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Increasing Environmental Awareness with immersive Virtual Reality?

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This study was designed to investigate the change in pro-environmental attitudes through exposure to one of three virtual reality (VR) environments visualising climate change.

One of the greatest challenges faced by humanity is climate change, which has already produced dramatic effects on the environment: sea ice and mountain glaciers are melting, sea levels are rising, precipitation patterns (rain, snowfall) are changing, extreme weather events are becoming more frequent, and wildlife populations and habitats are shifting (Watts et al., 2019). Due to negative effects of climate change on social and environmental determinants of health (e.g., air pollution, drinking water shortage, heat waves), the World Health Organization has identified climate change as one of the greatest health threats of the 21st century (McMichael et al., 2003). Climate change is associated with increased greenhouse gas emission by humans (Pachauri et al., 2014). In order to counteract climate change, it is therefore important to make people aware of the issue of global warming and to change their attitudes and behavior.

However, this endeavor has turned out to be challenging, and people's level of concern does not appropriately reflect the scope of the problem (Carmichael & Brulle, 2017).

One source of the problem is that climate change is a relatively invisible and abstract phenomenon: many people are not directly faced with the consequences of climate change, the effects take place over many years (temporal distance) and the consequences don't necessarily occur at the same place as the causing behavior (spatial distance). In the present study, we explored the use of immersive VR as a tool to overcome this problem and potentially increase people's environmental awareness.

Environmental awareness (or environmental literacy) requires knowledge about climate change (cognitive aspect) and a pro-environmental disposition (affective aspect Kim, 2020). VR interventions can visualize effects of climate change that can otherwise not be experienced directly due to large time spans (e.g., glacier melting). A carefully designed virtual experience can have an impact on both cognitive and affective aspects of environmental awareness. It might help users to generate a cognitive model of the

mechanism and effects of climate change, and it might increase the feeling of being related to and emotionally connected with the environment. We therefore suggest that VR can be an effective medium to target and shape environmental attitudes to a certain degree.

There is preliminary evidence that immersive VR increases environmental awareness and potentially pro-environmental behavior (Ahn et al., 2014; Fauville et al., 2020; D. M. Markowitz et al., 2018; Petersen et al., 2020). Researchers have for example visualized the tree-cutting process and studied its impact on paper conservation (Ahn et al., 2014), an underwater world to show the impact of rising sea water (D. M. Markowitz et al., 2018), or the landscape of Greenland to demonstrate the melting ice sheet (Petersen et al., 2020). While these studies report promising results, several crucial questions remain open. First, most of these results are based on a comparison of environmental awareness before and after immersive VR exposure, without an additional media comparison. It therefore remains unclear whether immersive VR is more powerful in increasing environmental awareness when compared to traditional media (e.g., text, 2D desktop demonstration). Second, previous studies did not manipulate basic design elements within the immersive VR (except for some avatar modifications; see D. M. Markowitz et al., 2018). It therefore remains open which design characteristics of an immersive VR are relevant for increasing environmental awareness. In this study we focus on a particular design aspect: visual realism (i.e., how realistic the virtual environment is). Previous studies showed that visual realism is one of the determinants of presence (i.e., the subjective feeling of being in the virtual world (Slater and Wilbur, 1997)). For example, in scenarios designed for participants suffering from fear of heights or other fear stimuli, more visual realism (polygon count and texture resolution) resulted in increased presence and affective responses (Gromer et al., 2019). Increased presence is also associated with enhanced interest and personal involvement in immersive VR learning experiences (Makransky & Petersen, 2021). Based on these results, we hypothesize that immersive VR is most effective with high levels of visual realism. Since developing a high realistic VR environment may costs

many times more than a less realistic VR environment, the results from this study will not only be crucial to optimize the positive effect of immersive VR experiences on environmental awareness but also for efficient VR development in general.

We chose to work with a visualisation of the Aletsch glacier to represent the negative effect of climate change in Switzerland. The Aletsch glacier is the largest and best known glacier in Switzerland and is featured in many newspaper articles about climate change as the glacier is expected to diminish severely within the next 80 to 100 years. By demonstrating the effects of climate change via melting glaciers, and by simulating many years in a few minutes, we aimed to make the invisible effects of climate change visible and directly experiential to the study participants.

