A Mixed Methods Examination of Immersive Virtual Reality Green Exercise.

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Thesis Abstract

There is increasing research suggesting virtual reality (VR) can enhance exercise experience, yielding additional psychophysiological benefits. Combining VR, nature and exercise may provide additional health benefits compared to indoor (control) and virtual urban exercise; thus, this thesis' aims are:

a) to examine how VR environments can influence psychophysiological outcomes of exercise

b) to explore individual expectations and reactions to using VR exercise.

The first study was designed to assess green (nature) and urban VR environments on psychophysiological outcomes during a controlled cycling-based exercise. Participants (n=12) cycled at an RPE of 12 for ten minutes. Participants reported improvements in positive and negative affect from pre- to post-exercise in the virtual green condition ($p<0.001$). Yet, compared to the virtual urban condition no significant difference was observed ($p>0.05$). A significant difference was observed in positive affect between the control condition (no VR) and the virtual green condition ($p>0.001$). Heart rate was significantly higher in the control condition compared to the urban ($p=0.005$) and green ($p=0.02$) conditions. Distance travelled (m) was significantly higher in the control condition compared to the urban ($p=0.003$); there was no significant difference between the green and urban; and green and control condition ($p>0.05$). Results revealed virtual green exercise can be beneficial to psychological outcomes but compared to urban/indoor environments, the results can vary. Little is known about participant thoughts and beliefs regarding VR, Study 2 was a qualitative study designed to assess expectations and reactions to VR exercise. Participants reported limited VR experience. VR improved enjoyment, and motivation and lowered perceived effort (despite RPE 12 instructions. Participants preferred the green over urban and indoor environments and suggested VR should be a substitute for real outdoor exercise. Overall, VR improved the exercise experience of participants. Future research should branch into clinical populations that may benefit from virtual green exercise.

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Abbreviations

IVE	Immersive Virtual Environment
IVN	Immersive Virtual Nature
VR	Virtual Reality
BDST	Backwards Digit Span Test
bpm	Beats Per Minute

1.0 Thesis Justification

Century living, especially in developed countries, is linked to the increase in noncommunicable physical and mental health conditions (1). These conditions are often caused by physical inactivity, daily stresses and variance in behavioural choices (1). Physical inactivity causes 1.9 million deaths per year worldwide and roughly 1 in 25 of all deaths (2, 3). Exercise has been shown to provide a wide range of health benefits, from protecting against disease to enhancing physical and mental health (4). Regular exercise decreases the risk of morbidity and mortality from coronary heart disease and stroke (5). Furthermore, low exercise levels are a major cause of obesity and contribute to the rising cases of diabetes and cancers (5). Sedentary behaviour is increasing in numerous developed countries, with global estimates showing that one-quarter of adults are insufficiently active worldwide (4, 5). Technological developments with a modernised sedentary lifestyle have caused an increase in diseases associated with inactivity such as obesity and other non-communicable diseases (6). A cross-sectional study researching the relationship between overall sedentary time and risk of depression found that those who reported greater amounts of overall sedentary time were at a higher risk of having symptoms of depression (7). Exercise is often prescribed as an effective measure for treating and even preventing mental health issues such as anxiety and depression (8). Public health recommendations for aerobic exercise are effective in treating mild to major depression (9). Moreover, exercise is increasingly being recommended to improve the quality of life of individuals with or without health conditions (8).

The environment in which exercise takes place has appeared as an additional element that can determine the benefits seen through exercise (4). It has been suggested exercising in the presence of nature, more commonly known as green exercise, can enhance the health benefits seen by regular exercise, thus offering additional value regarding disease prevention and overall health improvement of a population (10). A recent systematic review revealed that exercising in a natural environment improved anxiety, energy and mood compared to an urban environment (11). Yet, there is increasing threat to the natural environment, due to urbanisation and populations moving away from this setting, thereby potential health benefits associated with nature are lost (12). The percentage of the world's population that live in these urban areas has increased from 30%-54%, with the United States of America and Canada being as high as 84% post-war (13). Because of the increase in urbanisation, more people are now facing the prospect of living in environments with fewer green spaces (14). This separation from the natural environment could have a detrimental effect on an individual's wellbeing (15, 16). A two-week experimental study revealed that positive affect and feelings of elevation were significantly higher when individuals experienced a greater frequency of nature interactions (17).

