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(From) virtual (to) reality: a mixed-methods exploration of immersive virtual nature as a tool to promote green exercise

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ABSTRACT

The salutogenic effects of green exercise are widely recognised, yet many individuals do not engage in this health-related behaviour. Using a convergent mixed methods approach, this study explored the impact of Immersive Virtual Nature (IVN) on the decision-making process relating to green exercise. Three experimental trials were conducted (overall n = 136), in which healthy adults were exposed to different types of IVN reproducing an existing urban green area. Participants reported medium-high rating of intent to visit the location. Significant pre-to-post increments in future green exercise intention were observed after the IVN exposure, though a significance difference was not achieved in comparison with control. Qualitative analysis revealed the impact of IVNs on behaviour regulation, and highlighted the pivotal role of anticipated emotional benefits. Despite scepticism regarding the IVN experience, it was effective in arousing curiosity to explore natural environments, which was associated with environmental perceptions, nostalgic and socio-cultural perspectives.

Keywords: Exercise, health promotion, mental health, nature-based tourism, virtual reality.

Introduction

The salutogenic effects of nature and green exercise

Natural environments provide great value for the health and well-being of people, as spending time in contact with nature provides benefits to people's physical and psychological health. For instance, literature reviews show evidence of positive associations of nature exposure or interactions with indicators of physical health, such as biomarkers of immune function [1], obesity and obesity-related diseases [2], and incidence of other chronic diseases [3]. Moreover, a recent study across 18 countries found that people who live in neighbourhoods with greater availability of natural environments (including both, "green" and "blue" setting) reported higher levels of well-being [4]. It has been suggested that, in order to maintain higher levels of general health and subjective wellbeing, people should spend at least 120 minutes a week in nature [5]. Green exercise (i.e., physical activity taking place in presence of nature [6]) is particularly beneficial in this regard, as it combines the synergic benefits of physical activity with those provided by nature exposure [7,8].

Green exercise can provide health benefits above and beyond physical activity taking place indoors or in urban settings [9,10]. A 2016 study estimated that the health benefits of green exercise saved society around £2.2 billion in the UK alone through welfare gains [11]. Green exercise, in different forms, has been also shown to be an effective preventative intervention in vulnerable groups (see e.g., [12,13]) as well as an effective supplement in the treatment of different clinical conditions (see e.g., [14-16]). Promotion of green exercise is thus important to achieve public health goals [3], and visits to local natural environments should be encouraged in the population. In this respect, while there is large consensus on the importance of interventions that act on the physical and perceived environment, such as increasing accessibility to and safety of local natural environments [3,17], initiatives that focus on

behaviour changes have been also proposed as effective strategies to promote green exercise [18-20]. In particular, as virtual reality (VR) technology is becoming increasingly popular and economically accessible, it may represent an additional strategy to complement the current initiatives to promote green exercise.

Immersive virtual nature and its potential to promote green exercise

VR, and in particular so-called immersive virtual environments, can be defined as synthetic sensory information providing a surrounding and continuous stream of stimuli, creating the illusory perception of being enclosed within and interacting with a real environment [21,22]. The application of this technology to recreate virtual simulations of natural environment has been defined as *immersive virtual nature* (IVN [23,24]). Evidence from studies in the context of nature-based tourism indicate that VR-based advertising may be an effective tool in promoting visits to natural destinations and enhancing attitudes towards green spaces [25-27]. A characteristic of IVN that may play an important role in their effectiveness as a tool to promote green exercise, is the concept of *presence*. Presence is a person's "(psychological) sense of being in the virtual environment" [28]. While it is primarily a subjective experience, presence is associated with the characteristics of the VR technology (both, it terms of software and hardware), more specifically with the extent to which it can allow the user to immerse themselves in the virtual world [28,29]. In this context, studies that have investigated the potential of IVN as a tool in nature-based tourism have indicated that higher levels of presence are crucial for information-processing, attitude formation, and affordance [25,27]. Yet, to the best of the authors' knowledge, little evidence exists on the extent to, as well as the psychological processes through which IVN may promote green exercise as a health-related behaviour.

