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What is the best way of delivering virtual nature for improving mood? An experimental comparison of high definition TV, 360° video, and computer generated virtual reality

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ABSTRACT

Exposure to 'real' nature can increase positive affect and decrease negative affect, but direct access is not always possible, e.g. for people in health/care settings who often experience chronic boredom. In these settings 'virtual' forms of nature may also have mood-related benefits (e.g. reducing boredom) but it has been difficult to separate effects of nature content from those of delivery mode. The present laboratory-based study explored whether exposure to three different delivery modes of virtual nature could reduce negative affect (including boredom) and/or increase positive affect. Adult volunteer participants ($n = 96$) took part in a boredom induction task (to simulate the emotional state of many people in health/care settings) before being randomly assigned to view/interact with a virtual underwater coral reef in one of three experimental conditions: (a) 2D video viewed on a high-definition TV screen; (b) 360^0 video VR (360-VR) viewed via a head mounted display (HMD); or (c) interactive computer-generated VR (CG-VR), also viewed via a HMD and interacted with using a hand-held controller. Visual and auditory content was closely matched across conditions with help from the BBC's Blue Planet II series team. Supporting predictions, virtual exposure to a coral reef reduced boredom and negative affect and increased positive affect and nature connectedness. Although reductions in boredom and negative affect were similar across all three conditions, CG-VR was associated with significantly greater improvements in positive affect than TV, which were mediated by greater experienced presence and increases in nature connectedness. Results improve our understanding of the importance of virtual nature delivery mode and will inform studies in real care settings.

1. Introduction

1.1. Contact with nature, mood and positive/negative affect

There is growing evidence that direct contact with, and psychological connectedness to, the natural world can support a variety of health and wellbeing outcomes (Bratman et al., 2019; Hartig, Mitchell, Vries, & Frumkin, 2014) including affect and mood (Bowler, Buyung-Ali, Knight, & Pullin, 2010; McMahan & Estes, 2015). Key foundational theories propose different mechanisms linking nature exposure and improvements in emotional wellbeing. The Biophilia Hypothesis, for example, argues that humans evolved in close proximity with natural environments, and as such, have an innate need to affiliate with nature, which when satisfied, leads to positive feelings (Wilson, 1984). Stress Reduction Theory (SRT) proposes that encountering the kind of unthreatening natural scenery that supported our ancestor's survival, triggers a rapid psycho-physiological response via parasympathetic activation, leading to decelerated arousal, a reduction in negative feelings and an increase in positive ones (Ulrich, 1981). Evidence to support SRT has, however, been inconsistent. For example, one study found that viewing nature images led to lower stress and greater positive affect, compared with viewing urban scenes (Ulrich et al., 1991); but others found that walking

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in natural and urban areas produced equivalent effects on stress indicators, while only the nature walks produced significant increases in positive mood (Stigsdotter, Corazon, Sidenius, Kristiansen, & Grahn, 2017).

Another approach, Attention Restoration Theory (ART), holds that our over-stimulating modern lifestyles can deplete attentional resources, leading to cognitive fatigue and negative mood (Kaplan & Kaplan, 1989) Nature, on the other hand, is suggested to be rich in 'softly fascinating' elements (such as dappled light on water) which are proposed to engage involuntary attention in an effortless fashion, allowing for recovery of mental processes and associated improvement in mood (Hartig & Jahncke, 2017; Kaplan & Kaplan, 1989; Ohly et al., 2016; Stevenson, Schilhab, & Bentsen, 2018). Again however, evidence is mixed - while some field studies have found that exposure to 'restorative' nature improved attention, decreased negative mood and increased positive mood significantly more than urban environments (e.g. (Hartig, Evans, Jamner, Davis, & Gärling, 2003); others found improved attentional capacity following nature exposure was unrelated to mood (e.g. (Berman, Jonides, & Kaplan, 2008). Differences in the ways that experiments are conducted and in how ART is measured, have made meta-analysis/quantitative synthesis challenging (Hartig & Jahncke, 2017). Thus, although natural environments evidently have the capacity to improve positive mood states and, to a slightly lesser extent, reduce negative ones (McMahan & Estes, 2015), findings have been inconsistent, and this may in part be because previous research has tended to focus on positive and negative moods in general, rather than specific affective states. A key aim of the current research was to explore the role of one negative mood state in particular that has received relatively little research attention in the nature field but which may have particular importance, namely boredom.

1.2. The issue of boredom

Boredom can be defined as "an unpleasant, transient affective state in which an individual feels a pervasive lack of interest" (Fisherl, 1993). Daily time-use studies suggest that feeling bored is widespread and can be experienced in a range of contexts (Chin, Markey, Bhargava, Kassam, & Loewenstein, 2017). This often includes health and care settings where long waiting times, lack of meaningful activity, and low external environmental stimulation, social engagement, and personal autonomy, have frequently been linked with low morale and complaints of boredom among hospital inpatients (Clarke, Stack, & Martin, 2017; Newell, Harries, & Ayers, 2011; Steele & Linsley, 2015) and care home residents (Cohen-Mansfield, Marx, & Werner, 1992; Ejaz, Schur, & Noelker, 1997; Slama & Bergman-Evans, 2000). In turn, boredom in care homes has been linked with loneliness (Slama & Bergman-Evans, 2000), agitation (Cohen-Mansfield et al., 1992), and depression (Ejaz et al., 1997). It is the latter context that we were particularly interested in, because we felt it was a setting where nature exposure could play a key role in improving mood and reducing boredom (see below).

There are several definitions and theoretical views on boredom (Westgate & Wilson, 2018). Proponents of situational perspectives describe boredom in terms of under or sub-optimal stimulation (Posner, Russell, & Peterson, 2005) suggesting that boredom results from being trapped in an under-stimulating situation. We believe this perspective applies to many health and care situations and is thus of particular interest for the current work. Cognitive theories describe boredom as a state of disengagement and a failure to focus attention (Danckert & Merrifield, 2018). Given the importance of Attentional Restoration Theory in the nature-health field (Kaplan & Kaplan, 1989), natural environments could help re-focus attention, particularly through soft-fascination processes, and thus also play a role from a cognitive perspective on boredom. Finally, functional theories suggest that feelings of boredom provide a useful signal to motivate behavioural change (Elpidorou, 2018), which may not be readily possible in many health and care settings. Consequently, our main focus was on a combination of situational and cognitive perspectives, which draw on the idea that nature's intrinsically fascinating properties may alleviate boredom by providing a welcome alternative to a frustrating, under-stimulating situation.

1.3. Simulated forms of nature: issues and advances

Accessing 'real' outdoor natural environments is not always practical, including for individuals in isolated/confined indoor environments such as health and care settings. This has led researchers to explore the potential benefits of a range of 'simulated' natural stimuli in these settings, such as biophilic corridors (Cohen-Mansfield & Werner, 1998), indoor plants (Bringslimark, Hartig, & Patil, 2009), fish aquariums (Edwards & Beck, 2013), bedside nature murals (Diette, Lechtzin, Haponik, Devrotes, & Rubin, 2003) and nature artwork (Nanda, Eisen, Zadeh, & Owen, 2011), in addition to indirect access via nature window views (Raanaas, Patil, & Alve, 2015; Ulrich, 1984).