In order to study design aspects of VR, we created three virtual environments (VE's), all displaying the same narrated sequence of the Aletsch glacier melting but systematically differing in the visualisation style along the dimensions *design* (well designed vs. standard) and *realism* (realistic vs. abstract). *A+* was the well designed abstract condition, *R+* was the well designed realistic condition, whereas *R-* was less sophisticated in design but stylistically realistic (see figure 1). In a secondary step, three control groups were recruited to account for the possibility of changed attitudes by merely engaging with topics related to climate change. The control interventions systematically varied the level of visualisation and were: Watching a screen cast of *R+* (*V*), reading a text which included screenshots of *R+* (*TP*) and just reading a text (*T*). The information content and the duration of all six interventions were comparable. Our three research questions were: Does the experience of glacier melting in VR increase peoples' environmental awareness? Is visual realism in VR necessary to increase environmental awareness? Are VE's more effective than traditional media in increasing environmental awareness?

Results

The structure of the results section follows the structure of the experimental setup. First, we checked whether the manipulation worked as intended, then we compared the three VE conditions to each other. In a third step, we compared the VE conditions to

the control conditions.

Manipulation check

After participants were exposed to the VE, they were asked to rate their general affective experience on the three single item scales *excitement*, *enjoyment*, *pleasantness of the experience*, and their specific experience regarding the virtual environment on the two single item scales *graphical pleasantness of the environment* and *realism of the environment*, as well as their feeling of presence and suspension of disbelief. We designed the VE's in such a way that the affective experience should not differ between the conditions. Participants should rate the VE's differently with respect to *realism* and *graphical pleasantness* - the visual design components of the VE's. Presence and suspension of disbelief are subjective judgments that measure how strongly a participant felt like *being in the environment*. These two scales are strongly related to the concept of immersion. We did not expect that rating to differ between the conditions.

As intended, the realism of the environment was rated significantly different for the three conditions, $F_{realism} = 5.26$, $p = 0.008$; $M_{R+} = 5.48$, $M_{R-} = 5.09$, $M_{A+} = 4.33$. We designed the VE's to differ in graphical pleasantness, with $R+$ and $A+$ being the more pleasant environments. The trend of graphical pleasantness went into the same direction as the scale *realism* and was not significant. $F_{graph.pleas.} = 2.99$, $p = 0.057$. The different VE conditions had no significant influence on the three ratings of the experience (enjoyment; pleasantness; excitement; a trend for *excitement* was going into the same direction as the ratings of the environments, $F_{excitement} = 2.467$, $p = 0.093$). Neither presence (*ipq*) nor suspension of disbelief (*sod*) varied significantly between the three conditions, $F_{sod} = 0.47$, $p = 0.628$; $F_{ipq} = 1.84$, $p = 0.167$. When we compare the three VE conditions to the three control conditions with respect to the experience, the VE conditions were rated as more exciting ($M_{VE} = 6.38$, $M_{Control} = 5.53$) and more enjoyable ($M_{VE} = 6.38$, $M_{Control} = 6.45$) than the control conditions, *excitement*: $F = 27.45$, $p < 0.001$; *enjoyment*: $F = 17.60$, $p = 0.013$. *Pleasantness* of the experience was not affected, neither was *realism* nor *graphical pleasantness* when comparing the

VE conditions to the *V* condition.

To summarize, the VEs varied discernibly in realism and somewhat in graphical pleasantness, while the overall experience remained unchanged (as visualized in figure 2). We therefore considered the manipulation of VEs as successful.

VE Conditions

There was a consistent increase in pro-environmental attitudes across the NEP and the NR scales after the VE experience, *NEP* increase: $\beta_{time} = 0.09$ $CI[0.031 \text{ to } 0.157]$; *NR* increase: $\beta_{time} = 0.08$ $CI[0.007 \text{ to } 0.144]$. Moreover, both the average IAT and the average NR score showed differences between conditions. Importantly, neither of the four dependent variables showed any interactions between *time* and *condition*. The missing interaction terms indicated that the *change* in attitudes was not dependent on the VE-design. While the interventions had an impact on attitudes, there is no evidence for differential effects regarding the design choices we presented. Importantly, our results suggest that investing in more realism does not necessarily foster changes in attitudes over that achieved by a much less effortful abstract design.

