Fast Forward: Influencing the future in virtual reality increases real-life pro-environmental behaviour

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Abstract

To reach necessary greenhouse gas (GHG) emissions targets, behavioural change is necessary at the consumer level. Nevertheless, behavioural interventions have only a limited impact on habitual behaviours such as beef consumption, which significantly contributes to the GHGs released. Immersive virtual reality (VR) in the metaverse can transform the current information-based environmental communication into more experience-based communication. To study how such a shift might change its effectiveness, we randomly assigned participants to a VR experience (experiencing and influencing future climate change scenarios based on food choices) or a VR information condition (receiving the same information from a virtual human). The VR experience led to higher intentions to reduce meat consumption and more pro-environmental behaviour in VR and real life as compared to the information condition. Mediation analyses confirm that experiential VR environmental communication can increase people's efficacy beliefs, which increase their intentions and, consequently, lead to a reduction in beef consumption.

1. Introduction

Imagine standing in a national park, watching animals approaching a lake and listening to the sounds of nature. After a few seconds, you travel into the future, witnessing how nature will gradually degrade over the next 30 years due to climate change. Nature becomes silent. The lake water disappears. Animals die. With the increasing availability of immersive virtual reality (VR) technology, we can not only imagine and read about these climate change consequences but also experience them. Moreover, we can experience changing the future by changing our behaviour in VR\(^1\). With the predicted arrival of the metaverse\(^2\), the next iteration of the internet using VR headsets and avatars within virtual worlds\(^3\), we can expect a surge in VR use and, consequently, VR experiences. Users will interact with content in a more interactive way, resulting in a shift from information-based to experienced-based communication\(^4\). Therefore, in this study, we investigate how such experiential versus information-based VR communication can lead to more pro-environmental behaviour (PEB).

To reach global emissions targets and mitigate the consequences of climate change\(^5\), structural measures must be accompanied by behavioural change on the consumer level\(^6\)–\(^9\). Reducing meat consumption is considered crucial, as the current food supply chain contributes more than one quarter of global emissions\(^10\). Food-related emissions could be reduced by up to 70% by adopting more plant-based diets\(^11,12\). Nevertheless, the reported effectiveness of interventions promoting PEB varies\(^9,13\)–\(^15\), and their underlying mechanisms are often unclear, which limits the possibility of scaling up these effects\(^16\). Therefore, creating more persuasive and theory-based interventions for promoting dietary change and understanding when and why they are effective are crucial\(^16\).

There are two main approaches to influencing PEB: via a choice architecture\(^17\), which can be also called ‘nudging’\(^18\), or by influencing the conscious determinants of our behaviour, including knowledge,
attitudes, and intentions\textsuperscript{19}, sometimes referred to as ‘boosting’. The nudging interventions aim to improve the decision-making process by restructuring the environment rather than influencing the conscious determinants of decision-making\textsuperscript{18}. This could include changing the descriptions of food dishes or repositioning meat products.\textsuperscript{17} For example, distinct types of food labelling are cost-effective, easy to implement and believed to influence our taste expectations; therefore, they indirectly influence our food choices\textsuperscript{20}. On the other hand, receiving information on climate impact or animal welfare can influence our attitudes and conscious decisions; still, it may have only a limited impact on our real-life behavior\textsuperscript{17}. In contrast to nudging interventions, boosting interventions are designed to increase competencies so people can make better choices, leading to a potential impact that lasts after the intervention is over. Therefore, while nudging may be especially suitable for improving our decision-making when we have limited time or resources\textsuperscript{16}, influencing the determinants of PEB via behavioural interventions may be necessary to ensure long-lasting behavioural change, pro-environmental lifestyles and broad support for potential adaptive measures\textsuperscript{21,22}.

According to a meta-analysis by van Valkengoed and Steg\textsuperscript{22}, descriptive norms, negative affect, perceived self-efficacy and response efficacy are most strongly associated with motivation to engage with climate change adaptation actions. This is in line with protection motivation theory (PMT), which highlights that a heightened threat appraisal and a coping appraisal are crucial to promoting protection motivation, i.e., intentions to act to diminish a threat\textsuperscript{23–25}. Threat appraisal consists of considerations regarding severity (i.e., how severe one perceives the threatening event) and vulnerability (i.e., how vulnerable one perceives oneself to be to that event). Coping appraisal includes considerations regarding self-efficacy (i.e., the belief that one can perform the protective action) and response efficacy (i.e., the belief that the protective action will reduce the risk of the threat)\textsuperscript{23}.