The restorative potential of digital representations of nature via images (e.g. (Kjellgren & Buhrkall, 2010), videos (Kahn et al., 2008), and projections of videos through different screen sizes (de Kort & Ijsselsteijn, 2006) has also been extensively studied (Browning, Saeidi-Rizi, McAnirlin, Yoon, & Pei, 2020), yet many of these forms of simulated nature remain limited in their ability to truly represent natural environments, which may reduce their effectiveness compared with real nature (White et al., 2018). For example they may have lower capacity to: a) offer the scope and scale of a natural setting, b) transport a person 'away from' their physical surroundings, c) depict change, development and novelty, d) allow individual choice or personalised experiences, and e) engage multiple sensory modalities (Hedblom et al., 2019; Kjellgren & Buhrkall, 2010).

Developments in virtual reality (VR) technology offer a way to potentially overcome some of these limitations by allowing people to more fully immerse in a simulated natural environment. This is achieved either by sitting in a small room onto which images of nature are simultaneously screened on all visible surfaces (e.g. (Annerstedt et al., 2013), or by wearing head-mounted display (HMD) equipment which excludes or reduces sensory stimulus from the outside world, allowing them to become fully immersed in the panoramic viewing of an alternate environment (Furman et al., 2009; Mosso et al., 2009). Although both approaches have been shown to reduce stress and pain, HMDs are often more practical and cheaper in applied settings such as offices (Yin, Zhu, MacNaughton, Allen, & Spengler, 2018), dental surgeries (Tanja-Dijkstra et al., 2018), intensive care units (Gerber et al., 2017) and other care settings, where their ability to mask the external environment may allow individuals a brief 'escape' from these often busy and noisy environments.

In addition to differences in technology, VR approaches to 'immersing' people in nature also differ in the mode of content, between: a) pre-recorded 360° videos of real environments made using specialist cameras (i.e. 360-VR, e.g. (Yu, Lee, & Luo, 2018)); and b) graphical simulations of real or imagined environments built using computer software (i.e. Computer Generated or CG-VR, e.g. (Small, Stone, Pilsbury, Bowden, & Bion, 2015). Both approaches use a HMD with a head tracking system to generate instantaneous co-ordination of the user's head movements between the physical and virtual worlds (Slater & Sanchez-Vives, 2016). This allows the user to "look around" the virtual environment, in a way that is not possible with standard video presentations. However, although the most popular approach used to date in the nature field (e.g. (Anderson et al., 2017; Browning, Mimnaugh, van Riper, Laurent, & LaValle, 2020; Palanica, Lyons, Cooper, Lee, & Fossat, 2019; Yu et al., 2018), 360-VR has an important restriction - the filming is set in advance, meaning that the user is still a relatively passive observer with limited choices about "where to go" or "what to do". By contrast, through the use of, for instance, hand-held controllers, the CG-VR approach can enable users to make decisions about where to explore and to reach out and "touch" objects in the environment which can react in turn to the user's own movements, and thus offers a more interactive and dynamic experience, e.g. (Tanja-Dijkstra et al., 2018).

The obvious drawback of CG-VR is that these settings are not "real" in the same way 360-VR settings are. A key, as yet unanswered, question therefore is whether it is better for mood and other outcomes (e.g. boredom) for virtual experiences to use real nature environments with limited individual agency (360-VR), or simulated natural environments but with more agency (CG-VR). Key to unpacking this issue could be the degree of 'experienced presence' users feel in the two situations, where presence is defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998, p. 225). To the extent that experienced presence is beneficial for improving outcomes such as mood, then it becomes important whether presence is higher in the 360-VR or CG-VR setting.

There have been relatively few studies which directly compare the delivery mode of different virtual technologies, which has made it difficult to tease apart content from delivery. Crucial for any investigation of this issue would be the development of CG-VR settings that were as close to the real 360-VR settings as possible, otherwise differences could be the result of context and environments rather than the reality versus interactivity trade-off (see (Higuera-Trujillo, López-Tarruella Maldonado, & Llinares Millán, 2017) for a similar approach in the context of a virtual shopping experience). Further, to gain a more informative picture of how useful either technology might be relative to the standard delivery mode in care settings (i.e. television or video), a third condition would also need to be developed where again the context and content was as similar as possible. The aim of the current study was to do precisely this, and develop highly similar content that could be delivered through the three modes of television (control), 360-VR and CG-VR, a task aided by having access to unseen footage of 360-VR content from the BBC's Blue Planet II series.

1.4. Use of VR in health and care settings

A 2017 review of virtual nature in hospital inpatients identified that use of VR technology across different medical settings has generally been safe and resulted in high patient satisfaction (Dascal et al., 2017). Although relatively few clinical studies have trialled nature-based immersive VR specifically; there have been some promising findings. For example, 360-VR of local nature scenery has been shown to promote feelings of relaxation for cancer patients undergoing chemotherapy in Florida (Scates, Dickinson, Sullivan, Cline, & Balaraman, 2020), and exposure to a CG-VR tropical island correlated with significant reduction in anxiety within individuals with Generalized Anxiety Disorder, versus a waiting list control group (Gorini et al., 2010). In more acute settings, nature-based VR has most often been utilised for short-term distraction from pain, anxiety or distress during surgical procedures, e.g. (Furman et al., 2009; Mosso et al., 2009; Tanja-Dijkstra et al., 2018).

However, taking a holistic view of people's experiences in these environments, the majority of a hospital inpatient's time is not spent undergoing procedures or receiving treatment. In nursing and long term care homes, most of a resident's time is spent not engaged in any activity at all (Cohen-Mansfield et al., 1992; Harper Ice, 2002). A frequent consequence of long periods of unoccupied time is onset of chronic poor mood states, including feelings of boredom (Cohen-Mansfield et al., 1992; Slama & Bergman-Evans, 2000). As alluded to in section 1.2, we know of no previous research that has examined whether and how contact with nature, let alone virtual forms of nature, could be used to help alleviate boredom. Nevertheless, we anticipated that if nature contact is beneficial for mood (including boredom), the greater presence an individual experiences in a virtual natural environment, the greater the beneficial impacts on mood should be.

1.5. Nature connectedness

One potential pathway through which greater feelings of virtual presence in nature afforded by the immersive capability of VR may lead to improved wellbeing, could be through inducing increased subjective feelings of connectedness with nature. There is evidence that psychological connectedness to the natural world, over and above direct contact, is associated with positive subjective wellbeing; higher levels of nature connectedness positively correlates with happiness, positive affect, vitality and life satisfaction (Capaldi, Dopko, & Zelenski, 2014). Some have argued that 'nature connectedness' has trait-like properties similar to attitudinal constructs (Brügger, Kaiser, & Roczen, 2011) and, as with other attitudes, changes can occur with greater exposure to nature associated with increases in state connectedness in the short-term (Mayer, Frantz, Bruehlman-Senecal, & Dolliver, 2008; Nisbet & Zelenski, 2011). Further, the beneficial impacts of nature exposure on positive emotions can be partially mediated by increases in connectedness to nature (Mayer et al., 2008). Thus by facilitating contact with nature, individuals may develop greater feelings of nature connectedness, which in turn could have positive impacts on their mood. In the current research we were interested to see whether interacting with the same virtual nature context through different delivery modes that offered increasing levels of immersion in nature might impact state nature connectedness to different extents, and thus also have an effect on positive and negative affect (Mayer et al., 2008).

1.6. The current study

Before field testing can take place in applied medical/care contexts it is necessary to conduct more controlled laboratory-based studies to ensure that the intervention is feasible and does no harm, and to provide evidence of effect sizes needed to develop formal clinical trials (e.g. see (Tanja-Dijkstra, Pahl, White, Andrade, May, et al., 2014; Tanja-Dijkstra, Pahl, White, Andrade, Qian, et al., 2014). The research presented here relates to this early stage of the process.