Due to the increase in urbanisation, there has been growing interest in using virtual environments that depict nature to enhance public health (18). With the development of affordable and user-friendly virtual reality technology, human-nature interactions could transition from real interactions to virtual interactions (1). Virtual reality can simulate a sense of immersion that is not seen by traditional two-dimensional displays (19). According to research on actual nature exposure, immersion within a natural environment may be crucial to receiving additional health benefits (20). Regarding green exercise, virtual reality might be the future for individuals who can't access nature typically.

2.0 Introduction

2.1 Environments and Health

2.1.1 The Natural Environment

The natural environment is increasingly being recognised as crucial to human health and wellbeing (27). This can be seen by the growing pool of research that has explored the relationship between the natural environment and health (21-23). Research often suggests that there is a positive relationship, with exposure to natural environments improving individuals' psychological wellbeing (24-26) and physical wellbeing (27). The natural environment encompasses any outdoor spaces that retain noticeable elements of nature, ranging from pristine or seminatural areas to urban green or blue spaces, including green infrastructure (28). Thus the natural environment represents a range of spaces such as gardens and urban allotments, parks, wilderness, rivers, lakes and farmland (28)(19). Furthermore, an individual may also engage with nature by viewing natural environments through buildings, in photos or movies and virtual reality set-ups (19).

During the last decade, scientific interest in the relationship between human health and the natural environment has increased significantly, as shown by the increase in the number of papers published annually (29). A large selection of health factors have been researched, from physiological to mental health and wellbeing, as well as self-reported general health (22, 30, 31). The diversity in health factors is complimented by the diversity in gaining access to nature or green space (32). Living in an area with a large percentage of green space, observing nature through a window and having access to parks and green spaces have all been positively associated with improved health factors (32).

The different types of nature individuals are exposed to that have been shown to affect psychological outcomes, such as mood, are placed into certain categories: virtual or simulated nature (e.g. images, videos and virtual reality), viewing nature passively (e.g. sitting in a park or through a window), walking in nature, green exercise studies and self-reported or observational studies of nature exposure on mood (1). All categories, such as walking in woodland and sitting in a park, have been shown to improve psychological outcomes, yet the magnitude of the effect can vary, for example, viewing nature virtually creates less of a mood effect than actual nature does (33, 34).

One of the most common outcomes when interacting with nature is improved affect and emotional wellbeing (33). Research conducted in Japan and China points to a plethora of positive psychological and physiological health benefits associated with the practice of Forest Bathing (immersing oneself in nature) (35). The reported research suggests Forest Bathing increases parasympathetic nervous system activity, which is frequently linked with a decrease in stress, negative affect and an increase in positive emotions; increases mental relaxation, aids with depression and anxiety elicits human feelings of “awe” and increases gratitude and selflessness (1, 35, 36). A fundamental limitation of Forest-Bathing research is the sampling bias, with the majority of studies consisting entirely of males (37, 38). Nevertheless, results suggest that Forest Bathing reduces the severity of signs and symptoms of depression in older adults and indicates a unanimous preference for forest walks versus urban walks (38, 39).

One mechanism suggesting the relationship between nature interaction and psychological wellbeing is the Pyscho-Evolutionary Stress Reduction theory (40). The Pyscho-Evolutionary Stress Reduction theory suggests that nature exposure encourages recovery from stress (40). Interacting with nature creates positive distractions from daily stresses and evokes feelings of interest, pleasantness and calm, thus decreasing the symptoms of stress and fostering positive affect (41). The reduction in stress restores psychological wellbeing through emotional and affective alterations (41). One study assessing this hypothesis saw self-reported ratings of positive affect increase and negative feelings, such as fear, decrease when participants viewed natural scenery compared to those that viewed a city landscape with little or no nature (42). Furthermore, decreases in self-reported stress and increases in positive affect have been found after prolonged exposure to a wilderness area (42). Further studies have reported reductions in stress predictors such as blood pressure, heart rate and stress hormones (41).