The underestimation of the risk of climate change consequences due to their abstract and distant nature\textsuperscript{26} is considered one of the main psychological barriers to acting on the threat of climate change\textsuperscript{27}. Immersive VR allows us to visit distant places, have superpowers, or travel in time while feeling that what is happening is real and that it is happening to us\textsuperscript{28}. Therefore, immersive VR has been repeatedly proposed as a suitable tool with which to promote PEB by making the threat of climate change more proximal\textsuperscript{29–31}, e.g., by providing users with the experience of witnessing the icebergs melting\textsuperscript{32}, ocean acidification\textsuperscript{33,34} or coral reef bleaching\textsuperscript{35}. Merely increasing the level of threat appraisal via providing more information about climate change or experiencing its consequences is rarely enough to support behavioural change, as people often lack a feeling of behavioural control over the threat\textsuperscript{27}. As shown by Meijers et al.\textsuperscript{36}, when 360 degree videos are used to increase threat appraisal and thus promote PEB, there is no clear benefit of using immersive VR as compared to less immersive technology. Even though increased spatial presence can result in a higher emotional response\textsuperscript{31,36,37} this is not always sufficient to elicit more PEB\textsuperscript{36,38}. It has been proposed that VR has the capacity to specifically enhance coping appraisal by allowing users to change their behaviour and experience the ability to act pro-environmentally (\textit{self-efficacy}) and that this behaviour makes an impact on nature (\textit{response appra}

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Efficacy \(^1,36,37\). This experiential communication of efficacy has been proposed as more efficient than communicating efficacy beliefs via verbal interventions \(^1,39,40\). Therefore, in this study, we argue that the effectiveness of environmental communication is not only related to what is communicated but also to how it is communicated.

Virtual reality has been shown to have a stronger persuasive power as compared to traditional, less immersive media regarding increasing intentions to act more prosocially \(^38,44,45\), but the impact of VR in terms of affecting real-life behaviour is not very clear \(^36,38,46\). Therefore, in this pre-registered study, we investigated whether experiencing different climate change scenarios in VR while having the chance to change the future by altering food preferences would influence food behaviour in terms of real-world food choice and consumption. We randomly assigned participants to either a VR experience condition or a VR information condition. See Fig. 2 for a comparison of the conditions.

In both VR conditions, participants visited a virtual buffet at which a virtual human invited them to choose between three dishes to eat: beef Bolognese (1), Bolognese with 50% reduced beef content (2), or vegetarian Bolognese, made with plant-based mince (3). After the selection, they received information about the carbon footprint of each dish in written form. Thereafter, participants in the VR experience condition travelled to the national park, where they witnessed the degradation of the natural environment over the next 30 years if everyone continues to eat what they eat today. Afterward, they observed the climate change scenario based on their food choice, and then, they made a new choice to experience a different scenario. By selecting a more climate-friendly choice, participants were able to be part of the solution, thereby gaining a mastery experience with strong experiential feedback, which is the most effective way to gain efficacy \(^45\). Participants in the VR information condition received the same information from the virtual human. At the end of the simulation, participants in both conditions were once again asked to select the dish, from the same three options, that they would choose to eat. After the VR intervention, participants were invited to a real-world buffet, which was visually identical to the VR buffet, where they could select and eat one of the three dishes.

Our behaviour is influenced not only by our attitudes but also by various other factors \(^46\), for example, our habits, the surrounding environment or costs, leading to the well-known intention-behaviour gap. Therefore, boosting and nudging influence only some of the factors that fuel environmental (in)action \(^27,46\), with boosting aiming to change attitudes/intentions and increase the competence needed to make a beneficial decision and nudging aiming to change the microenvironment in which the decision is taking place (see Fig. 1). Whether we act or do not act pro-environmentally after the intervention depends very much on situational factors that are not always present in the laboratory setting. Consequently, providing information about the environmental impact of a specific food can lead to increased pro-environmental attitudes, but this may fail to promote actual behavioural change \(^19\). Thus, as has been shown by a recent study by Hoffman et al. indicating that experiencing extreme weather changes promotes environmental concern and Green voting \(^47\), more salient communication via experiencing may be necessary to trigger behavioural change. This is especially relevant when
influencing efficacy beliefs that seem resistant to analytical processing\textsuperscript{39}, such as when verbal efficacy instructions fail to promote actual behavior\textsuperscript{48}. It is therefore indispensable to measure the impacts of interventions on actual behavior in the laboratory and the real world.

Therefore, in this study, to test the long-term, real-world impact of the intervention, the participants completed a self-reported food questionnaire before and one week after the intervention, from which a corresponding dietary carbon footprint was calculated. In addition, as it is believed that food behavior can be difficult to influence via appealing to attitudes and values, we also tested the impact of nudging, in terms of cost-effective dish label manipulation, on food choices. We manipulated the dish labels in the real-life buffet using an indulgent label (Rich Mediterranean Bolognese) or an explicit label (Vegetarian Bolognese). Based on previous findings\textsuperscript{49,50}, we expected that indulgent labelling would promote vegetarian meal selection by improving taste expectations.

We pre-registered nine hypotheses, of which two were related to intentions and VR behaviour:

H1. The participants in the VR experience condition will report higher intentions to eat less meat in the future as compared to those in the VR information condition.

H2. The participants in the VR experience condition will, in VR, choose food with a lower environmental impact as compared to those in the VR information condition.

Furthermore, two hypotheses were linked to the real-life buffet choice:

H3. The participants in the VR experience condition will, in real life, choose food with a smaller environmental impact as compared to those in the VR information condition.

H4. The participants in the indulgent-labelling condition will, in real life, choose food with a smaller environmental impact as compared to those in the explicit vegetarian-labelling condition.