Possible pathways explaining behaviour-regulation processes associated with IVN

In order to understand the behaviour change processes elicited by IVN-based interventions, it is important to consider the function of emotions on human behaviours, alongside the anticipated emotional benefits triggered by IVN-mediated nature exposure. According with Baumeister et al. (2007)'s Feedback Theory, emotions have the function to provide feedback to which behaviours one should or should not pursue in future. In this context, *anticipated* emotions are seen as more important in guiding behaviour than actual, experienced emotions [30]. Although in some conditions emotions may have a direct causation on behaviours (such as in "fight or fly" situations), in more sophisticated behaviours the decision-making process is rather conscious, involving the evaluation of past experienced emotions, as well as influences from a person's cultural and social contexts. It is especially important that a person anticipate powerful emotional outcomes [30], which, in the context of IVN exposure, may be facilitated by high levels of presence (see previous section). While IVN may elicit anticipated emotional benefits on the base of generalized previous experiences of green exercise (i.e., enjoyment and relaxation), such anticipated psychological benefits could be also seen through the prism of *nostalgic reconsumption of places*. Place consumption refers to the act of a cultural event or experience that is carefully created by a 'producer' (e.g., tourism board) for the benefit of a 'consumer' (visitor) and these actors feed off each other in a circuitous fashion [31]. Moreover,

reconsumption refers to the active and conscious decisions to seek an experience again [32]. A poignant theme in this field refers to the interactions with physical places and displays significant connotations for "revisiting a fondly remembered place" [33]. In essence, a visitor to a place will develop place attachments through their interaction with a range of stimuli [34], that leads to the creation of place experiences which fuel nostalgic reconsumption of places [33].

Aim of the study

In recent years, studies on the effectiveness of IVN in different clinical contexts have been proliferated [35]. Although conceptual analyses have proposed IVN as an effective tool in behaviour-change interventions, specifically in the promotion of green exercise [24,36], the scientific evidence in this field remains scarce. Some studies, mainly within the field of tourism, have demonstrated that IVN can elicit intent to visit naturalistic locations [25-27]. However, to the best of the authors' knowledge, studies specifically investigating this phenomenon in a behaviour-change perspective are still missing. In order to address this gaps, as an explorative study, the present paper is set to shed light on this under-research subject. The study is based on data retrieved from three experimental trials during which healthy adults were exposed to a 10-minutes IVN reproducing an existing naturalising location. Across the three trials, different ways of developing the IVN were tested, which resulted in the IVN containing high ("unstable video") or low ("stabilized video" or "3D model") levels of scene oscillations. These were administered, in different combinations, during either a "sedentary" (i.e., sitting on a chair) or an "active" (i.e., self-paced walking on a manually driven treadmill) exposure. Using a convergent mixed-methods approach, quantitative measurements of the participants' intention to visit the location and possible changes in future green exercise intention were collected, as well as qualitative information on their perceptions and experiences relative to the IVN exposure. The overarching purpose of the study was two-fold: i) to explore the potential of IVN as a tool to promote green exercise, and ii) appraise the pathways explaining behaviour-regulation processes associated with IVN, as well as the participants' perception associated with different ways of developing and delivering IVN.

Results

Quantitative findings

Figure 1 shows the distribution of the participants' ratings of intention to visit the naturalistic location reproduced in the IVN across the different experimental conditions –each experimental condition representing a different combination of different ways to develop and administer the IVN. In all the experimental conditions tested in Study 1 and 2, the intention ratings were distributed around intermediate levels, indicating that less than half for the participants reported a positive intention to visit the location. More specifically, the median intention ratings was 5.00 (*IQR* = 4.25) in both the "sedentary*unstable video 1" and the "active*unstable video", while they were 5.00 (*IQR* = 4.00) and 5.00 (*IQR* = 3.00) respectively in the "sedentary*unstable video 2" and "sedentary*stabilized video". The median ratings of intention were higher in both the experimental conditions tested in Study 3,

which were the "active*stabilized video" (*Mdn* = 7.00, *IQR* = 3.00) and the "active*3D model" (*Mdn* = 7.00, *IQR* = 4.00). In these conditions, overall, more than two thirds of the participants (*n* = 27) reported intention ratings above 5, which are indicating of positive intention to visit the location, while only four participants reported ratings below 5. No significant differences were found between conditions within any of the individual studies. Significant differences were found between men and women in Study 2 ($U = 190.00$; $p = 0.018$), with higher values among the women (*Mdn*: 7.00, *IQR* = 5) compared with the men (*Mdn*: 5.00, *IQR* = 2.00). Such sex-related differences were not replicated in Study 1 and 3. No significant correlations were found with the participant's age or BMI in any of the studies.