The main aim was to compare the effects of three increasingly immersive modes of virtual nature exposure by randomly assigning experimental subjects to 5 min exposure to one of three conditions: 1) high definition 2D television (TV); 2) 360-VR; and 3) CG-VR, on people's affective sates including, we believe for the first time, boredom. A key difference between the two types of VR is that 360-VR only allows viewers to observe the virtual environment, whereas CG-VR allows users to actively influence the virtual environment through use of handheld controllers (thus, increasing potential immersion). TV was selected as a control condition because it is less immersive than VR and watching TV is a common pursuit in health and care settings (Wood, Womack, & Hooper, 2009).

In order to simulate the experience of a 'boring' healthcare environment, participants took part in a boredom induction task before being exposed to one of the three virtual nature conditions. In order to reduce the possibility of content confounding with delivery mode, all three conditions were designed to present participants with a dynamic underwater scene with colourful fish, corals and a turtle. The choice of content was partly due to research finding that aquaria and tropical fish have been found to be particularly good at promoting positive emotions, and are regularly used in a range of health-care settings (Cracknell, Pahl, White, & Depledge, 2018; Cracknell, White, Pahl, Nichols, & Depledge, 2016) partly because underwater environments are novel natural settings which are not readily accessible for most individuals and so may be a worthwhile environment to re-create virtually, and partly due to the availability of very high quality material across all three conditions linked to the BBC's award winning Blue Planet II series. In line with previous nature-wellbeing research we also collected data on positive and negative mood (McMahan & Estes, 2015) and nature connectedness (Mayer et al., 2008), as well as experienced presence in line with previous simulated nature work (Higuera-Trujillo et al., 2017; Weinstein, Przybylski, & Ryan, 2009). We reasoned that the more immersive the delivery mode, from 2D TV to 360-VR, to CG-VR, the greater the 'presence' participants would feel (Cummings & Bailenson, 2016;

Higuera-Trujillo et al., 2017), which in turn would reduce negative mood and boredom in particular, while simultaneously increasing positive mood. Because nature connectedness has also been found to be associated with mood, we reasoned that the more immersive VR experiences would lead to increases in nature connectedness, which in turn would (at least partly) explain the anticipated greater improvements in mood in the VR modes. Our specific hypotheses (summarised in Fig. 1) were as follows:

1.6.1. Hypothesis 1: experienced presence

H1. Experienced presence will be significantly higher in the VR conditions than TV, with CG-VR condition being higher than 360-VR condition.

1.6.2. Hypothesis 2: boredom

H2. After controlling for pre-intervention boredom, post-intervention boredom will be significantly lower in the VR conditions than TV, with the CG-VR condition being lower than 360-VR condition.

1.6.3. Hypothesis 3: General mood

H3a. The pattern of overall negative mood will follow the same pattern as for boredom.

H3b. The pattern for positive mood will be reversed such that positive mood will be significantly higher in the VR conditions than TV, with CG-VR higher than 360-VR.

1.6.4. Hypothesis 4: Nature Connectedness

H4. Nature connectedness will follow the same pattern as for positive mood in H3b.

1.6.5. Hypothesis 5: Mediation

H5a. Presence will mediate the relationship between condition and mood (boredom, negative affect, positive affect).

H5b. Nature connectedness will (partially) mediate the relationship between presence and mood (boredom, negative affect, positive affect).

2. Materials and methods

2.1. Design and participants

The study had a 3 level virtual nature exposure mode (TV, 360-VR, CG-VR) between-participants design. As there was a lack of previous research using our measures, we consulted a University of Exeter statistician, who advised estimation of sample size based on a conservative anticipated effect size of d = 0.3. The minimum total sample size required to produce this effect with 80% power, allowing for an alpha error of α = 0.05 and a correlation of 0.6 among repeated measures was calculated as n = 90. Although independently derived this was exactly the same conclusion as the authors of a similar paper, which also used three conditions to compare the effects of VR nature with actual nature on mental health (Browning, Mimnaugh, et al., 2020).

Participants (n = 96) were adults >18y recruited from the general public (i.e. external to the host university) through traditional and social media. There was no upper age limit. Participant demographics are available in Table 1. We did not formally assess the individuals' health but did exclude participants if they met certain self-reported criteria (for example, motor issues affecting the head or neck – see supplementary materials SM1 for a complete list). All participants provided informed consent, and the study was approved by the University of Exeter Medical School Research Ethics Committee.

2.2. Setting, VR equipment and virtual nature environment exposure stimuli

The VR equipment was installed in a quiet windowless room measuring 3 × 4m at The University of Exeter. For the 360-VR and CG-VR conditions, an HTC VIVE VR headset with inbuilt headphones was connected to a PC Specialist custom-built gaming PC with an Intel® Core™i7 Quad Core Processor i7-7700k (4.2 GHz) 8 MB Cache and 8 GB NVIDIA GEFORCE GTX 1080 graphics card. A high-definition 17-inch high-definition LCD monitor was used for the TV condition.

Table 1
Participant demographics. Tests for significant differences between groups conducted with Chi-square.

Characteristic	TV (n = 31)	360-VR (n = 31)	CG-VR (n = 34)	Between conditions
Sex, n				X^2 (2) = 1.403, *p* = 0.50
Female	18	17	15	
Male	13	14	19	
Age group, n				X^2 (10) = 7.66, *p* = 0.66
18-25	6	5	3	
26-35	10	8	8	
36-45	8	8	9	
46-55	4	2	8	
56-65	2	6	5	
66-75	1	2	1	
VR experience, n				X^2 (4) = 1.87, *p* = 0.76
Never	20	18	17	
Once or twice	7	10	12	
More often	4	3	5	
UW experience, n				X^2 (4) = 0.438, *p* = 0.36
Never	11	8	10	
Once or Twice	5	12	8	
More often	15	11	16	

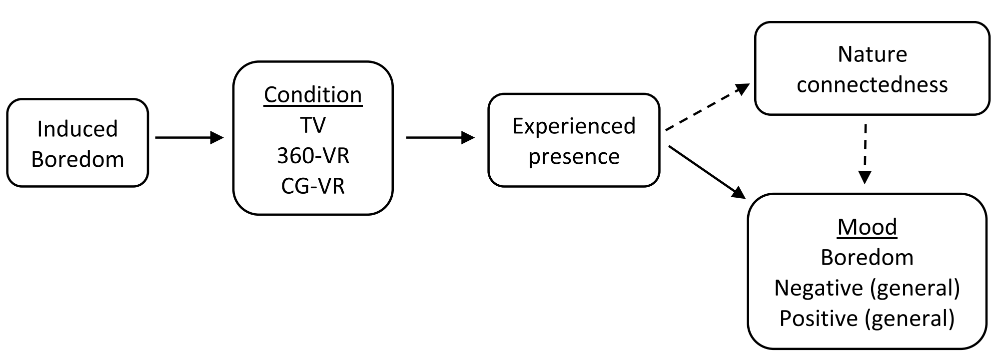

Fig. 1. An overview of the induction, intervention and hypotheses.

All three exposure modes focused on underwater tropical coral reef scenes (See Fig. 2 for example stills from each setting). The control video (TV) used footage from the BBC Blue Planet II series (permission granted by the BBC). This was edited to match the content of the other conditions as closely as possible.