Two hypotheses were focused on real-world behaviour in terms of dietary carbon footprint:

H5. The participants will have reduced their dietary footprints one week after the intervention (pre- versus follow-up) regardless of the experimental condition.

H6. The participants in the VR experience condition will have a lower dietary footprint one week after the intervention as compared to those in the VR information condition.

Furthermore, to answer the call to investigate how various interventions target the conscious determinants of PEB\textsuperscript{16}, we pre-registered three hypotheses explaining the psychological mechanisms of the presented interventions:

H7. The impact of the VR experience condition on food behaviour (A) and dietary footprint (B) will be mediated by the increase in response and self-efficacy beliefs.
H8. The participants in the indulgent-labelling condition will have higher taste expectations of the vegetarian dish as compared to those in the explicit vegetarian-labelling condition.

H9: The impact of indulgent labelling on food behaviour will be mediated by increased taste expectations.

Moreover, we also explored the relationship between VR behaviour and real-life behaviour to investigate whether VR can be used as a valid PEB measure.

2. Results

Prior to the main analyses, we investigated whether there was any interaction between the two independent factors: the virtual reality scenario (experience versus information) and the labelling (explicit versus indulgent). As we did not find any interactions, we conducted randomisation checks for the two factors separately. We did not find any difference between the groups; therefore, we consider the randomisation procedure successful (for a complete analysis of the interactions and group differences, see Supplementary Results).

First, we investigated whether the VR experience scenario was more effective in inducing intentions to reduce meat consumption. As hypothesised, the VR experience of the future scenario led to higher intentions ($M = 4.28$, $SD = 1.26$) as compared to the VR information scenario ($M = 3.79$, $SD = 1.24$), $W = 2621$, $p = 0.011$, $r = 0.2$, 95% CI [0.04, 0.34]; therefore, Hypothesis 1 was supported. See Fig. 3A for the comparison.

Furthermore, as hypothesised, in VR, the participants in the VR experience condition selected food with less meat than participants in the VR information condition, $W = 4090.5$, $p = 0.028$, $r = 0.17$, 95% CI [0.02, 0.32]. Therefore, Hypothesis 2 was also supported (see Fig. 3B).

When analysing the impact of the conditions on the real-life buffet choice, the difference between the VR conditions was not significant, $W = 3063$, $p = 0.218$, $r = 0.09$, 95% CI [0.01, 0.24],[1] and therefore, Hypothesis 3 was not supported. Nevertheless, the intelligent buffet allowed us to measure the exact consumption levels for all food and, thus, the consumption of beef in grams. An independent t-test showed that participants in the VR experience condition took significantly less beef from the buffet ($M = 60.5$, $SD = 90.3$) as compared to those in the VR information condition ($M = 99.4$, $SD = 145$), $\Delta M = 38.9$, 95% CI [1.87, 75.85], $t(137.12) = 2.08$, $p = .040$, $d = 0.32$, 95% CI [0.03, 0.6]. As beef consumption consisted of a two-step decision, that is, selecting the vegetarian or non-vegetarian option (1) and the amount of sauce taken (2), which resulted in a zero-inflated distribution, we opted to use the Hurdle model to investigate the impact of the VR condition on beef consumption. We found that the VR experience condition influenced the amount of consumed beef, $b = -0.34$, $z = -18.49$, $p < .001$, but did not significantly impact the participant's choice of a vegetarian versus non-vegetarian dish, $b = -0.31$, $z = -1.00$, $p = .316$, which is in line with our previous analysis. Therefore, even when the participants in the VR experience
condition chose the meat option, they ate less meat as compared to the VR information condition. See Fig. 3C for the comparison.

To investigate the effect of nudging, we compared the impacts of indulgent and explicit labelling on the real-life buffet choice. According to our results, the participants in the explicit-label group did not differ from participants in the indulgent-label condition in their real-life buffet choice, \( W = 3327, p = 0.811, r = 0.02, 95\% \text{ CI } [0.003, 0.19] \); therefore, Hypothesis 4 was not supported.

Furthermore, we investigated the impact on real-world behaviour in terms of reported dietary footprint, which was measured one week after the intervention. As hypothesised, the results of the food frequency questionnaire administered one week after the intervention confirmed that participants significantly decreased their dietary footprint from pre- (\( M = 120.78 \text{ kg/CO}_2 \)) to follow-up (\( M = 100.42 \text{ kg/CO}_2 \)), \( \Delta M = 24.6, 95\% \text{ CI } [6.68, 42.46] \), \( t(144) = 2.71, p = .007, d = 0.23, 95\% \text{ CI } [0.06, 0.37] \). Therefore, Hypothesis 5 was supported. Importantly, the self-reported measure of dietary footprint in the follow-up was significantly correlated with the real-life buffet food choice, \( \rho = 0.36, p < .0001 \), which supports the validity of the self-report measure of real-life food behaviour.