< Figure 1 about here >

Figure 2 shows the *EMM* and standard errors (*SE*) of green exercise intention expressed as change from baseline (delta values), corrected for the participants' physical activity levels. In Study 2, the mixed between-within subjects ANCOVA on green exercise intention, corrected for physical activity levels, found a statistically significant within-subjects effect ($F(1,47) = 5.570$; $p = 0.022$; *Partial* $\eta^2 = 0.106$) and a significant time by condition interaction ($F(1,47) = 6.200$; $p = 0.016$; *Partial* $\eta^2 = 0.117$). The pairwise comparisons of the *EMM* demonstrated a significant increment of green exercise intention from baseline in the "sedentary*stabilized video" condition ($p < 0.001$), but not in the "sedentary*unstable video" condition ($p = 0.981$). In Study 3, the ANCOVA found a statistically significant within-subjects effect ($F(1,56) = 7.016$; $p = 0.010$; *Partial* $\eta^2 = 0.111$), though no statistically significance was found for the time by condition interaction ($F(2,56) = 0.126$; $p = 0.882$; *Partial* $\eta^2 = 0.004$). However, the pairwise comparisons of the *EMM* showed no significant changes from baseline in the control condition ($p = 0.062$), while a significant increment was found in the "active*stabilized video" condition ($p = 0.014$) alongside a borderline significant increment in the "active*3D model" condition ($p = 0.054$). When examining the delta-values for green exercise intention in relation to the participants' background information, no significant differences were found between men and women, nor where significant associations with the age and BMI found, in any of the studies.

< Figure 2 about here >

Qualitative findings

Three themes emerged through the analysis of qualitative findings. Firstly, participants presented diametrically opposed views towards IVN as an effective tool for promotion of green exercise. Secondly, the anticipated emotional outcome of the experience featured heavily in participant reflections. Thirdly, a rich vein of interpretations were provided in light of eliciting curiosity for exploration or nostalgic reconsumption of green spaces.

Mixed views surfaced regarding IVN as an effective motivation tool. Participants displayed positive affirmation of their intention to engage in green exercise and exploration of green space:

> *"It is a great idea! With more research and better technology, I think that it (IVN) can be an amazing tool to motivate people to exercise." (Male, 23)*

Critical reflections towards IVN-mediated nature experiences were also evident, in particular related to the extent of the performativity of the IVN experience. In one poignant example, a participant was unimpressed with the experience, suggesting that nothing compares to the experiential consumption of nature:

> *"walking outdoors should be an experience, and if you get that feeling by sitting inside on the sofa, you have made a fool of yourself." (Male, 21)*

Aside from the negative connotations expressed, analysis revealed how the locus of the argument stems from an intense appreciation of nature. Many comments such as this espoused a consistent perception of IVN through a sceptical lens based on premise that it does not compare to the real life experience. This poses an intriguing conundrum for the role of IVN as a promotional tool for visiting green spaces, as participants viewed it as simply a replacement for the inability to visit such a place. Similarly critical commentary on physical experiential aspects of the IVN tool was commonplace. A focus on the audio-visual and sensory aspects were evident, and the resulting effects these had on the participants, such as dizziness and nausea.

> *"It [IVN] will not be especially motivating if you get this feeling of nausea. That will not give you the motivation to continue". (Female, 39)*

Again this reflection is grounded on a highly personal motivation for experiential consumption of green space. This suggests that, while the audio-visual and sensory aspects of the IVN have an impact on the enjoyment of the experience, they did not affect the participants' overall attitudes toward IVN as a persuasive strategy. Hence critical comments such as these offer promising results in terms of the viability of IVN as a promotional tool for green exercise.

On the other hand, participants indicated a range of sensory elements which were key to their enjoyment of the IVN experience. Most notably, the presence of other people in the IVN was a motivating factor for influencing participants' intentions:

> *"When I see others in the video, I want to go outdoors with them and feel the nature". (Male, 23)*

Whereas exposure to the IVN from a sedentary position was seen as not truly reflective of active exposure to nature.

> *"The sitting condition was the worst because what happened on the screen did not match with what I did. The treadmill VR will probably motivate people to go more out in the nature." (Male, 25)*

In this respect, the IVN exposure was shown to elicit a desire for green exercise through novel and fascinating environments in order to trigger the curiosity to revisit the space that was virtually created.