Interactions with nature can also improve cognitive functioning (43). Especially in tasks that require attention and working memory (1). Research regarding the influence of nature exposure on cognitive performance found a positive correlation between cognitive development in children and green space around schools (44). In an adult population, residents of greener public housing buildings showed higher attentional functioning compared to counterparts in barren buildings (less green surroundings) (45). The cognitive benefits of nature exposure do not seem to be triggered by changes in mood because there is no correlation between mood and cognitive functioning (46). For example, walking in winter versus summer elicited greater improvements in mood for the latter, yet there was no significant difference in cognitive functioning (43, 47, 48) Several cognitive tasks, differing in working memory load, have been used in experimental research; the backwards digit span task, which requires participants to repeat sequences of numbers, increasing in length, in reverse order, shows the most consistent improvement after nature exposure (48, 49).

The Attention Restoration Theory offers an explanation for promoting cognitive functioning (43). This theory suggests two types of attention: directed attention, where attention is directed by a cognitive control process and involuntary attention, where attention is captured by inherently interesting stimuli (41, 43). Attention can be referred to as the process that brings a stimulus to consciousness; in other words, the process that allows us to notice something (50). Directed attention is a psychological outcome that can be influenced by the environment in which exercise is undertaken (43, 51, 52). Directed attention is the effortful cognitive ability to avoid distraction by competing stimuli (51, 53, 54). Regions of the brain that process mental effort, attention and mediation of cognitive control can fatigue over time (51, 54). This reduction in directed attention has been characterised as directed attention fatigue (51). When involuntary attention is used, this decreases the use of directed attention as mental effort is not involved, this provides an opportunity for directed attention ability to improve (43, 51, 55). Directed attention requires cognitive effort and concentration and once overused will lead to directed attention fatigue (41). Directed attention is regularly used in our everyday lives, often resulting in mental and cognitive fatigue (41). Yet, according to this theory, interacting with inherently interesting stimuli, such as the natural environment, invoked involuntary attention, thus allowing directed attention to replenish (43). One study showed that walking in nature can improve directed attention when measured with a backwards digit-span task (43). Furthermore, it has been reported that resting for one hour in a natural environment (outdoor garden) results in improvements in directed attention (41).

Involuntary views of nature or the presence of plants have also reported a reduction in mental fatigue in a workplace environment (41).

2.1.2 The Urban Environment

Despite the positive effects linked with interacting with the natural environment, accumulating evidence indicates that occasions for nature interactions are declining globally (56). For example, less than 40% of the population of the United Kingdom visits a natural environment in a week, with only a fraction of visits involving exercise (57). As well as the reduced opportunities for contact with the natural environment, the world population are becoming less connected with nature, which has the potential to affect a range of psychological and physiological health factors (58). Only 3% of the total world population lived in urban areas in 1800, by 1900 this had risen to 14% and by 2007 over 50% of the population of the world have been urbanised (59). Furthermore, a 2014 report by the United Nations stated that over 55% of the globe’s population is currently living in an urban environment, with the number expected to increase to 68% by 2050 (13). Urban environments generally have fewer and more degraded natural ecosystems, making nature less accessible to individuals (60). Likewise, behavioural changes related to a modern lifestyle, such as increased time spent indoors and a higher preference for indoor recreational activities further reduced interactions with the natural environment (61). For example, a typical European individual will spend 15.7 hours inside per day and the average American will spend 90% of their lives indoors (42, 62). Furthermore, the rate at which individuals interact with nature is expected to decline even further, as children in the 2010s and 2020s spend less time outside than previous generations (63, 64). The rapid increase in technological development is believed to be part of this problem, with research implying that screen time is replacing experiences with the natural environment (58).