We found no difference between conditions in terms of dietary carbon footprint, \( F(1,142) = 0.41, \text{MSE } = 7,519.10, p = .521, \eta^2_p = .003 \); therefore, Hypothesis 6 was not supported. See Fig. 3D. Nevertheless, the change in VR choice (difference between the first and second selections in the VR simulation) predicted the change in dietary footprint from pre- to post-test for the participants in the VR experience condition, \( b = 54.46, 95\% \text{ CI } [10.66, 98.27] \), \( t(73) = 2.48, p = .016 \), but not those in the VR information condition, \( b = -27.10, 95\% \text{ CI } [-69.00, 14.80] \), \( t(68) = -1.29, p = .201 \), suggesting that the VR experience condition influenced the participants’ behaviour one week after the intervention.

To gain a better understanding of the psychological mechanisms behind the behavioural change intervention, we tested various mediation models using the PROCESS macro\textsuperscript{51}. All reported indirect effects were tested for significance using bootstrapping procedures, with the indirect effects being computed using 10,000 bootstrapped samples and 95\% confidence intervals being computed by determining the indirect effects at the 2.5th and 97.5th percentiles. As preregistered, real-life food choice was treated as a dichotomous variable (meat versus vegetarian choice), as PROCESS uses logistic regressions only in the case of dichotomous outcome variables and, therefore, is not suitable for using ordinal variables as an outcome.

The first model (preregistered) assumed a direct effect on the part of self-efficacy and response efficacy on the real-life buffet choice. As hypothesised, the preregistered model revealed indirect effects on the part of self-efficacy (indirect effect: \( -0.15, 95\% \text{CI } [-0.44, -0.003] \)) and response efficacy (indirect effect: \( -0.18, 95\% \text{CI } [-0.446, -0.022] \)). Therefore, Hypothesis 7A was confirmed (see Fig. 4a).

To provide a more comprehensive model in line with PMT, we included intentions as a predictor of behaviour. Mediation analyses showed that the VR experience condition indirectly influenced the real-life buffet choice via increases in self-efficacy and response efficacy, which led to an increase in intentions.
and, consequently, more sustainable food choices. That is, those exposed to the VR experience scenario were more likely to improve their self-efficacy, which increased their intentions to reduce meat consumption, and they were, therefore, more likely to choose more sustainable food (indirect effect: -0.14, 95% CI [-0.336, -0.0106]). Furthermore, they were also more likely to exhibit increased response efficacy, which, again, improved intentions and, consequently, led to more sustainable food choices (indirect effect: -0.08, 95% CI [-0.179, -0.009]). See Fig. 4b.

We tested the same model for dietary carbon footprint, which was measured one week after the intervention. The preregistered model confirmed the indirect effect of the VR experience scenario via increased response efficacy (partially standardised indirect effect: -0.09, 95% CI [-0.204, -0.003]) but not via self-efficacy (partially standardised indirect effect: -0.08, 95% CI [-0.191, 0.0002]). Therefore, Hypothesis 7B was only partially confirmed. Nevertheless, exploring the comprehensive model, including intentions, we found the same indirect pathways as for food choice. We found a significant indirect effect on the part of self-efficacy on intentions (partially standardised indirect effect: -0.041, 95% CI [-0.105, -0.001]), as well as an indirect effect on the part of response efficacy on intentions (partially standardised indirect effect: -0.029, 95% CI [-0.068, -0.002]). See Figs. 5a and 5b for a graphic depiction of the models.

Similarly, exploring the same comprehensive model regarding beef consumption in grams, we also found a significant indirect effect on the part of self-efficacy on intentions (partially standardised indirect effect: -0.05, 95% CI [-0.1128, -0.004]) and indirect effects on the part of response efficacy and intentions on beef consumption (partially standardised indirect effect: -0.03, 95% CI [-0.066, -0.003]). That is, again, the experience VR scenario increased participants’ self-efficacy and response efficacy, which, in turn, enhanced intentions to reduce meat consumption and resulted in lower consumption of beef in grams in the buffet. See Fig. 6 for details.

Furthermore, as the VR buffet was intentionally designed to be an exact visual copy of the real-life buffet, we explored the relationship between the participants’ behaviour in VR and their real-life behaviour. We found a strong correlation between the second VR food choice (after receiving all the information) and food choice in real-life, $\rho = 0.6, p < .0001$, and we also found a correlation between the second VR choice and dietary footprint in the follow-up, $\rho = 0.34, p < .0001$. On the other hand, the reported intentions show a significant but lower correlation with the real-life food choice than the VR food choice, $\rho = -0.48, p < .0001$, indicating that VR behaviour may be a better indicator of PEB in the real world as compared to reported intentions.

Lastly, as preregistered, we investigated the impact of indulgent labelling on taste expectations. The indulgent label group did not differ from the explicit label group in terms of the taste expectations, $M = -0.18, 95\% CI [-0.59, 0.24], t(161.91) = -0.84, p = .400, d = -0.13, 95\% CI [-0.45, 0.18]$. Therefore, Hypotheses 8 and 9 were not supported. Finally, despite the taste expectations predicting the food choice in the buffet, we did not find any evidence for the indirect effect of labelling via taste expectations (indirect effect: -0.11, 95% CI [-0.396, 0.139]). See Fig. 7 for details.
In the preregistration, we specified that we would analyse the impact of the VR condition and the labeling condition on food choice in the buffet using the Kruskal-Wallis test; however, as the Kruskal-Wallis test does not have an option for two independent factors, we opted to use the Wilcoxon Rank Sum Test.