The second theme which emerged is the impact of anticipated affective benefits resulting from the IVN experience. Crucially, participant's insights offered an understanding of mechanisms of IVN as a tool for green exercise promotion:

> "*It contributed to my desire to walk along that road (seen in IVN) on one of my walks later." (Male, 21)*

Remarkably, such salutogenic benefits were reported by participants who presented positive affirmation as well as sceptical attitudes towards IVN technology, underlining the potential for IVN as a promotional tool for green exercise.

> *"Now I feel like going for a walk in real nature because I thought it (IVN) was comfortable and it had a positive effect on my mood." (Male, 23)*

In light of the desired outcomes for exposure to the IVN experience, it is clear that the tool is effective in arousing desire for green exercise, satisfying motivations for salutogenic reasons.

Thirdly, participants made explicit reference to the fact that IVN was an effective tool in eliciting curiosity for exploration of green spaces, including places which were previously visited.

> *"If you get to know a new place using VR, someone might get curious to visit the place in reality." (Male, 27)*

> *"The virtual walk made me want to visit the area that was reproduced in VR in real life. I also want to spend more time in nature in my own local area when I get the opportunity to do so." (Female, 24)*

With these findings, there are clear connotations for reconsumption of places. In that the desire to revisit a place or experience, in this case a natural environment near the testing site, was a strongly held view as a result of the IVN exposure. Reconsumption practices were also evident through participant descriptions of the testing site, suggesting that the real nature exposure was a dominant factor in the mind-set of the users. In this manner, analysis of findings revealed how a significant proportion of participant motivations to visit and revisit the green space were derived from personal interpretive reasons such as nostalgia. The role of nostalgia is clear in many participant reflections, whereby previous memories from visits to green spaces similar to the IVN featured in their reflection on the experience.

> *"Most of all, I feel like I miss summer / spring, when I go for a walk every day." (Male, 29)*

> *"I did not feel that I came into more contact with nature, but maybe I would have done so if the environment was, for example, forest or mountains." (Male, 22)*

On the other hand, participants exhibited highly personal reflections on natural environments, which extended beyond the realm of nostalgia.

> *"What is a little fascinating is that it feels a bit like walking there for real, but the graininess of the film ruined it. There could have been slightly louder sounds from the wind, which would have made the experience more real." (Female, 63)*

> *"It was interesting to see the wind blowing through the trees without any other senses being able to help determine how much it was blowing." (Male, 25)*

In this respect we see an intriguing juxtaposition whereby participants are motivated to the point of constructing a personal version of the green space in the IVN. Considering how the IVN was constructed by the research team to reflect the natural space as closely as possible, it highlights the role of personal introspection in the construction of realities. This is a warning call for future use of IVNs, in that the most scientifically accurate replication of a natural environment may not match up to the highly subjective personal interpretation of the 'perfect' green space.

Discussion

IVN effectiveness in promoting green exercise

The quantitative findings of the present study provide indications that IVN can be, though to a limited extent, an effective tool to promote green exercise, eliciting intention to visit natural locations as well as enhanced general intention to engage in green exercise. While this corroborates and extends previous studies in the context of nature-based tourism [25-27], on the other hand it is important to notice that there was a large variation in the participants' intention ratings. Moreover, although the increases in intention appeared to be more pronounced after viewing the IVN compared with a non-IVN control, a statistical significant difference was not achieved between these two conditions. Partially confirming these quantitative findings, the qualitative analysis revealed participants had diametrically opposed views towards IVN as an effective tool for promotion of green exercise. At the same time, the qualitative findings provided further expansion on the underlying motivational processes that may link IVN exposure to green exercise promotion.

Anticipated psychological benefits

The qualitative work performed revealed substantial appreciation of the salutogenic effects of green exercise despite mixed opinions in relation to the quality of the IVN experience. These findings expand on the quantitative findings, providing an insight into the underlying mechanisms that link IVN experiences to green exercise intentions. Moreover, this displays a direct contribution to Feedback Theory, showing how anticipated emotions from physiological and cultural dimensions were elicited through IVN [30]. Notably, we highlight a significant degree of scepticism towards IVN experiences, whereas this serves as a reminder of user's appreciation and reminder of the salutogenic effects of green spaces. This supports the assumption that IVN can produces powerful anticipated emotional outcomes in the users, as well as offer a contentious 'talking point' that affirmed participant views on green exercise. In this respect, an interesting perspective may be provided by viewing such trigger for

appreciation of nature under the prism of the *perceived environmental restorativeness* (i.e. the extent to which an environment is perceived by a viewer as possessing characteristics that can elicit psychological restoration [37]. In previous studies, it was shown how perceived restorativeness is replicable in a virtual green exercise setting [38], thought this was not associated with *actual* psychological benefits, such as enhanced positive affect of reduced fatigue [38,39]. This addresses a gap within the understanding of perceived restorativeness and its value for eliciting (and, possibly, quantify) *anticipated* psychological benefits in the context of (virtual or actual) green exercise experiences, as opposite to traditional perspectives that focus on *actual* psychological benefits (see e.g., [37,40-42]).