The rapid increase in urbanisation may give rise to worldwide health issues (65). Mental health problems are a typical urban phenomenon as instability and mental isolation are features of an urban community (66). A meta-analysis conducted by Peen et al., included data from 20 adult population surveys conducted in developed countries since 1985, reporting a 38% increase in rates of depression and a 21% increase in anxiety compared to rural areas (67). Furthermore, the Centre for Urban Design and Mental Health found higher rates of most mental health problems in cities compared to villages, there were over 20% more cases of anxiety, almost 40% higher risk of depression, double the risk of schizophrenia, higher levels of stress, seclusion, and loneliness in cities (68). Yet, increased frequency of greenspace use and the existence of natural views from a window within a home are associated with increased levels of self-esteem, life satisfaction, and decreased levels of depression, anxiety and loneliness (69). Individuals living in urban environments suffer from physical and mental problems due to pollution, environmental degradation, fast-living culture and food habits compared to their nature-dwelling counterparts (68). Within an urban environment's social and cultural structure, every group tends to have its own health concerns (alcoholism, drug use, homelessness and crime), with these concerns being more concentrated within a city (59).

The rapid increase in technological development and increased urbanisation are believed to be decreasing an individual’s chance of being exposed to nature (56, 58). Yet, recent technological developments may be the answer to increasing human-nature interactions.

2.1.3 Technology and Nature

Technology and nature is somewhat a broad concept; it incorporates any technology that mediates, augments and/or stimulates an individual's experience of the natural world (70). A recent development in technology is the advancement in virtual reality (1). Virtual reality is a medium composed of interactive computer simulation that senses the user's position and actions and augments the feedback to one or more senses, giving the user a feeling of being mentally immersed or present in a simulation or a virtual environment (71).

Virtual reality can be used to augment the experiences, behaviours, and beliefs of an individual (72). For example, a recent study on using virtual reality for depression showed that participants elicited more positive emotions than negative emotions and an increased positive attitude toward help-seeking behaviours for depression after exposure to an immersive virtual environment, consisting of a calm and soothing lake scene, using a head-mounted device (73). Yet, participants reported below-average intentions to physically seek help (73). Furthermore, a systematic review of virtual reality use for relaxation in a general population suggested that virtual environments consisting of pleasant and natural stimuli were a "feasible and acceptable tool to promote relaxation" and restore stress (74).

During the turn of the millennia, Levi and Kocher explored the potential impact of technological nature on society, revealing that with the forthcoming increased commerciality of immersive virtual reality technology, virtual reality may increase an individual's connectedness and support for the natural environment (58, 75). This type of technology has been suggested to promote nature connectedness and support in the form of psychological attachment to nature, positive attitudes towards nature, and increased motivation to visit natural environments (76).

Recently, the application of virtual reality to create virtual simulations of the natural environment has generated greater attention as an opportunity to deliver nature exposure to those who cannot access the natural environment for medical reasons or other barriers or to contribute to reconnecting individuals with the natural world (58, 77, 78). In particular, this increased attention has focused on virtual nature and especially immersive virtual environment (IVE) technology (comprised of synthetic sensory information that provides a surrounding and constant stream of stimuli, creating an illusory sensation of being enclosed within a real environment that the user can interact with) (75, 79). IVE technology allows researchers to collect multiple types of response data such as heart rate, skin temperature, respiration patterns, movements and speech that can be easily gauged through commercially available biomonitoring instruments or audio/visual recordings of participants (79).

The combination of the IVE and virtual nature is often referred to as immersive virtual nature (IVN) (80). Previous research has shown IVNs can elicit positive psychological responses such as increased positive affect and reduced negative affect, stress, and anxiety, when compared to other virtual environments such as urban settings (81-84). Moreover, Anderson et al., found that an IVN, displaying large expansive natural vistas with views of water, reduced stress and negative affect more than a non-virtual indoor control scene, comprised of an empty indoor classroom (85). IVNs have also been shown to promote cognitive effects in participants following exposure to a computer-generated depiction of a forest (86). Furthermore, IVNs can provide similar psychophysiological responses to that experience by a real natural environment yet have been perceived as less enjoyable and were unable to fully reproduce the effects of real nature (87-91).

