 itself.

COVID-19 empathy, Likert-type scales from 1 (strongly disagree) to 5 (strongly agree):

- **AE1**, I am very concerned about those most vulnerable to coronavirus (COVID-19).
- **AE2**, I feel compassion for those most vulnerable to coronavirus (COVID-19).
- **AE3**, I am quite moved by what can happen to those most vulnerable to coronavirus (COVID-19).

Embodiment, Likert-type scales from -3 (strongly disagree) to 3 (strongly agree):

- **MyBody**, I felt that the virtual body I saw when looking down at myself was my own body.
- **Mirror**, I felt that the virtual body I saw when looking at myself in the mirror was my own body.

- **Agency**, I felt that the movements of the virtual body were caused by my own movements.

Presence, Likert-type scales from 1 (completely disagree) to 5 (strongly agree):

- **Physical Presence 1**, The virtual environment seemed real to me.
- **Physical Presence 2**, While I was in the virtual environment, I had a sense of "being there".
- **Social Presence 1**, I felt like I was in the presence of another person in the virtual doctor's office.
- **Social Presence 2**, I had a sense that I was interacting with another person in the virtual doctor's office, rather than a computer simulation.

Demographic variables

- Gender
- Country (determined by IP)
- Age
- VR experience
- Education