Nostalgic reconsumption of places

Reconsumption studies have previously focused mainly on habitualistic rituals [32] and interaction and exposure to physical experiences [31], and there are no significant studies in relation to interpersonal motivations to visit (or revisit) a natural environment through IVN-mediated stimulus. Not least, place consumption stimuli, physical or otherwise, is also yet to be understood. The qualitative findings provide insights into the underlying motivational processes that link IVN exposure to green exercise promotion via nostalgic reconsumption of places. In doing so, the findings also contribute to the ongoing debates around place reconsumption. By unveiling the conscious and unconscious decisions to engage in green exercise, our findings contribute with prior reconsumption studies [32]. Moreover, by focussing our attention on participants desire to revisit a physical environment subsequent to exposure to IVN, we extend the work of Cervellon and Brown (2018)'s interpretation of '*fondly remembered places*' [33]. Considering place reconsumption has ramifications for place branding [31], our work extends our understanding of desires and motivations for visitors to green spaces within places. Hence, we have shown that IVN is a powerful tool in eliciting desire to visit and re-visit a natural space.

Technical aspects of the IVN

Lastly, although a direct statistical comparison across the quantitative studies (and thus across all IVN conditions) was not possible, from the qualitative and, to a limited extent, the quantitative findings it is evident that the characteristics of the IVN substrate can play a role in the resulting experience and consequent behaviour-change. In particular, some indication emerged suggesting that "active" IVN exposures (e.g., IVN combined with treadmill walking) may be more effective than "sedentary" ones (i.e., viewing an IVN whilst sitting on a chair). Not only was this explicitly mentioned by the participants in the qualitative interviews, but it would be supported by the quantitative findings indicating greater levels of intention in the active exposures of Study 3. However, it is important to take into account that, compared with the previous studies, in Study 3 new-generation technology was used as a substrate for the IVN. Moreover, it would rather appear that a major factor influencing both the overall experience and the behavioural intentions was whether the IVN scenario was stabilized (i.e., it did not contain any oscillations). This is corroborated both, from the qualitative reports as well as the fact that the intention ratings tended to be higher in the exposures that included a stabilized scenario (i.e., a stabilized 360° video or the 3D model). This can be explained by

the fact that presence of oscillations in IVN scenarios, as in unstable 360° videos, can elicit cybersickness [43]. Cybersickness, a malaise that can occur in users exposed to different digital visual medium, can dramatically impact the users' psychological responses to IVN [36]. Previously published findings [38,39] demonstrated that some of the IVN conditions included in the present study, which contained a greater degree of scene oscillations (i.e., the "passive*unstable video" in Study 1 and 2, as well as the "active*unstable video" in Study 2), were quite prone to elicit cybersickness in the participants. On the other hand, the IVN conditions where maximal stabilization was applied (i.e., the "sedentary*stabilized video" in Study 2 and the "active*stabilized video" and "active*3D model" in Study 3), were associated with lower incidence and severity of cybersickness [39]. Altogether, this suggests that the effectiveness of IVN as a tool to promote green exercise may be more reliant on the quality of the technological substrate than the way it is administered. However, as we envisage that IVN technology will improve, so will its application in the developing field of digital placemaking [44] and health promotion [39].

Strengths and limitations

Strengths of the present study are its novelty and experimental rigour of the individual studies (laboratory-based RCTs, two of which applied blind allocation of participant to conditions). The use of a mixed methods methodology can be also seen as a strength, as this allowed both to establish possible statistically significant effects of the IVN treatment, as well as provide an in-depth understanding of the participants' perceptions and experience. Moreover, validated and theoretically sound instrument were used in the qualitative part, while a rigorous and transparent analytical approach was used for the qualitative findings. A number of weakness, however, need to be taken into consideration. Firstly, green exercise intention was used as an indicator of behaviour-change, whereas the effect of IVN exposure on actual green exercise behaviour yet is unknown. Only one of the studies (Study 3) included a non-IVN comparison condition, hence the present study provides only limited evidence on the effectiveness of IVN-based interventions as compared with other types of green exercise promotion initiatives. Finally, as Norwegians are known to generally appreciate green exercise [45], interpretation of the findings should account for the cultural context where the study was conducted.