The 360-VR was compiled from footage filmed as part of Blue Planet II but never publically broadcast. The footage was of the same reef location as the TV content and was provided by the BBC's Natural History Unit. The 360-VR exposure mode allowed head rotation for viewing in all directions, but not movement around the room or virtual interaction (i.e. participants did not use the handheld controllers).

The CG-VR condition consisted of an 'off-the-shelf' underwater experience, TheBlu: Reef Migration (WeVR: https://www.viveport.com/apps/1b591122-7ab7-4c27-9d31-cbaf9ef8e1e1). This programme places the participant on an underwater ledge among corals, anemones and small colourful reef fish. It allowed head rotation (as with the 360-VR) but the user could also physically move around within the confines of the room. They could also interact with fish and corals using the HTC VIVE handheld controllers. The programme includes an inbuilt semi-transparent grid that appears around the user when they are approaching the pre-programmed parameters on room size. Participants in this condition were advised before putting the HMD on, to step backwards if this grid appeared. An experimenter was always present in the room to prevent collisions and provide guidance where needed.

Each virtual nature exposure mode included natural underwater sounds and a corresponding documentary-style narrative, which was again edited to be as similar as possible across conditions. The narrative was included because: a) the original Blue Planet II TV footage had such a narrative and this is considered a key feature of this format of delivery in realistic settings; b) piloting in the VR conditions suggested occasional audio prompts aided orientation, especially for first-time users; and c) we wanted to increase comparability across the three settings (i.e. if narrative had only been included in the TV condition, any differences could be due to this alone). To mitigate potential confounding effects, narratives for each mode were designed to be as comparable as possible. Each was recorded by the same person, a colleague chosen by the team after pre-testing several candidates. The narrative provided context for each scene, but was brief and interspersed with long periods of silence to support immersion into the setting (full texts available in supplementary materials SM2).

2.3. Procedure

Participants attended one session of approximately 1 hour for their respective condition during summer 2018. They first provided information on demographics and prior VR and underwater experiences, then viewed a boredom induction video before undergoing randomisation (using a random number generator) to one of the three virtual nature conditions for 5 min. Nature connectedness, positive affect and state boredom were measured before and after the virtual nature exposure. The level of presence experienced during the virtual exposure was reported at post-test. There followed a short exit interview and finally, a full experimental debrief. Fig. 3 summarises the experimental procedure.

2.4. Boredom induction

Boredom was induced using a previously validated 4-minute video (Markey, Chin, Vanepps, & Loewenstein, 2014). In a monotone voice, a man talks about his work at an office supply company and describes a conversation with a client, eating lunch at his desk, and the determinants of stationary prices.

2.5. Measures

The full versions of all scales discussed here, along with principal components analyses, can be found in supplementary materials (SM3-SM6).

Experienced presence. The sum score of five items from the Presence and Reality Judgement Questionnaire (Baños et al., 2000), which was specifically developed for virtual environments, was used to measure experienced presence. Items with high factorial loadings representing each of the scale's three factors (reality judgement, internal/external correspondence and attention/absorption) were selected based on applicability to the current work. Participants gave ratings on a 0–10 Likert scale; sum scores potentially ranged 0–50. Internal consistency for

Fig. 2. Example stills from the TV (above left), 360-VR (above right) and CG-VR (below right) exposure conditions.

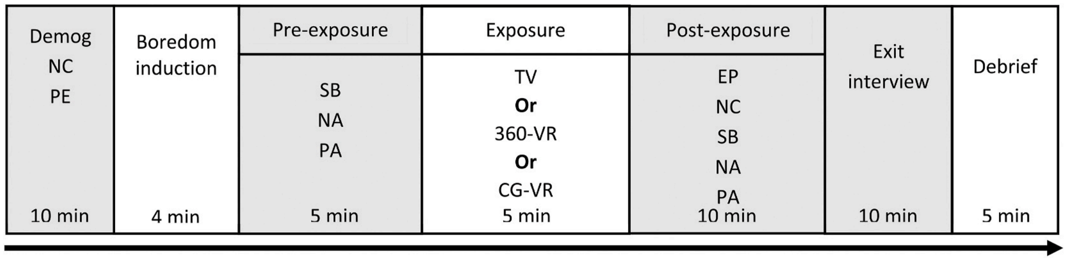

Fig. 3. Experimental procedure. Data collection periods shaded in grey. Demog = demographics; NC = nature connectedness; PE = prior experiences; SB = state boredom; PA = Positive affect; NA = Negative Affect; EP = experienced presence.

this scale was high (Cronbach's α = 0.89).

Boredom. The sum score of 14 items from the Multidimensional State Boredom Scale (MSBS) was used to measure state boredom (see supplementary materials SM4 for the full scale with items used highlighted (Fahlman, Mercer-Lynn, Flora, & Eastwood, 2011). The MSBS has demonstrated strong psychometric properties including convergent validity with similar constructs such as trait boredom, depression, inattention, and life satisfaction (Fahlman et al., 2011). Example items include "I feel bored", "It is difficult to focus my attention", and "I wish I was doing something more exciting". Participants indicated agreement with each item on a 1 (strongly disagree) to 7 (strongly agree) Likert Scale; sum scores potentially ranged between 14 and 98. Internal consistency measures for the items at pre- and post-exposure were high (Cronbach's α = 0.94; 0.89 respectively).

Mood. Positive and negative mood was measured with sum scores of the 6 negative and 6 positive items from the Summary of Positive and Negative Experiences (SPANE) scale, respectively (Diener, Wirtz, & Tov, 2010). Participants indicated using a 1–5 scale the frequency with which they have experienced general feelings (e.g. negative, positive, sad, happy) over the past four weeks. For present purposes, wording was adapted to ask about participant's feelings right now, and strength of feeling descriptors (1 = Not much or not at all; 2 = A little bit; 3 = A moderate amount; 4 = Quite strongly; 5 = Very strongly) were used. Sum scores for each sub-scale potentially ranged from 6 to 30. Internal consistency for the positive affect items at pre- and post-exposure was high (Cronbach's α = 0.92; 0.92 respectively).

Nature connectedness. The single item Inclusion of Nature in Self (INS) scale (Schultz, 2002) was used to measure nature connectedness. We adapted the scale's original wording to reflect our use as a state measure and to specify marine environments, by asking participants to: "Please put a circle around which diagram best describes how you feel *right now* about your connection with marine environments". Participants indicated from series of increasingly interlocking Venn diagrams their subjective feeling of connection with marine environments (with the two circles being labelled "self" and "marine"). Scores range from 1 (completely separate circles) to 7 (completely overlapping circles). INS was selected for its simplicity, spatial representation of connectedness, high positive correlations with both wellbeing (Capaldi et al., 2014), and environmental attitudes (Schultz, 2001), and due to its previous use as a state measure following nature exposure (Liefländer, Fröhlich, Bogner, & Schultz, 2013; Nisbet & Zelenski, 2011).

Prior experiences. Participants' previous experiences of VR and underwater settings were explored at the beginning of the session by asking: a) "How many times have you experienced virtual reality?" and b) "How many times have you been snorkelling, free-diving or scuba-diving?" with response options: "Never"; "Once or Twice"; "More often". Our study was not powered to be able to explore whether responses to these moderated outcomes, but asking them did ensure we could check whether experience differed as a function of condition and thus needed to be controlled for.