A conceptual framework developed by Markevych et al., (Figure 2.1) (92) based on understanding the psychophysiological benefits of nature exposure might suggest how a virtual environment can produce similar benefits to that of exposure to a real natural environment (93). Three sets (domains) are reported in this framework that explain the health benefits of natural settings, including reducing harm ("mitigation" domain), restorative capacities ("restoration" domain) and building capacities ("instoration" domain) (92, 93). Both virtual and real nature environments can support the renewal of depleted adaptive resources through stress reduction and attention restoration (92, 93). Additionally, other mechanisms such as reducing air and noise pollution (mitigation pathways) and promoting exercise and social contacts (instauration pathways) are less likely to be active in a virtual environment (78). Visual environments could activate mitigation and instauration pathways if the virtual technology masked the noise of loud environments, including exercise on treadmills or stationary cycle trainers (94). Yet, the majority of virtual technology today offers passive experiences such as audio input (95). Thus, virtual reality benefits work through restoration pathways, with restoration mainly including recovery from boredom or lack of stimulation (93, 96).

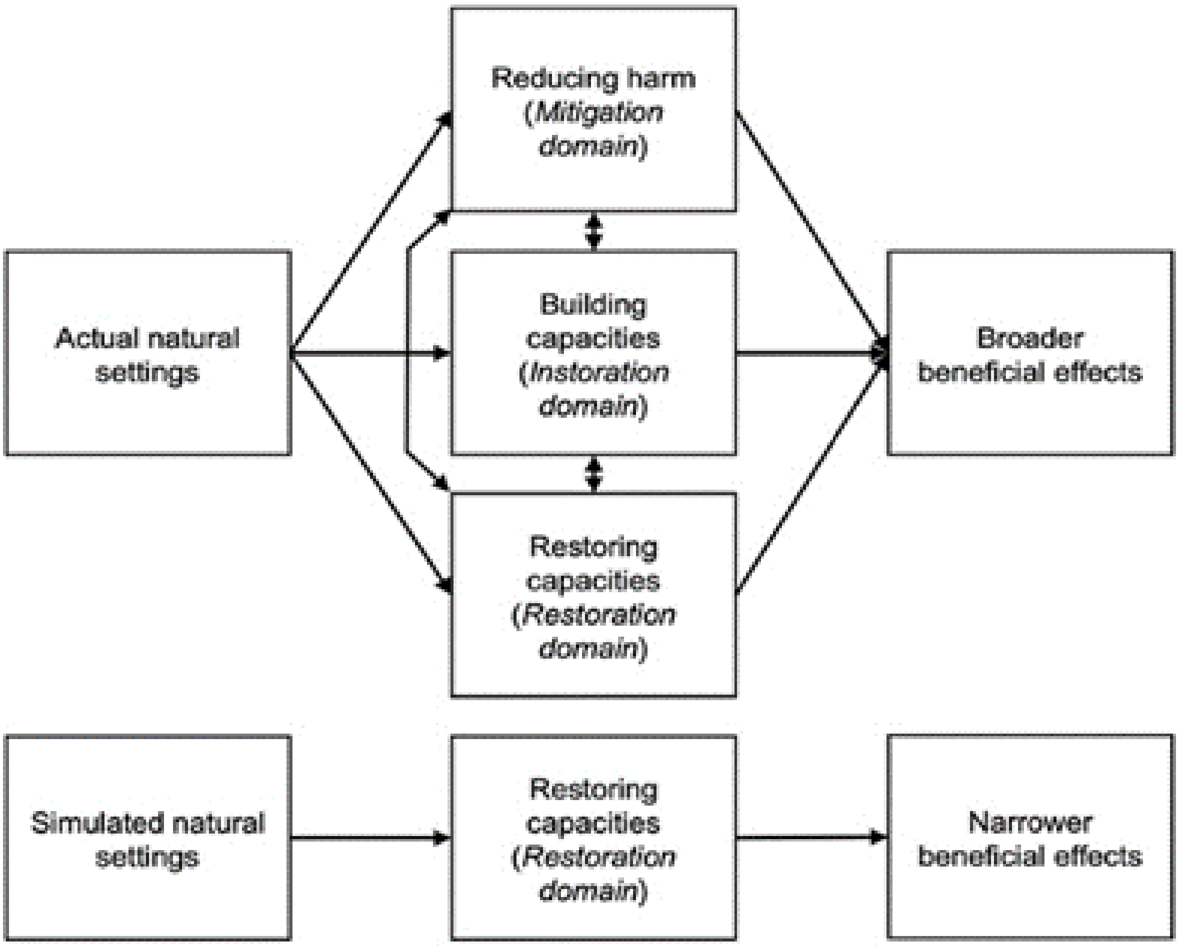


Figure 2.1: Real natural settings activate more pathway domains that promote health benefits than virtual natural settings. Conceptual framework adapted from Markevych et al. (94,95)

2.1.4 Virtual Reality: Immersion, Cyber Sickness, and Mood Influence

Head-mounted displays (HMDs), more commonly known as VR headsets are often used to present IVE/IVNs via single or multiple displays placed immediately in front of an individual's eyes, with the goal of occupying as much of an individual's field of view as possible (1, 79). (58, 75). In recent years, this type of