Conclusions

The findings of the present study provide promising evidence on the potential of IVN as a tool to promote green exercise, as well as novel and valuable insights into behaviour regulation associated with IVN exposure, highlighting the pivotal role of anticipated emotional benefits and nostalgic reconsumption of places. This knowledge can inform green exercise promotion interventions. In this respect, although this study focused on non-clinical populations, the knowledge generated may be applied to different clinical population who would particularly benefit from green exercise, such as individuals with mental health challenges or those in need of increasing their physical activity levels. More research is needed in this field. In particular, it is recommended that future research include non IVN-related interventions as a comparison/control, as well as follow-up assessments of green exercise behaviour.

Methods

Study designs and data

A convergent mixed methods design was employed [46,47], which was deemed to be appropriate for the exploratory nature of this study. The quantitative and qualitative strands were conducted and analysed in parallel, hence the results presented separately, in line with a "separative" relational dimension. Merging was performed using an explanatory unidirectional approach, with the qualitative findings enhancing and deepening the quantitative findings. This was facilitated by the fact that the quantitative and qualitative data were collected in the same experimental context, among the same participants, with the qualitative questions being purposefully developed based on the same overarching themes of the quantitative instrument. Interpretation and reporting was eventually done narratively using a weaving approach, presenting both qualitative and quantitative findings together on a theme-by-theme basis.

The data were retrieved from a larger study including three controlled randomized trials conducted between 2017 and 2020 [38,39,48] [*please, note that the main publication for Study 3 [48] is currently under review for publication. Trial registration number: ISRCTN14275608*]. The primary goal of these trials was to examine the participants' psycho-physiological responses to different ways of developing and delivering IVN experiences, though additional measurements were collected to examine the potential of IVN as a strategy to promote visits to real natural environments and green exercise, which will be presented in this paper. All studies were conducted at the Sport physiology laboratory of the Inland Norway University of Applied Sciences – Campus Elverum (Norway), and were designed by the same principal investigator (GC) and laboratory coordinator (SL). Details about the research design of all individual studies are available in the main publications [38,39,48], and summarized in Table 1.

< Table 1 around here >

Participants

Participants (overall n = 136) were recruited among students and employees at the Inland Norway University of Applied Sciences – Campus Elverum and among other citizens living in the vicinity. In Study 1, the inclusions criteria were: being between 20-45 years old, being able to walk for 10 minutes outdoors, and not being an elite athlete. For Studies 2 and 3, the inclusions criteria were: being 18 years or older, have normal or corrected-to-normal sight, and not having any diagnosis of balance impairments. Quantitative data were collected among all participants, of whom 68 were men (age range: 19 - 63 y.) and 68 were women (age range: 17 - 67 y.). Most (though not all) individuals showed normative BMI values (men: 20.00 - 37.30; women: 17.23 – 34.30) and reported a rather large range of weekly physical activity (the Metabolic Equivalent of Task [MET] assessed by Leisure-time exercise questionnaire [49] was 18 – 119 and 15 – 128 METs for men and women, respectively). A subset of participants (n = 65) partook in the qualitative study. The characteristics of this sub-sample were similar to those of the overall sample with respect to age (men: 19 - 63 y.;

women: 19 - 67 y.), BMI (men: 20.00 - 37.30; women: 18.20 – 34.30) and weekly physical activity levels (men: 18 – 119 METs; women: 15 – 91 METs). No relevant differences across the studies were noticed with respect to participants' characteristics, with the only exception for a lower mean age in Study 1 compared with Study 2 and 3, which was due to the more restrictive inclusions criteria relative to age. All studies were performed according to the Declaration of Helsinki and approved by the Norwegian Centre for Research Data (Study 1 and Study 2, ref. n. 53246 and 60451, respectively) or the Regional Comittees for Medical Research Ethics South East Norway (Study 3, ref. n. 134663). All participants were informed about the purpose of the study and associated risks before, and provided an Informed written consent.