Exit interview. Participants were fully debriefed about the purposes of the study during an exit interview, and as the current study represented a stage in the development of a full randomised controlled trial, they were also asked about their experiences of the technology, the procedures etc. A full analysis of this qualitative data is beyond the scope of the current paper and will be presented elsewhere as part of the development of the next stage of research.

2.6. *Analytical approach*

2.6.1. *Linear regressions to explore effects of condition on outcomes (Hypotheses 1–4)*

Following Tanja-Dijkstra et al. (2018), who used a similar 3 condition VR experimental design, the effect of condition on our dependent variables (i.e. boredom, mood, presence, nature connectedness) was explored using a series of regressions with condition as the main predictor, and with TV as the reference category and 360-VR and CG-VR as dummy variable predictors. In the case of boredom, negative affect, positive affect and nature connectedness, pre-intervention scores were controlled for. Although our main concern was with whether the two types of VR would be different from TV, we were also interested in possible 360-VR and CG-VR differences, and for these analyses we made 360-VR the reference category against which to compare CG-VR.

2.6.2. *Structural equation models (SEMs) to explore potential mediating pathways (Hypothesis 5)*

If support for hypotheses 1–4 was found, such that different conditions influenced outcomes, we planned to conduct serial mediation models exploring the potential paths to boredom, negative affect and positive affect through presence and nature connectedness as proposed in Fig. 1. Following Valente and MacKinnon's (2017) recommendations on assessment of mediation in the pre-test-post-test control group design (Valente & MacKinnon, 2017), a structural equation model (SEM) would be specified using ANCOVA and latent change score specification (McArdle, 2008) to represent change between pre- and post-test outcomes. Further details of the precise model specified is presented in section 3.6, as it depended on the support for previous hypotheses. Data analyses were performed in the STATA v.14 (StataCorp, College Station, TX) and Mplus v.8 software packages.

3. Results

There were no significant differences in any of the participant demographics as a function of condition (see Table 1), so they were excluded in subsequent analyses. Pre- and post-intervention scores for boredom, negative affect, positive affect and nature connectedness, as well as post-intervention experienced presence scores are presented in Table 2. A series of one-way ANOVAs comparing pre-intervention scores as a function of condition (TV, 360-VR, CG-VR) found no significant effects on any of our variables of interest: Boredom: F (2,93) = 1.04, p = 0.359, $\eta^2 = 0.02$; Negative mood F (2,93) = 1.40, p = 0.253, $\eta^2 = 0.03$; Positive Mood F (2,93) = 0.71, p = 0.931, $\eta^2 = 0.02$; Nature Connectedness F (2,93) = 0.26, p = 0.773, $\eta^2 = 0.01$. Bivariate correlations between all variables are given in supplementary materials (SM7).

Table 2
Means (M) and standard deviations (SD) of presence; boredom; negative affect; positive affect; and nature connectedness by measurement time (Pre = before nature exposure; Post = following nature exposure) and exposure mode condition.

Measure	Time	TV		360-VR		CG-VR	
		M	(SD)	M	(SD)	M	(SD)
Presence	Post	21.06	(6.97)	32.87	(9.98)	40.00	(6.60)
Boredom	Pre	53.19	(17.27)	49.10	(17.21)	55.71	(20.86)
	Post	30.94	(9.32)	29.58	(12.14)	28.29	(10.24)
Negative affect	Pre	7.55	(2.91)	7.0	(2.35)	8.32	(4.05)
	Post	5.19	(0.54)	5.61	(1.41)	5.71	(2.01)
Positive affect	Pre	18.10	(5.69)	18.06	(4.63)	17.65	(5.76)
	Post	22.52	(4.93)	22.55	(4.95)	25.06	(3.48)
Nature connectedness	Pre	3.52	(1.59)	3.65	(1.54)	3.79	(2.00)
	Post	4.52	(1.46)	4.74	(1.55)	5.38	(1.65)

3.1. Manipulation check

Participants showed moderate levels of boredom after the induction (M = 52.76 (SD = 18.61)). A one-samples *t*-test comparing the mean (across all three conditions combined) to the mid-point on the MSBS (i.e. 56) suggested that our participants were, on average, not significantly different from the mid-point on the scale, $t\ (93) = 1.71$, $p = 0.09$.

3.2. Hypothesis 1: experienced presence

Supporting H1, both the 360-VR (B = 11.81, p < 0.001) and CG-VR (B = 18.94, p < 0.001) elicited greater experienced presence than TV (Table 3). Further, CG-VR also elicited greater presence than 360-VR (B = 7.13, $p < 0.001$).

3.3. Hypothesis 2: boredom

Despite a substantial drop in boredom across the three conditions combined ($M_{diff} = -23.20$, t (95) = 11.79, p < 0.001), contrary to H2 neither the 360-VR (B = −0.82) nor CG-VR (B = −2.97) resulted in significantly lower boredom than TV (Table 3), and there was also no difference between the 360-VR and CG-VR (B = −0.82, $p = 0.41$).

3.4. Hypothesis 3: general mood

As with boredom, there was a significant drop in negative mood across the three conditions combined ($M_{diff} = -2.23$, t (95) = 6.91, p < 0.001), but contrary to H3a neither 360-VR (B = 0.49) nor CG-VR (B = 0.41) resulted in significantly lower general negative mood than TV (Table 3). Of note however, although not significant, both coefficients are positive, suggesting that negative mood, if anything, was slightly higher than in the VR conditions compared to TV.

There was a significant increase in positive mood across the three conditions combined ($M_{diff} = 5.50$, t (95) = 8.88, p < 0.001), and partially supporting H3b, CG -VR was associated with significantly greater positive mood than TV (B = 2.65, $p = 0.015$). Indeed, positive mood in the CG-VR condition was also significantly greater than for 360-VR (B = 2.61, $p = 0.017$).

3.5. Hypothesis 4: Nature connectedness

Nature connectedness also increased significantly across the three conditions combined ($M_{diff} = 1.23$, t (95) = 9.75, p < 0.000), and partially supporting H4b, CG-VR was associated with significantly greater nature connectedness than TV (B = 0.67, $p = 0.015$), and marginally significant greater connectedness than 360-VR (B = 0.52, $p = 0.052$).

3.6. Mediation analysis

Given the similar drops in boredom and negative affect across all three conditions, we focused the mediation analysis on only those variables that were sensitive to condition, i.e. presence, nature connectedness and positive mood. Specifically we developed a model that tested: a) whether the differences between the modes of virtual nature exposure on positive affect were mediated by experienced presence; and b) whether any effects of experienced presence on positive affect would be mediated by improvements in nature connectedness.

The SEM had the following specification features (Fig. 4): a) experienced presence was regressed on (i) the CG-VR and 360-VR exposure mode categories (with TV as the omitted reference category), and on (ii) pre-exposure positive affect, and (iii) pre-exposure nature connectedness to account for any confounding; b) change in nature connectedness was regressed on (i) CG-VR and 360-VR exposure mode categories; (ii)

Table 3
Regressions predicting outcomes as a function of condition and pre-intervention scores.