3. Discussion

In this pre-registered intervention study, we investigated whether VR experience can promote pro-environmental behavioural change in real life. We compared the impact of (1) experiencing and influencing future climate change scenarios based on different food choices with the impact of (2) receiving the same information from a virtual human. We study behavioural changes not only in terms of intentions but also choices performed in virtual reality, real-life buffet settings and the real world (follow-up self-reported food consumption, as well as the derived dietary carbon footprint), and we provide findings about how this intervention targets specific determinants of environmental action. We generate four findings that are crucial to the future development of pro-environmental content in immersive environments, including the metaverse.

First, our results indicate that experiencing different climate change scenarios in VR and having the ability to influence the future by making a more pro-environmental choice can lead to change not only in attitudes but also in virtual and real-life behaviour. By providing the same information via a virtual human in the comparison condition, we controlled for the demand characteristics of the study and the knowledge effect. In line with our preregistered hypotheses, the participants who experienced the different future scenarios had higher intentions to reduce their meat consumption. Furthermore, after experiencing the different scenarios, they made virtual choices that were more sustainable as compared to those of the participants who merely heard about the impact of the different food choices from a virtual human. Importantly, in the real-world buffet, the participants who experienced the scenarios consumed significantly less beef as compared to the participants who received the same information from a virtual human. One week after the intervention, participants had significantly decreased their dietary footprint, regardless of the condition. Despite not finding a difference between conditions, the behavioural change in VR (difference between first and second VR choice in the simulation) predicted the change in the dietary footprint (difference between pre- and follow-up) for the participants in the experience condition but not in the information condition. This indicates that the VR experience influenced participants’ behaviour one week after the intervention and that this effect was not due to the study’s demand characteristics.

Second, the results show that experiencing different climate change scenarios and being part of the solution is crucial for promoting coping appraisal because it leads to a significant increase in response and self-efficacy as compared to simply receiving information. Therefore, the effectiveness of environmental communication is not only related to what content is provided but also to how that specific content is communicated. Previous studies have focused primarily on showing the consequences of climate change to promote PEB and related attitudes, which does not always
promote behavioural change. This study shows that the affordance of VR is not only to experience different scenarios that would not be possible in real life but also to show people that they can make a difference and that their behaviour can change the future. By experiencing such a change, coping appraisal increases as compared to having received the same information from a virtual human, which is in line with the previous findings regarding the resistance of efficacy beliefs about change via an analytical approach. As hypothesised, we found that this impact on coping appraisal was crucial to promoting PEB behaviour. Consistent with PMT, we found an indirect effect on the part of the VR scenario on coping appraisal, which, in turn, led to higher intentions to consume less meat and, thus, predicted all behavioural outcome measures, including food choice in the buffet, beef consumption and dietary footprint at follow-up. These results indicate that using more interactive VR simulations that allow users to experience different scenarios that they can influence may be a more powerful way to target threat and coping appraisal and, consequently, PEB as compared to simulations with fixed scenarios, which may not represent an improvement over desktop or even paper communication.

Third, using a digital twin of the real-life buffet in VR allowed us to investigate how much food behaviour in VR translates into real-life food choices. We found a strong correlation (\( \rho = 0.6, p < .0001 \)) between the VR choice after the intervention and the buffet choice. This indicates that, in VR, even a behaviour such as food choice, which is influenced by factors that cannot be present in VR (e.g., smell), corresponds to our real behaviour. Therefore, VR can be a more valid tool with which to measure PEB as compared to attitudinal measures, as indicated by a lower correlation between intentions, \( \rho = -0.48, p < .0001 \), and the real-life buffet choice. This is in line with the assumption that a high sense of presence, a feeling of ‘being there’ in the virtual environment, which is especially strong for immersive VR, can lead to a realistic behavioural response in VR, as has also been shown by previous studies focussing on realistic social behaviour in VR.

Fourth, we found no evidence to support the notion that the nudging manipulation, in terms of labelling, influenced participants’ behaviour or improved the effectiveness of the boosting VR experience scenario. The hypothesised indirect pathway from indulgent labelling to taste expectations to food choice was also not found, as the indulgent labelling did not result in higher taste expectations for the vegetarian option. Most of the studies finding a positive effect on the part of indulgent labelling have been conducted online, which may have limited the external validity of the findings. Nevertheless, nudging through labelling manipulation may be a much more subtle method, and it would require a larger sample size to detect the effect. In addition, it is evident from the results that a subtle nudge is less effective in changing behaviour than a boosting approach.

These findings must be viewed in light of two main limitations. First, we used a self-reported food frequency questionnaire to investigate the impact of the intervention on real-world behaviour in terms of dietary footprint one week after the intervention. This measure is less precise than using the intelligent buffet; nevertheless, it allows us to capture the participants’ behaviour outside of the laboratory. In future studies, it would be beneficial to investigate the long-term effect of the intervention using more reliable
instruments, potentially combining these repeated visits with additional intervention sessions. Second, the nudging intervention used, in the form of dish labelling, could be considered too subtle as compared to the applied VR intervention; therefore, using a more powerful nudging method, for example, reducing the portion size of the meat serving\(^{17}\), would be more meaningful in the following studies.