Experimental conditions and IVN technology

The IVNs used in the different studies showed the exact same location, an existing urban green area with a walking path by the river Glomma in Elverum (Norway), though different techniques were used to develop and administer the IVN in the different studies. In particular, the IVN for the different conditions were developed using techniques resulting in higher or lower levels of scene oscillations. The former consisted in 360° video-making with minimal stabilization ("unstable video"), the latter consisted in 360° video-making with maximal stabilization ("stabilized video") or three-dimensional modelling ("3D model"). These were administered, in different combinations, either during a sedentary (i.e., sitting on a chair) or an active (i.e., self-paced walking on a manually driven treadmill) session. In the active conditions, the participants walked on a manually-driven treadmill (Woodway, Curve), which allowed the participants to walk at a self-paced speed, operating the treadmill directly with the movement of their feet. The self-pacing was preferred to a standardized speed not only for safety reasons (as the participants eyes were covered by the VR headset), but also to provide greater autonomy during the IVN exposure, an important factor supporting future physical activity behaviour [50,51]. The resulting combinations characterizing the different experimental conditions were the following:

- Sedentary*unstable video (Study 1)
- Active*unstable video (Study 1)
- Sedentary*unstable video (Study 2)
- Sedentary*stabilized video (Study 2)
- Active*stabilized video (Study 3)
- Active*3D model (Study 3)

Additionally, in Study 3, a control condition was also included, in which the participants walked for 10 minutes on the manually driven treadmill without being exposed to any IVN. Each exposure lasted around 10 minutes –previous studies found significant effects on exercise intention after as little as 5-minutes' walk [52]. Within each study, no between-conditions differences were found with respect to ratings of perceived environmental restorativeness [38,39]. Information about the technology and techniques employed to develop and deliver the IVN is presented in Table 2. Further details are available in the primary publications [38,39,48].

< Table 2 around here >

Quantitative measurements

The participants' intention to visit the real location viewed in the IVN was assessed in all studies through a single item, which asked the participants to rate their level of agreement with the following statement: "After the 'virtual walk', I want to visit that place in reality." The participants reported their response on a 0-10 visual scale with anchor at 0 (= "Absolutely disagree"), 5 (= "Neither agree, nor disagree"), and 10 (= "Absolutely agree"). Although it has been recommended that scales for general intentions relative to people's health-related behaviours are developed as a three-items scale [53], single-items scales have been previously used to assess intention to exercise in specific locations (see e.g., [52]).

The effects of viewing the IVN on the participants' general green exercise intention was assessed by administering the *Intention to Perform Green Exercise Questionnaire* [54] before (pre) and after (post) undergoing each experimental condition. Green exercise intention was assessed only in Study 2 and 3, as the instrument was yet not available when Study 1 was conducted. The instrument is compounded of five items (e.g., "I intend to do green exercise"), each being rated on a 1-7 scale with anchor at 1 (= "Absolutely disagree") and 7 (= "Absolutely agree"). The caption provided a specific time reference ("in the course of the next week") and a definition of green exercise ("Examples of what is intended as green exercise: walking or exercising in parks, green- or natural environments. This can include commuting to and from work/school or walk/exercise with a dog or other domestic animal"). The instrument showed a high internal consistency in both studies and in both the pre- and post-exposure assessments (alpha = 0.94 – 0.95).

As past exercise behaviour influences future exercise intention and behaviour [55], the participants' physical activity levels were assessed at baseline (i.e., before the beginning of the experimentations), to be used as a covariate for green exercise intention. Physical activity levels were assessed using the Godin's Leisure Time Exercise Questionnaire [49]. The instrument assesses physical activity of different intensities (light, moderate, and vigorous) to generate an overall score in metabolic equivalent of task (MET). For the purposes of the present study, the caption was modified to include non-leisure forms of physical activity, such as active commuting –such modified version was previously found to be highly correlated with objective assessments of physical activity [56].

Qualitative information

Participant perspectives were collected through qualitative data via the survey instrument. The open-ended nature of the questions allowed participants to offer a personal reflection on the extent to which IVN encourages experiential consumption of green exercise. Questions were framed in line with the tenets of Feedback Theory regarding the emotional benefits of the IVN. Additionally, participants were offered the opportunity to indicate the reasons why (or why not) they perceived the virtual walk as enjoyable. Questions were objectively phrased to allow for negative, positive as well as neutral viewpoints.