	Presence			Boredom			Negative mood			Positive mood			Nature connectedness		
	95% CIs			95% CIs			95% CIs			95% CIs			95% CIs		
	B	Upper	Lower	B	Upper	Lower	B	Upper	Lower	B	Upper	Lower	B	Upper	Lower
Condition	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
TV	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
360-VR	11.81***	(7.82,	15.80)	-.82	(-6.08,	4.44)	.49	(-.22,	1.28)	.04	(-2.14,	2.22)	.14	(-.40,	.68)
CG-VR	18.94***	(15.03,	22.84)	−2.97	(-8.10,	2.16)	.41	(-.29,	1.12)	2.65*	(.52,	4.78)	.67*	(.14,	1.20)
Pre-intervention															
Boredom	–	–	–	.13*	(0.16,	.25)	–	–	–	–	–	–	–	–	–
Negative mood	–	–	–	–	–	–	.13**	(.04,	.22)	–	–	–	–	–	–
Positive mood	–	–	–	–	–	–	–	–	–	.23**	(.07,	4.78)	–	–	–
Nature connect.	–	–	–	–	–	–	–	–	–	–	–	–	.66***	(.53,	.78)
Constant	21.07			23.98			4.20			18.28			2.21		
R^2	.49			.06			.10			.14			.56		

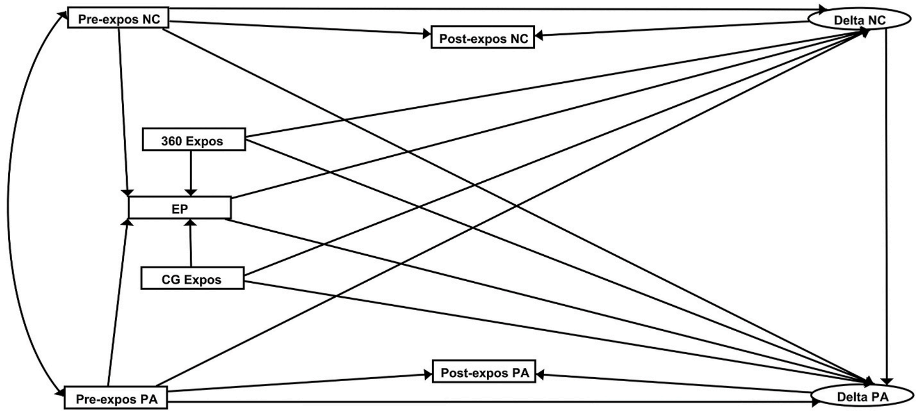

Fig. 4. Pre/Post-expos NC = pre/post-exposure nature connectedness; Delta NC = change in nature connectedness; 360 Expos = 360-VR exposure mode; CG Expos = CG-VR exposure mode; EP = Experienced presence; Pre/Post-expos PA = pre/post-exposure positive affect; Delta PA = change in positive affect.

pre-exposure nature connectedness, to account for stability, and on (iii) pre-exposure positive affect scores, to account for cross-lagged effects; (iv) experienced presence; c) change in positive affect was regressed on (i) the CG-VR and 360-VR exposure mode categories; (ii) change in nature connectedness, (iii) experienced presence, (iv) pre-exposure nature connectedness, (v) pre-exposure positive affect scores; d) covariance was accounted for between pre-exposure nature connectedness and pre-exposure positive affect. Bootstrap 95% Confidence Intervals (CIs) were derived from 1000 replications.

Mediation model results are given in Table 4. Replicating the simple regression, condition significantly predicted presence (the slightly different coefficients are due to also including pre-nature connectedness and positive affect in the model). Further, and supporting H5 for positive affect the bias-corrected 95% CIs for the indirect effects of both the CG-VR and 360-VR (*vs*. TV) on nature connectedness via experienced presence did not include zero. This implies that the greater improvement in nature connectedness associated with the CG-VR exposure mode (over TV) stemmed from the sense of presence experienced during both types of virtual nature exposure. In the case of the 360-VR mode however there were negative direct effects on nature connectedness which countered the positive indirect effects through experienced presence, such that there was not a significant total effect.

Inspection of the 95% CIs for the indirect effects of both the CG-VR and 360-VR (*vs*. TV) on positive affect via both experienced presence, and via experienced presence and subsequently via improved nature connectedness, did not include zero. This is consistent with the interpretation that the greater improvement in positive affect associated with the CG-VR exposure mode (*vs*. TV) also stemmed from the sense of presence experienced during the virtual nature exposure. Again, for 360-VR, there were negative direct effects on positive affect which countered the positive indirect effects through experienced presence, such that there was not a significant total effect.

4. Discussion

4.1. Summary of main findings and relations to previous research

As far as we are aware, this is the first study in the nature-wellbeing literature to measure boredom, a common negative emotion with important implications in a variety of contexts, including medical and care settings (Cohen-Mansfield et al., 1992). It is also the first study to compare matched nature content from TV documentaries, with two different types of virtual reality (film-based 360-VR and interactive CG-VR). Thanks to support from the BBC's Natural History Unit, we were able to match content across three modes in a manner that is rarely possible, by selecting documentary footage that closely paralleled the experience of an off-the-shelf CG-VR package, 'TheBlu'; the latter allowing interactive engagement with the virtual underwater environment.

Supporting predictions (H1), participants in the CG-VR condition reported the greatest level of experienced presence, followed by 360-VR, followed by TV. Further, supporting the basic contention that even virtual nature can be good for subjective wellbeing, we found significant reductions in boredom and negative affect, and significant increases in positive affect and nature connectedness (Mayer et al., 2008; McMahan & Estes, 2015), across conditions post intervention. Contrary to predictions, reductions in boredom (H2) and negative affect (H3a) did not differ as a function of condition; all three were associated with similar significant drops. Partially supporting predictions, positive mood (H3b) and nature connectedness (H4), were greater post intervention in the CG-VR condition than either the TV or 360-VR conditions (which were similar to each other). The stronger findings for positive than negative mood are consistent with several earlier studies (Berman et al., 2012; Gatersleben & Andrews, 2013; McMahan & Estes, 2015). Finally, partially supporting H5, the effects of condition on positive mood were in part serially mediated by presence and nature connectedness in turn.

Our results compliment and extend similar research into immersive virtual nature environments. Anderson and colleagues, for example, explored whether exposure to 360° nature VR videos could reduce stress and improve mood in experimentally-stressed participants (Anderson et al., 2017). Whereas we found that positive affect improved following both our 360-VR and TV control exposures, Anderson et al. found that positive affect *remained stable* following exposure to 360° nature scenes, while their control group's exposure to indoor VR scenes elicited significant *decreases* in positive affect. A similar outcome was reported for 360-VR in a study comparing against real nature (Browning, Mimnaugh, et al., 2020), where positive affect increased with exposure to real nature, remained stable with 360-VR, and decreased with an indoor control. Yet others have shown that exposure to 360-VR versus the real version of the same lake landscape led to similar beneficial effects on both positive and negative affect (Chirico & Gaggioli, 2019). The differences in findings highlights: 1) that the literature on nature VR remains relatively sparse; and 2) the importance of selecting experimental controls that are relevant for the particular research context.

We chose to use TV as our control because it is a common activity in confined settings such as hospitals and care homes, and we wanted to assess any *additional* effects of VR in terms of its increased technical immersion, rather than looking at differences in content (e.g. nature *vs*. urban or indoor scenes), or comparing with the outdoors, which is often inaccessible for these individuals. We considered that, for people without access to outdoor environments, our comparison to the standard method of viewing nature content (typically on a small TV) may be more relevant for identifying any marginal gains provided by VR delivery methods. That we found little difference in outcomes between TV and

Table 4

Results of the serial mediation model exploring the effects of condition on changes in positive affect through the pathways of presence and nature connectedness.[a] Indicates 0 was not in the bootstrap 95% CI;[†] = p < 0.1; * = p < 0.05; ** = p < 0.01; *** = p < 0.001. Model fit: χ^2 (df = 4) = 0.810, p = 0.937; RMSEA estimate (95% CI) = 0.000 (0.000, 0.037); Probability RMSEA ≤ 0.05 = 0.959; SRMR = 0.023; CFI = 1.0; TLI = 1.05. Note that the CIs of the estimates are more informative than the p values since they take into account possible non-normality in the sampling distribution of the random bootstrapped samples.