Despite these limitations, this study has generated crucial findings for future environmental communication. Communicating environmental consequences has been found to be effective in promoting pro-environmental attitudes and intentions\(^{19}\), but it is not always able to promote actual behavioural change. In this study, we show that experiencing different climate change scenarios and being part of the solution can lead to behavioural change, as compared to simply receiving the information, even when the information is communicated in an engaging VR environment.

We found yet another piece of evidence indicating that, in VR, people behave similarly to how they behave in the real world\(^{53,54,56}\). Furthermore, the behavioural change in VR influenced participants’ behaviour outside of the laboratory. That indicates that interventions focused on influencing people to adopt more PEB in the metaverse could potentially spill over into their everyday behaviour. With the predicted arrival of the metaverse and increased digitalisation, we can expect to increasingly consume immersive content and have more immersive experiences\(^{2,57}\), which have the potential to transform our real-life behaviour. This study shows that the shift from information-based to experience-based communication can have a much more persuasive impact on users’ behaviour. In addition to the positive use of immersive experiences, there are domains in which exposing people to experiences rather than information could have less favourable consequences for society, such as influencing people’s shopping behaviour and political preferences or spreading fake news\(^{58}\). Therefore, ensuring that immersive content is created and used responsibly is crucial.

In conclusion, our results indicate that experiencing different climate change scenarios based on different food choices is an effective way to reduce real-life meat consumption and increase intentions to eat less meat, as compared to receiving the same information from a virtual human. Mediation analyses have shown that these effects are due to increases in response and self-efficacy, which are crucial to affecting behavioural intentions. These findings indicate that the shift from information- to experience-based communication may have a more persuasive impact on the user and, therefore, have important implications for future environmental communication in the metaverse.

4. Methods

This study’s design, data collection and analysis plan were registered at Open Science Foundation on 5/09/2022. Unless otherwise stated, the presented study followed the pre-registered plan (access here: https://osf.io/taecm/?view_only=1db5fd833b4147b3b3ba8c61661778e0). The study was approved by the relevant ethical board (approval number 504 – 0339/22-5000, processing of personal data approval number 514 – 0357/22-5000) and was performed in accordance with the ethical standards of the
Declaration of Helsinki (1964) and its subsequent amendments. Informed consent was obtained from all participants.

4.1 Participants

Non-vegetarians aged 18–41 were recruited one week before the study at a large European University campus and via social media (Facebook and Reddit). To recruit participants, we used a pre-questionnaire, which aimed to both query the availability of participants on study days and ensure that participants in our study met all criteria for participation (see Supplementary Fig. 1 for exclusion criteria and participant flow). Participants who met the eligibility requirements were scheduled for one of the five study days (September 5th–9th, 2022) in various time slots (5 pm–8 pm). Participants were compensated with Goodie Bags (filled with food products), which they received after filling out the post-questionnaire one week after the experiment.

The overall sample consisted of \( N = 167 \) participants who completed the experiment, of whom 48% were women (51% men, 1% non-binary). They were aged between 18 and 41 \((M = 26.6; SD = 5.34)\). A total of 46% of participants were from the country, where the study was conducted; 13% were from Southern Europe; 12.5% were from Eastern Europe; 5% were from Western Europe; 4% were from Northern Europe and 12% of the participants were from Asia and the remainder of the world. Regarding education, 28% of the participants had completed a high school education, 37% had completed a college or university degree at the bachelor’s level, 32% of participants had completed a master’s degree or higher and the remaining 3% had completed primary school or other education.

4.2 Procedure and Materials

After filling out the pre-survey, participants were randomly assigned to one of the VR conditions, experience \((n = 83)\) or information \((n = 84)\), and one of the labelling conditions, indulgent \((n = 78)\) or explicit label \((n = 89)\). On the day of their timeslot, participants filled out an informed consent form and completed the VR intervention. After the VR intervention, they were taken to an intelligent Buffet (iBuffet), where they chose and consumed one of three meals (100% beef Bolognese, 50% reduced beef Bolognese or vegetarian Bolognese) and filled out a questionnaire. As the last step, one week after the experiment, participants filled out a post-questionnaire sent out to them via email. See Supplementary Methods for the exact wording of all questionnaires. All additional supplementary materials, including the VR intervention video footage and the original questionnaires, can be accessed from the study repository: (https://osf.io/8k9c5/?view_only=ee19d0ed002f4f08868569c7aeebcb50).

4.2.1 VR intervention and conditions

The VR simulation we created using Unity\[2\] was presented using Oculus Quest 1 or 2, and the virtual humans in the simulation were adapted from the RocketBox library\[59\]. The participants used the Oculus Quest controller to answer questions and indicate their food preferences in the virtual environment.
In both VR conditions, the VR simulation began in a virtual buffet, where participants chose one of three dishes to eat: beef Bolognese (1), Bolognese with 50% reduced beef content (2) or vegetarian Bolognese (3). After making their choices, all participants read information about the environmental impact of each dish (in terms of carbon dioxide emission, e.g., *Traditional Bolognese sauce with minced beef is a less sustainable food choice as compared to a reduced meat sauce and a plant-based sauce. The production of beef used for this dish emits approximately 4.3 kg CO2*). After this, the simulation differed based on the condition that was used. For a detailed manuscript on the VR conditions, see Supplementary Methods.