technology has become more affordable, allowing users to immerse themselves in a virtual environment via the use of smartphone adaptive HMDs, for example, Google CardboardTM costs less than 20 USD (1). Furthermore, reasonably inexpensive cameras can capture 360° pictures and videos that can be viewed using HMDs (1). The use of HMDs in virtual nature is more immersive than other forms of virtual nature, such as videos and images (58).

Immersion is an important concept in the effectiveness of virtual reality-mediated nature (77). Immersion describes the extent to which virtual reality technology is capable of delivering an inclusive (extent to which reality is shut out), extensive (range of sensory modalities accommodated) and vivid (resolution and quality of displays) illusions of reality to one or more senses (97). A subjective correlate of immersion is presence (98). Presence is an individual’s sense of being in a virtual environment (97). Presence depends on the technology’s ability to augment sensory input from the physical reality, when the sensory feedback creates a believable virtual environment, it contributes to increased levels of place illusion (77, 98, 99). When a virtual environment responds to an individual’s actions, incorporates personal references, and aligns with expectations of how objects and people should behave, plausibility illusion emerges; this illusion convinces individuals that the events taking place in the virtual environment are genuinely happening (98). These components of illusion within a virtual environment are believed to increase an individual’s level of presence and immersion (77). This translates to immersive virtual nature's ability to create similar responses seen by a real natural environment (58). For example, increased stress reduction and positive affect are seen when a virtual reality head-mounted display (HMD) was used compared to a non-immersive virtual desktop experience of an underwater environment (83).