VE vs Control

In a hierarchical model that estimated random effects for each individual and random effects for each experimental conditions, we investigated the overall effect of all three VE conditions compared to the three control conditions. In figure 3 we display the conditional means of each dependent variable including bootstrapped confidence intervals for participants in the VE conditions and the participants in the control conditions over both time points. This figure is based on the most flexible model which includes the VE main effect and the interaction of time and VE.

For CCS, NEP, and NR whether a participant received a VE or a control intervention did not affect the respective score change. The VE intervention had a significant effect on the increase of the IAT score, $\beta_{interaction} = 0.16$, $CI[0.021 \text{ to } 0.307]$; $\chi^2 = 5.01$, $p = 0.025$. The NR score painted a similar picture (see figure 3) but the difference in increase between the control group and the VE group was not significant,

$\beta_{interaction} = 0.078$, $CI[-0.015 \text{ to } 0.17]$; $\chi^2 = 2.70$, $p = 0.100$. We found that the VE's were consistently favourable at changing environmental attitudes, but only significantly so for the IAT.

Discussion

This study investigated the effectiveness of VE visualisations of climate change on environmental attitudes. We were specifically interested in the role of design choices where we compared one abstract and two realistic depictions of the Aletsch glacier melting.

We could show that our VE environments did work in the intended way: R+ was perceived as more realistic, A+ was perceived as not realistic. Overall, we found no evidence that realism in VE depictions favours either presence, suspension of disbelief, nor pro-environmental attitude changes. All three VE's were as likely to improve the two aspects of environmental awareness NEP and NR, but neither improved CCS nor IAT scores. When compared to control groups we found that VE's were not only more exciting to use for participants, but also managed to increase a participant's implicit associations with the environment. Although non-significant, our results might also point to the possibility that also nature relatedness might increase more using VE as compared to less immersive media, but this needs to be confirmed with increased statistical power. This would be especially hopeful, as connectedness to nature is a key component of the affective part of environmental awareness and essential to developing and furthering pro-environmental behavior (Kim, 2020).

As there were many subjective choices going into the design and the realisation of the different environments, we cannot conclusively say that realism plays no role in presence or suspension of disbelief. It may well be that our *well designed and realistic* condition (R+) was not realistic enough, or that the design of the *less realistic* condition (R-) was still too good to produce to see differences in experience effect between the conditions. We could show that on the level of our virtual environments the abstract and well designed environment (A+) elicited just as much presence and suspension of disbelief,

and the user experience was just as good as it was for the two realistic conditions.

Capturing the many facets of environmental awareness proved to be challenging. While we defined both cognitive and affective components of environmental awareness as crucial, there is no one set of scales and tests which cover the range of dimensions of environmental awareness. Thus, we had to incorporate independent and potentially overlapping scales to capture aspects of environmental awareness which we found most useful for our study. NR, NEP, and CCS were well validated scales, but the IAT was created by ourselves (for lack of an existing IAT) based on a validated example IAT to capture an implicit dimension of environmental awareness. As for the CS scale, we found that participants scored very low. This may have been due to the lack of climate change scepticism which naturally lead to less reliable results at the extremes of a scale. A more subtle scale for CCS might have been of more use for this study. Further, we did not capture any behavioural dimension of environmental awareness, nor did we capture climate change knowledge. The content we created and used as stimuli did not primarily aim to educate, and the information it contained was very specific to the melting of the Aletsch glacier and not about climate change or the environment in general.

The results from this study have important implications for future research. First of all, our results highlight the need for a rigorous assessment of the effectiveness of immersive VR interventions, by comparing immersive to less immersive media. Our results also point to the importance of using implicit measurements in addition to questionnaires when capturing environmental awareness. More efforts need to be done to develop and validate such implicit measurements. For future VR experiences, we also recommend to create a more solution-oriented VE where participants can have a more interactive role and learn more about actions they can take to reduce greenhouse gas emissions and other pro-environmental behaviour (e.g., reducing animal product consumption and effective heating). This concurs with recent claims that effective climate change communication should also focus on solutions rather than solely highlight impacts (e.g.; E. Markowitz et al., 2014).