		Pathway	Estimate	SE (95% CIs)	
Regression of Experienced Presence (EP)					
	R^2 (SE)		0.55***	0.06	
Control variables	Cross-lagged effect on EP	Pre-exposure NC	1.73**	(0.61,	2.75)[a]
		Pre-exposure PA	−0.19	(-0.46,	0.11)
Variables of interest	Direct effect on EP	360-VR Exposure	11.58***	(7.94,	15.79)[a]
		CG-VR Exposure	18.37***	(15.31,	21.48)[a]
Regression of Δ Nature Connectedness					
	R^2 (SE)		0.34***	0.08	
Control variables	Stability of NC	Pre/Post-exposure	0.60***	(0.46,	0.75)[a]
	Cross-lagged effect on ΔNC	Pre-exposure PA	−0.02	(-0.07,	0.02)
Variables of interest	Direct effect on ΔNC	360-VR Exposure	−0.48	(-1.04,	0.10)
		CG-VR Exposure	−0.32	(-1.00,	0.41)
		EP	0.05***	(0.02,	0.08)[a]
	Mediated Effect on ΔNC	360-VR Exposure through EP	0.62**	(0.26,	1.04)[a]
		CG-VR Exposure through EP	0.98**	(0.41,	1.61)[a]
	Total Effect on ΔNC	36O-VR Exposure	0.14	(-0.36,	0.66)
		CG-VR Exposure	0.66*	(0.18,	1.16)[a]
Regression of Δ Positive Affect					
	R^2 (SE)		0.68***	0.06	
Control variables	Stability of PA	Pre/Post-exposure	0.22**	(0.09,	0.39)[a]
	Cross-lagged effect on ΔPA	Pre-exposure NC	−0.16	(-0.92,	0.50)
Variables of interest	Direct effect on ΔPA	360-VR Exposure	−2.69*	(-4.94,	−0.23)[a]
		CG-VR Exposure	−2.21[†]	(-4.69,	0.41)
		EP	0.22***	(0.10,	0.32)[a]
		ΔNC	0.95*	(0.12,	1.75)[a]
	Mediated Effect on ΔPA	360-VR Exposure through EP	2.49**	(1.16,	4.05)[a]
		360-VR Exposure through ΔNC	−0.46	(-1.42,	0.08)
		360-VR Exposure through EP*ΔNC	0.59[†]	(0.06,	1.36)[a]
		CG-VR Exposure through EP	3.95***	(1.89,	5.92)[a]
		CG-VR Exposure through ΔNC	−0.30	(-1.21,	0.44)
		CG-VR Exposure through EP*ΔNC	0.93[†]	(0.08,	2.08)[a]
	Total Effect on ΔPA	360-VR Exposure	−0.08	(-2.32,	2.33)
		CG-VR Exposure	2.37*	(0.41,	4.28)[a]

360-VR formats, suggests that exposure to natural scenery via standard TV screens may be just as effective for wellbeing as more immersive 360-VR.

Our stronger findings for positive than negative mood are in line with the literature in this field which has shown that exposure to nature, even through virtual means, tends to improve positive feelings to a greater extent than it reduces negative ones (McMahan & Estes, 2015). It is interesting to note, however, that our findings contrast with some recent VR studies which have shown the opposite. For example (Anderson et al., 2017; Browning, Mimnaugh, et al., 2020) both showed stronger effects of nature 360-VR on negative than positive affect, and (Chirico & Gaggioli, 2019) found that 360-VR reduced sadness to a greater extent than even real nature. A recent meta-analysis showed that positive affect only increased in real (but not simulated) natural settings, whereas negative affect improved to a similar extent in both contexts (Browning et al., 2020). Browning and colleagues have explored possible reasons for this, including the idea that being "sealed in" to VR nature by way of a HMD may provide a greater opportunity to escape negative thoughts and excessive cognitive demands, allowing for faster and more complete recovery of attentional processes, and associated reduction in negative affect (Browning, Mimnaugh, et al., 2020).

Alternatively, that we saw stronger increases in positive affect across all three of our conditions may relate to our use of a particularly novel/exciting coral reef environment; with underwater biodiverse settings having been shown to elicit particularly high fascination (Cracknell et al., 2016). Moreover, that the CG-VR improved positive affect to a significantly greater extent than TV may have been due to its ability to offer greater interactivity. Previous studies have found similar responses between more passive and more active virtual experiences. For example, one study reported significant increases in positive affect for subjects exposed to an interactive VR forest *vs*. a control condition featuring a slideshow of abstract paintings (Valtchanov, Barton, & Ellard, 2010). In another, an 'active' VR nature programme was more effective for reducing pain and physiological stress during dental surgery, compared with passively viewing a children's movie inside the VR headset (Furman et al., 2009). Similarly, others found that awe-inducing interactive CG-VR nature environments were rated as more engaging than awe-inducing 360-VR (Chirico, Ferrise, Cordella, & Gaggioli, 2018). By employing multiple senses and requiring user input; perhaps interactive forms of VR are better able to hold attention, and facilitate more extensive engagement with nature, which perpetuates greater wellbeing effects.

Consistent with previous studies, our 5min exposures to virtual marine environments significantly increased people's subjective feelings of connectedness with these natural settings (Mayer et al., 2008; Nisbet & Zelenski, 2011). As with positive affect, the effect was most pronounced in the CG-VR mode. Our results differ from a previous study which found that the type of technology used (a computer screen *vs*. immersive VR) to view nature had no bearing on nature connectedness (Soliman, Peetz, & Davydenko, 2017). Of note, the difference may be due to our use of a relatively novel environment (i.e. underwater coral reefs) that is difficult to access for most people - verbal feedback suggested that being able to observe marine life in close proximity was a real highlight for many. Indeed, we believe this present study is also the first to demonstrate positive wellbeing effects following VR immersion in underwater environments. Having shown that VR can be used to increase nature connectedness, and given consistent results linking nature connectedness to pro-environmental behaviours (Mackay & Schmitt, 2019) a next logical step would be to explore whether VR can be used to foster pro-environmentalism (Nisbet, Zelenski, & Murphy, 2008), particularly for individuals who lack the means or time required to access real natural settings.

As hypothesised, participants in the VR conditions experienced greater feelings of presence on average than the TV condition, with those in the CG-VR condition reporting the highest levels. According to Slater and Sanchez-Vives (2016), presence in VR arises through altered sensory perception, whereby the immersive nature of HMD systems in particular (e.g. head tracking, wide field of view, low latency, etc.), combined with a lack of "real" sensory data from the physical world, but with prior experience of how the environment should appear, forces the user's brain to accept the virtual environment as if it were real, even though the user knows for certain it is not (Slater & Sanchez-Vives, 2016). They explain that inducing presence is even more likely where systems allow the participant to use their body in a natural and dynamic way - e.g. bending down, reaching out, looking around objects, influencing elements of the VR world - a phenomenon they term "plausibility illusion", and one which may help to explain why the highest presence levels were felt in our interactive CG-VR condition. The added layer of "involvement" afforded by CG-VR may have allowed individuals to more easily withdraw attention from the physical world, and to recall more "vivid" mental images of the VR environment after removing the HMD, a factor which has been shown in previous work to correlate with reporting greater feelings of presence (Iachini et al., 2019).