**VR experience.** In the VR experience condition, participants visited, together with the virtual human, a national park. Using exaggerated feedback, participants travelled thirty years into the future to witness the degradation of the natural environment if everyone were to continue to eat as they do today. This was followed by a demonstration of the future scenario based on the personal food choice they made in the virtual buffet. Subsequently, participants had a chance to see how the environmental impact would change if they had made a different choice. Consequently, participants witnessed all the potential scenarios, i.e., vegetarian Bolognese = the nature gets restored; 50% reduced Beef Bolognese = the nature gets partially restored, there is some water in the lake and some of the animals return; 100% Beef Bolognese = there are forest fires, the glacier melts and there is no water in the lake, that is, nature goes silent.

**VR information.** In the VR information scenario, the virtual human provided the same information as in the VR experience condition. That is how the environment will change if we continue to eat food that is high in carbon emissions, such as the 100% beef Bolognese dish, as well as how we can prevent it by adopting a vegetarian diet (vegetarian Bolognese) or minimising its impact by reducing our beef consumption (50% reduced beef content Bolognese).

At the end of the VR simulation, all participants were asked again to make a VR food choice and decide which dish they would like to eat.

### 4.2.2 iBuffet and Labeling conditions

After completing the VR intervention, participants went to the iBuffet and chose, in real life, between the three dishes: beef Bolognese (1), Bolognese with 50% reduced beef content (2) or vegetarian Bolognese (3). They consumed as much as they wanted. All tables were set beforehand and equipped with tablets, on which each subject had to fill out a questionnaire before, during and after the meal. The iBuffet setting was used as a model for the VR setting and replicated in VR (see Supplementary Fig. 2 for more details).

The iBuffet is an intelligent buffet that not only measures the users’ choice between different decision alternatives but also the quantity of food consumed using integrated scales, which measure the exact number of grams per subject. After arriving at the iBuffet, each participant had an NFC-integrated wristband, with which they had to register at the iBuffet. The participants were shown how to use their wristbands in the iBuffet setting but not the functions (e.g., integrated scales) of the iBuffet. In the beginning, all subjects were first asked to consider all the dishes at the buffet and then to rate them in
terms of their expected taste, healthiness and satiety. Subsequently, each participant could choose one dish and eat as much as they liked from the buffet. After finishing their plates, participants were invited to fill their plates again if they wanted to eat more.

Across all experimental days, the dishes at the iBuffet were labelled with nameplates next to each sauce (Beef Bolognese and 50% Reduced Beef Bolognese). To test the effect of changing the label of the vegetarian dish so as to promote a more sustainable food choice, we modified the explicit label (Vegetarian Bolognese) so as to make it an indulgent label (Rich Mediterranean Bolognese) across the experimental days.

4.3 Measures

4.3.1 The main outcome measures

Behavioural intentions to reduce meat consumption were assessed after the real-life buffet choice using three items on a scale from 1 (not at all) to 7 (every meal; Cronbach’s $\alpha = 0.75$) adapted from Hunter & Röös (2016) (e.g., ‘In the future, I intend to cut the number of meals with meat.’)

Virtual reality food choice was measured using participants’ dish choice between beef Bolognese (1), Bolognese with 50% reduced beef content (2) or vegetarian Bolognese (3) at the beginning and the end of the VR simulation. Because the subjects could choose between three levels of meat content in the dishes (100%, 50% and 0%), we treated this outcome as an ordinal variable for statistical analysis.

Real-life buffet choice was measured as the choice at the iBuffet between beef Bolognese (1), Bolognese with 50% reduced beef content (2) or vegetarian Bolognese (3). We treated this outcome as an ordinal variable for statistical analysis.

Beef consumption was measured using the iBuffet, which recorded the weight (in grams) of the sauces chosen by the participants. It describes the total weight (full-meat option), half the weight of the chosen Bolognese with 50% reduced beef content, and 0 for the vegetarian option.

Dietary carbon footprint, measured in the pre-and post-questionnaire, is calculated according to the results of the food frequency questionnaire adapted from Plechatá et al. in which participants indicate how many times they consumed specific foods during the previous week on a scale from 1 (never) to 9 (8 or more times). The average carbon footprint for each food category was multiplied by the frequency indicated by the respondents. All categories were pooled into one general carbon footprint.

4.3.2 Mediators

Data on the participants’ self-efficacy and response-efficacy were measured after the real-life buffet choice. Self-efficacy was assessed using two items (Cronbach’s $\alpha = 0.87$) adapted from Plechatá et al. (e.g., ‘I feel capable of adopting more climate-friendly eating habits.’) Response efficacy was measured using three items (Cronbach’s $\alpha = 0.87$) adapted from Hunter and Röös (e.g., ‘If most people change...’).
their eating habits (according to suggested measures) the consequences of climate change will decrease.) The response scale ranged from 1 (strongly disagree) to 7 (strongly agree).