Materials and methods

Materials

Four measures aimed to capture the multidimensional construct *environmental attitudes*. The *New ecological paradigm* questionnaire (NEP) measured pro-environmental sentiment most generally (Dunlap et al., 2000). The *climate change scepticism* scale (CCS) measured the extent to which participants questioned the severity of climate change (Whitmarsh, 2013). An affective component of environmental attitude was captured by the *nature relatedness* (NR) questionnaire (Nisbet et al., 2008). To measure the implicit attitudes towards the environment we created an *implicit association test* (IAT) analogous to Wilson and Smith (2017) which was scored using the improved scoring algorithm (Greenwald et al., 2003).

Particular for the VE's, secondary measures included the 14 item Igroup presence questionnaire (Igroup, n.d.), realism, two qualitative questions about the VE design (realism and graphical pleasantness) and three questions about the subjective experience of the VE's (excitement, pleasantness, and enjoyment).

Stimuli

The three VE's were all based on the same underlying 3d model and glacier melting simulation created for a museum experience. A narrator commented on what was happening and guided and directed the user through the experience. In the background, a realistic sound of the melting glacier (recorded with microphones in the actual glaciers) set the mood and the sound stage. The *V* condition was a video of a typical experience of *R+* recorded by us. The screenshots used in *TP* were from that very screen cast.

Subjects

A total of 142 participants were recruited (age: $mean = 27.21$, $sd = 9.47$) 82 of which identified as women. Participants were randomly assigned to the respective condition and were not aware of the alternative VE's and control conditions.

Design

The study employed a between subjects design measuring all dependent variables both before and after the exposure to the condition. All DV's but the IAT were first measured via online questionnaire approximately one week before the exposure. The first measure of the IAT was conducted upon arrival to the experiment session. There were a total of 6 conditions - three were VE's (A+, R+ and R-), three were control conditions (V, TP, T). The original experiment was planned with only the three VR sessions. Only after preliminary analysis the control groups were recruited as the effects did not differ much between the VE designs.

Analysis

We conducted separate repeated measures analyses of variance (RMANOVA) for each dependent variable using the lme4 package (Bates et al., 2015). A step-up modeling approach with subsequent likelihood ratio tests was used to determine the final model for each dependent variable. In these models, two parameters were of special interest: First, the main effect of time: We were interested whether pro-environmental attitudes generally increased after being exposed to the conditions. Second, the time-condition interaction: This parameter modeled whether an effect differed between the varying conditions. These analyses were conducted using the lme4 and the lmerTest packages in R (Bates et al., 2015; Kuznetsova et al., 2017).

The analysis consisted of three stages. First, we had to confirm that the experience and the impressions of the VE conditions truly mirrored our intentional design choices.

Then, on participants receiving a VE condition, we investigated whether there was a general increase in pro-environmental attitudes (main effect β_{time}) and whether such an effect differed between the VE conditions. Finally, we compared all the VE conditions to all the control conditions (main effect β_{VR}) using random effects both for the subjects and for the conditions.

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DV		Estimate	CI	Std. Error	t value
IAT.1	(Intercept)	0.40	[0.22; 0.569]	0.09	4.42
	time	-0.09	[-0.192; 0.007]	0.05	-1.81
	vrTRUE	-0.32	[-0.571; -0.071]	0.13	-2.51
	time:vrTRUE	0.16	[0.021; 0.307]	0.07	2.24
CCS.1	(Intercept)	1.47	[1.373; 1.569]	0.05	29.35
	time	-0.03	[-0.08; 0.015]	0.02	-1.36
NEP.1	(Intercept)	3.83	[3.718; 3.936]	0.06	69.03
	time	0.04	[-0.013; 0.083]	0.02	1.45
NR.1	(Intercept)	3.77	[3.674; 3.859]	0.05	80.06
	time	0.07	[0.031; 0.12]	0.02	3.33

Table 1

Best fitting model

Figure 1. Three views each taken from the three different VRE's.

Figure 2. Manipulation check

Figure 3. Conditional mean and CI of all four DV's