Finally, improvements in positive mood were, as predicted, mediated via subjective feelings of experienced presence in virtual nature and increases in state nature connectedness. Nevertheless, there was also the unexpected finding of a direct negative effect, such that once the indirect paths through presence and nature connectedness were accounted for, the TV condition was associated with higher positive affect than either the 360-VR or CG-VR conditions. The exit interviews provided a possible explanation for this. Although many participants mentioned feeling completely immersed in the VR, others spoke of being distracted by the bulkiness of the HMD equipment, which undermined their enjoyment of the experience. Thus, there may have been some opponent processes emerging in which the VR conditions tended to promote positive affect by being more immersive, but this was countered by awkward equipment that the simpler TV setup did not require. Overall, the positive immersion outweighed the negative practicalities (as evidenced by the positive total effect) but it is important to note that this negative aspect of the technology exists, especially if it is to be used in health and care settings where practical issues will likely be of greater importance.

4.2. Limitations

We recognise several limitations of this work. First, the boredom induction video produced only moderate levels of boredom, which may partly explain the lack of effect between our virtual nature exposures. Although the video was validated, it was quite short at only 4 min, and so future studies may wish to test effects of a longer boredom induction task. Second, our TV and 360-VR footage was taken from the BBC's Blue Planet II series, which may be considered as a particularly spectacular example of virtual nature given its rating as the UK's most watched TV programme of 2017 (BBC, 2018). This may have reduced the chance of finding effects between our TV and VR conditions. Viewing documentary-style natural history content has been shown to have a special role in improving positive emotions and decreasing negative ones (Keltner D, Bowman, & Richards, 2017), and while our findings support this, we cannot say whether the positive effects of TV would extend to less 'awe-inspiring' virtual nature scenes, e.g. films lacking wildlife or an interesting narrative.

Relatedly, we did not explore whether VR nature was better at improving our outcomes than urban settings, a comparison often used to explore changes in emotional states ((Yu et al., 2018). Although we considered including a non-nature content control, preliminary power analysis suggested we would need more participants than we felt we could recruit with limited time and resources. Thus, rather than seek to replicate widespread results showing nature tends to be better than urban, we instead tested the delivery mode of virtual nature. Estimating required sample sizes for a study with no clear precedent is also not a precise science, it may be that we did not have a large enough sample to fully tease out the boredom effect in particular, given that the pattern was similar to positive mood but with larger confidence intervals.

In addition, the lack of between-condition effects on negative mood may be because some of the negative SPANE items (by its original design) reflected high arousal states (e.g. angry, afraid), as opposed to the kind of low arousal states that we might expect with boredom (e.g. sad, (Posner et al., 2005). Disengagement and failure to focus attention are also key aspects of the experience of boredom which may conflict with high arousal negative mood terms such as anger and fear (Westgate & Wilson, 2018), and so future research on boredom may need to consider a more specific set of emotional states than included in the SPANE.

Finally, we used a relatively small convenience sample. This meant firstly that we were just below the recommended minimum sample size for SEM analysis and any future studies wanting to use similar analytical approaches would ideally collect larger samples in each condition. Secondly, we are unable yet to generalise the findings to other populations, especially to our future populations of interest in health/care settings. One aim of this work was to test the virtual environments with a "less vulnerable" group, in order to detect and address negative issues, and to optimise the experience, before piloting in a real-life setting. The lessons learnt will help us design the next phase of this research programme. Specifically, as we have learnt that 360-VR appears to offer little 'added value' over traditional TV, whereas CG-VR appears to offer a qualitatively different experience; we will concentrate on only TV and CG-VR in our next stage. We will use the current results to inform a more targeted power analysis; limiting to two conditions will also allow for larger samples sizes in each. We do recognise that the high levels of interactivity afforded by CG-VR may not be best suited for individuals in certain settings, e.g. high-dependency areas, or during surgery, and will take this into account when selecting our pilot settings. As alluded to in the introduction, our aim is not necessarily to target individuals while they are undergoing a procedure, but rather to offer an option for those who are simply bored of being in isolated, noisy or confined settings the chance to virtually "escape into nature".

Although we could not present a full analysis here, in the exit interviews, some users mentioned that the HTC VIVE felt quite heavy, which may make it less suitable for frailer individuals. Since conducting this work, there has been a proliferation in the HMD market; we may opt to pilot newer, lighter and more portable systems for our future groups of interest. By contrast, an encouraging outcome was that none of the 96 participants experienced any nausea from the virtual environments, which differs from some previous studies, e.g. (Calogiuri et al., 2017) a major factor supporting the future use of this imagery in real-life settings.

4.3. Implications

One of the most striking implications of this study was how effective a 5-minute segment of the original Blue Planet II series, as shown on a standard TV, was for reducing boredom and negative affect, as well as increasing nature connectedness and positive affect. This occurred despite the fact that it was the least immersive condition and the original narration from Sir David Attenborough had been substituted for a comparable version across all three conditions. Future work is needed to determine whether other programmes produce similar effects, but the viewing figures suggest this was a particularly attention-capturing programme. Nature programmers might consider using our basic approach to investigate the likely impact of their programmes before release, e.g. inducing boredom in different groups of viewers before exposing them to various kinds of footage, to investigate which have the greatest ability to reduce boredom and increase nature connectedness among their audiences.

Despite the power of TV, CG-VR did emerge as significantly better at increasing nature connectedness and positive affect. Given the large drop in nature connectedness in early adolescence (Richardson et al., 2019), use of newly-emerging technology may, somewhat ironically, be one way of engaging younger people with the natural world (Kawas, Chase, Yip, Lawler, & Davis, 2019). Our sample was comprised of adults and so we cannot make any firm conclusions about this possibility here, but future work could run a similar study with young people, to explore not only whether it enhances nature connectedness, but whether this has positive knock-on effects on pro-environmental behaviours. Zelenski and colleagues, for instance, showed clips from an earlier BBC nature series (Planet Earth) and demonstrated that viewers made more sustainable choices during a commons dilemma challenge, compared with viewers of a control video of an urban setting (Zelenski, Dopko, & Capaldi, 2015). If these results extend to children and young adults, and VR has an even greater effect than TV, the implications could be important if engaged in at scale.

Finally, as noted above, the results of the present study will directly inform the design and sample size calculations of the next phase of this research which will involve individuals in health/care environments.

4.4. Conclusions

The aim of this lab-based study was to investigate whether contact with different virtual forms of nature could reduce boredom, a widespread negative emotion that has associations with poor health and wellbeing, especially among people who cannot change their situation e.g. those in health/care settings (Farmer & Sundberg, 1986; Sommers & Vodanovich, 2000). Supporting the basic contention, 5 min of virtual exposure to a coral reef environment reduced state boredom, from experimentally-augmented pre-intervention levels. Contrary to predictions, these reductions were not significantly different across conditions: TV was as effective as matched content experienced via two forms of virtual reality. Nevertheless, participants in the CG-VR condition did show greater improvements in positive emotions compared with TV, which appeared to be mediated through greater feelings of presence and increased nature connectedness. Results will be used to inform the design of a field trial with individuals in real care settings who may be experiencing chronic boredom, but may also be informative for building nature connectedness among specific groups (e.g. adolescents).

Author statement

Nicola Yeo: Conceptualization, Methodology, Investigation, Formal analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2020.101500.

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