Data analyses

Statistical analysis

The quantitative data were preliminary examined for frequency distribution, possible outliers, and missing values. Due to the differences in study design, experimental condition, and time of assessment, the data from the three studies were analysed separately. The participants' ratings of intention to visit the location were examined using descriptive statistics and, as the data were not normally distributed, presented through Median (*Mdn*) with Inter-Quartile Ranges (*IQR*). According with the observed non-normal data distribution, Wilcoxon Signed Ranks Test (for Study 1) and Mann-Whitney test (for Study 2 and 3) were used to establish possible differences among the different experimental conditions within the individual studies. For the analysis of green exercise intention, which included pre and post assessments as well as between-groups comparisons, a mixed between-within subjects analysis of covariance correcting for the individuals' physical activity levels (ANCOVA) was preferred in order to reduce the risk of Type I error. An exponential transformation was preliminary applied to the green exercise intention data in order to enhance the data's negative skewedness. "Time" (pre/post assessment) was the within-subjects factor and "condition" (Study 2 = Sedentary*unstable video, Sedentary*stabilized video; Study 3 = Active*stabilized video, Active*3D model, Control) was the between-subjects factor, while physical activity levels was set as a covariate. If statistical significance was achieved in the ANCOVA, a pairwise comparison of the estimated marginal means (*EMM*) of green exercise intention corrected for physical activity levels was performed to test for possible pre-post differences in the individual experimental conditions. A Bonferroni adjustment of alpha was applied to reduce the risk of Type I error due to multiple comparisons. Additional analyses were conducted in order to establish possible associations of intention to visit the locations or green exercise intention (the latter expressed as delta-values) with the participants' background information (sex, age, and BMI). More specifically, Mann-Whitney test were used to establish possible differences between men and women, while Spearman's Rank Correlation Coefficient was used to establish possible associations with the participants' age and BMI. All statistical analyses were performed using IBM Statistics SPSS version 26 (IBM Corp., New York). Significance was set at $p < 0.05$.

Analysis of the qualitative data

The qualitative information was analysed by using the Gioia method [57]. Participants were invited to articulate their reflections and intentions which were gathered and analysed thematically into 1st and 2nd order constructs, leading to aggregate dimensions of the qualitative findings [57]. Following initial classification of the participant's reflections, two researchers (BJK SLB) independently coded the responses, which were reviewed by two further researchers (GC SL), who sampled the combined coding to check consistency and pattern matching to ensure validity, as well as inter-coder reliability. Subsequently, the output of the coding process was interrogated to classify emergent patterns and themes. Following this, the researchers engaged in a series of hermunetical cycles of analysis noting repetitions in the data and corollary themes. The analysis operation led to the development of second order themes, and aggregate dimensions which are presented in Figure 3.

< Figure 3 about here >

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Authors' contributions

GC conceived and designed the study, drafted the overall manuscript, led the team of authors, and conducted the quantitative analysis. BJK led and, in collaboration with SLB, conducted the qualitative analysis and wrote the sections relative to this part. TLR, OEF, and FF, in collaboration with GC and SL, developed the VR installations specifically for and in compliance with the study's purposes, and contributed writing and revising the sections relative to this part. SL provided substantial contribution in the conception and design of the study, conducted the data collection and, in collaboration with GC, contributed writing the sections relative to the general methods and the quantitative study.

Competing interests statement

The authors declare no conflict of interest.

Data availability

The datasets of this study is not publicly available at the moment. All relevant aggregated data are provided in the paper. The data used in the current study may be made available after agreement with the authors.

Ethics

All studies were registered at and approved by the Norwegian Centre for Research Data (Study 1 and Study 2, ref. n. 53246 and 60451, respectively) or the Regional Ethics

Committee (Study 3, ref. n. 134663). All participants were informed about the purpose of the study and associated risks before they provided their written consent.

Figures legends

Figure 1. Frequency distribution of ratings of intention to visit the location shown in the IVN (agreement with the statement "After doing the 'virtual walk', I now would like to visit that place in the reality"). The intention to visit the location was rated on a 0-10 scale, but for the sake of simplicity participants who assigned ratings 1 to 4 and 6 to 9 were conflated

Figure 2. Changes from baseline in green exercise intention (i.e., difference between post- and pre-exposure values), in relation to different experimental conditions (EMM±SE, as corrected for PA-levels). Left = Study 2; Right = Study 3.

Figure 3. Example of second order themes and aggregate dimensions emerginf from qualitative data.