Increasing positive aspects such as immersion and presence are not the only aspects that affect the success of a virtual environment but reducing the impact that negative aspects (1). High immersive virtual reality technology has been documented to cause cyber sickness among users (58). Cyber sickness has been reported to occur in as many as 100% of users when using highly immersive virtual reality (HMDs) and the period spent immersed, with the longer spent in the immersive virtual environment eliciting higher levels of cyber sickness (100, 101). Furthermore, a recent study reported that 19 out of 26 participants had experienced cyber sickness while using highly immersive virtual technology (91). Yet, almost all the negative side effects of cyber sickness have been shown to dissipate after several minutes (79). (1). A recent review found that cyber and sickness and presence are negatively related, with increased cyber sickness causing a reduction in presence (102). It has been suggested that cyber sickness distracts and suppresses an individual’s attention away from a virtual environment that is required for presence to occur, thus causing the inverse association (102). Due to the technological developments of virtual reality technology causing visual displays to become more immersive, such as HMDs, which are more prone to induce high levels of cyber sickness, the issue of cyber sickness has become more relevant (103). This paradox must be solved to increase the benefits that could be seen by immersive virtual natural environments, as the most immersive displays are needed to provide a sufficient level of presence (58). The cause of cybersickness is still unknown, yet two theories that currently leading the literature are the sensory conflict theory (104) and the postural instability theory (105). The sensory conflict theory suggests cyber sickness is caused by sensory conflict between vestibular, visual, and proprioceptive systems (104). In relation to immersive virtual reality, this translates to a mismatch between input from an HMD and the input from the real surroundings provided by the vestibular, visual, and proprioceptive systems (106). The postural instability theory suggests that periods without postural control cause cyber sickness (105). This theory suggests situations leading to cyber sickness are characterised by a period where neural patterns of movement control are reorganised to adapt to an unfamiliar stimulus, such as an HMD (106). During familiarisation with a virtual environment, movement control is inefficient, thus postural instability occurs (105). The negative effects of cyber sickness are a concern for studies involving immersive HMD virtual green exercise as there is increased sensory conflict and/or postural instability caused by exercise (106).

Mood has become an important effect in concepts of human behaviour and cognition (104). Mood Induction Procedures (MIP) are often used in conjunction with virtual reality to influence a participant's mood (107). MIPs are strategies designed to produce a transient emotional state in a controlled manner (108). The moods produced are intended to be similar to those experienced by a natural environment (109). Yet, influencing mood and affect in a laboratory setting has often faced criticism regarding the validity and empirical verification of some MIPs, such as success rate, the intensity of the induced mood or affect and the range of moods that can be produced (107, 110). It has been suggested that the participant's mood does not truly change but reports this change to satisfy the researcher's needs and/or expectations (107). Additionally, research has suggested that it is easier to create a negative mood rather than a positive mood in participants, this could be attributed to the fact that participants were not experiencing depression, thus it is difficult to produce a positive mood than a negative mood (107, 110). Various criteria are used to assess the intensity of the mood produced by a participant, including the amount of time in a condition (107). Some studies suggest that 10-15 minutes is sufficient to produce an effect (107). For example, a study on the duration of a mood induction procedure found that self-reports of mood taken immediately after induction successfully induced both elated and depressed moods, with depressed moods still evident following a 10-minute waiting period (111). Yet, this study did not involve virtual reality or exercise (111). Furthermore, exposure to the natural environment virtually using 7-10 minute videos elicited improvements in numerous self-reported emotions, such as, depression, tension, anger, happiness, stress and positive affect (1, 112). Additionally, numerous studies conducted in Japan, found that forest bathing for 10-15 minutes were associated with less stress and a large decrease in negative affect and increase in positive affect (1, 113-115). Virtual reality could be useful when involved with MIPs as it gives the researcher the ability to control different variables without compromising the methodological rigour of a laboratory while situating the participant in an environment similar to a real one (107).

2.2 Physical Activity Behaviours and Nature

As stated earlier, research has demonstrated that exposure to the natural environment can improve an individual’s health and wellbeing (15, 24, 25, 29). This has led to the suggestion that performing physical activity in nature may have additional benefits beyond physical activity in an urban and indoor environment (27). Performing physical activity in the presence of nature, commonly referred to as green exercise, has been shown to improve health and wellbeing, relieve stress, increase positive mood improve motivation and adherence to health behaviours such as continued participation in exercise (116, 117).

Research regarding green exercise adopts three different approaches for comparing psychological outcomes: built vs. nature-based outdoor exercise; indoor exercise vs. outdoor exercise and the use of ergometers in a laboratory setting to control the exercise performed and research the significance of different virtual exercise environments (51). Self-reported changes in psychological response often measures an individual's change in affect or mood (1). Studies have often used the Positive and Negative Affect Schedule (PANAS) or the Zuckerman Inventory of Personal Reactions (ZIPERS) when measuring self-reported affect in response to an environment (1, 118, 119). Negative affect is often linked with the development of psychological disorders such as anxiety, depression and other mood disorders (120). Positive affect describes a pleasant emotional state that includes the feeling of joy, enthusiasm and amusement (121). Positive affect has been linked with numerous health-related benefits such as stress resilience and overall mental health and wellbeing (121-123). Negative and positive affect are not opposites but are independent concepts not always correlated (121).