Taste expectations were measured before participants chose the dish in the iBuffet with one item on the scale from 1 (not tasty) to 7 (very tasty): “How would you rate your expectations regarding the satiety level (how full you would feel after eating it) of the following three dishes?”

### 4.3.3 Control variables

In the pre-questionnaire, we further collected data on climate anxiety (Cronbach's $\alpha = 0.68$) using four items adapted from Hogg et al.,62 food neophobia (Cronbach's $\alpha = 0.85$) using ten items from Damsbo-Svendsen et al.63, experience with meat analogues using one item adapted from Hartmann et al.64 and food choice motives using twelve items to map twelve motives adapted from Onwezen et al.65. Additionally, in the VR task, participants were asked about their spatial presence (Cronbach's $\alpha = 0.88$) using five items adapted from Makransky et al.66 and cybersickness (Cronbach's $\alpha = 0.67$) using three items adapted from Sevinc and Berkman67.

We also collected data on taste expectations and health expectations regarding satiety level during the VR and iBuffet experience (e.g., ‘How would you rate your expectations regarding the satiety level (how full you would feel after eating it) of the following three dishes?’) These variables were rated on a scale from 1 (healthy/full at all) to 7 (healthy/full). Finally, after their choice at the iBuffet, participants rated the liking (appearance, taste, texture and smell) of the dishes adapted from Gutjar et al.68. At the end of the study, food waste per person was documented by weighing the leftovers of the dishes in grams.

### 4.4 Deviation from the pre-registration

Despite pre-registering four VR conditions with different vegetarian dish labelling (explicit versus indulgent), due to human error, the labelling of the dishes in the VR simulation was explicit only (i.e., vegetarian Bolognese) in all conditions regardless of the labels in the real-life buffet. This resulted in two VR conditions and two labelling conditions. As we did not find any interaction effect between the labelling and VR conditions, we assume that this inconsistency did not influence the impact of the real-life labelling. Furthermore, in the pre-registration, we specified that we would analyse the impact of VR condition and labelling condition on food choice in the buffet using the Kruskal-Wallis test; nevertheless, as Kruskal-Wallis does allow testing for the effect of two independent factors, we opted to use the Wilcoxon Rank Sum Test.


### Declarations

#### Data availability statement

Anonymous individual participant data, analysis files and a data dictionary with the variable descriptions and other supplementary files are available to anyone from the OSF study repository.
References


16. van Valkengoed, A. M., Abrahamse, W. & Steg, L. To select effective interventions for pro-environmental behaviour change, we need to consider determinants of behaviour. *Nat Hum Behav* 6, 1482–1492 (2022).


**Figures**

**Figure 1**

Experimental procedure. The VR simulation began with an introduction to a virtual buffet by a virtual human. Prior to and after the intervention, all participants had to choose which one of three different Bolognese sauces they would like to eat. In the VR experience condition, the participants were then taken to a national park, where they travelled to the future to witness the consequences of climate change if everyone chose to eat the way they do today and, later, how the future would change if everyone chose the same as they did during the VR buffet (using exaggerated feedback\(^4\)). After that, the participants
picked another dish and witnessed different scenarios based on the different impacts of the food options, e.g., Vegetarian Bolognese = preservation of nature, and 100% Beef Bolognese = forest fires and glacier melt. In the VR information condition, the participants received the same information about the consequences of climate change from the virtual human. After the VR intervention, all participants made a real-life choice in a buffet, and the consumed amount of food was also registered.

**Figure 2**

Various PEB outcome measures and the factors influencing them in relation to the present study. The figure depicts the hypothesised relationships between our experimental manipulations and these factors.
Figure 3

Different intervention outcomes by VR condition. Beef consumption (D) depicts the participants who did not select the vegetarian option (0 grams of beef). Legend: the black line indicates the median of the data, and a box indicates the interquartile range. Black dots represent outliers.
Mediation analysis models show that the VR experience significantly influenced response efficacy and self-efficacy, which had a direct effect on the real-life buffet choice (A). The second model (B) shows an indirect path from response and self-efficacy to food choice via intention. The coefficients are partially standardised. Significance levels are as follows: *: p<.05, **: p<.01, ***: p<.001.
Figure 5

Mediation analysis models show that the VR experience significantly influenced response efficacy and self-efficacy, which had a direct effect on dietary carbon footprint (A). The second model (B) shows an indirect path from response and self-efficacy to food choice via intention. The coefficients are standardised. Significance levels are as follows: *: $p<.05$, **: $p<.01$, ***: $p<.001$. 
Figure 6

Mediation analysis models show that the VR experience significantly influenced response efficacy and self-efficacy, which had an indirect effect on beef consumption via intention. The coefficients are standardised. Significance levels are as follows: *: p<.05, **: p<.01, ***: p<.001.

![Diagram](https://example.com/diagram.png)

Figure 7

The mediation analysis model of the effect of labelling on taste expectations shows no direct or indirect effects on the part of labelling on food choice. The coefficients are partially standardised. Significance levels are as follows: ***: p<.001.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementarymaterialNHB.docx](https://example.com/supplementary_material.docx)