The use of nature for physical activity and health is not a new concept (124). For the majority of human history, we have been deeply linked to nature and not only often used nature for basic health and survival needs but leisure and physical activity, such as hiking and running (116, 124). Exercising outdoors also leads to greater adherence to exercise than exercising indoors, for example, in post-menopausal women, adherence to training outdoors was significantly higher than in an indoor setting (125). Increased adherence to exercising outdoors could be due to nature encouraging positive exercise behaviours (124). Individuals are also active for longer and at a higher intensity when engaging in physical activity in a green space (126). Activities that are performed in a natural environment are often undertaken for longer periods, such as running, mountain biking and horse riding (4). Moreover, the American Time Use Survey revealed participants' mean duration of exercise bouts was greater when exercising outdoors than when exercising at home or a gym/health club (127). Sedentary individuals who participate in green exercise have been shown to be effective in driving behavioural change by improving adherence to exercise (124). Additionally, there is evidence that individuals are active for longer and at a higher intensity when exercising in a green space, as they are distracted from biological signs of fatigue or have a decreased perceived effort (4, 128-130). Easier access to the natural environment, such as parks, fields and woodland areas also facilitates physical activity and may foster a healthier lifestyle (4). A systematic review of objectively measured access to green space and time spent exercising found positive associations in 20 studies. (4, 131).

Exercising in nature is also an important health and wellbeing facilitator, with the presence of nature augmenting the benefits of exercise and enhancing motivation and adherence to healthy pro-environmental behaviours (1). There is an increasing pool of literature suggesting that nature-based exercise (green space) promotes health and wellbeing and fosters future adherence to exercise (10, 41, 132, 133). Green exercise also reduces depression, stress and blood pressure, increases self-esteem, mood and wellbeing, and improves heart rate variability compared to indoor exercise (134). Moreover, a systematic review found that physical activity in an outdoor natural environment elicits additional positive effects on measures of mental wellbeing that are not seen when participating in an urban and indoor setting (27). Yet, a green outdoor environment has been shown to create no significant change in mood between pre-exercise and post-exercise conditions (132). This finding is unexpected given that green exercise frequently leads to an improvement in affective state. It is suggested that the duration of the study was great enough to promote fatigue in some participants, augmenting the important psychological elements that frequently cause the positive exercise-affect relationship (132). Yet, the study design in this area of research is often cross-sectional, often preventing the identification of causal relationships between the natural environment, health and physical activity (4).

2.2.1 Green Exercise versus Urban/Indoor Exercise

The majority of evidence in reviews have indicated that exercising outdoors is more beneficial than indoor exercise; exercising in nature has a larger impact on psychological health and can elicit positive psychological states such as improved positive affect and reduced stress (4, 124). Elevated improvements in directed attention and focus (i.e., the cognitive ability to avoid distraction from competing stimuli) have also been reported in green exercise compared to indoor exercise (51, 135, 136). It has been suggested that elicited feelings of connectedness to nature and visual recognition of characteristic features such as the colour green cause this outcome (4).

The effect that an environmental setting in which physical activity occurs on individuals' psychological health outcomes has received increasing research in the last decade (11). Particularly, whether being exposed to a natural environment while simultaneously performing physical activity is more beneficial to psychological outcomes than artificial or manmade environments, such as walking in a city or exercising in an indoor gym (11).

Three previous reviews have researched the effect of an individual's exercise environment on psychological benefits in adult populations. Lahart et al., and Thompson Coon et al., both compared exercise in natural versus indoor environments (4, 27). Lahart et al., found that exercising in the presence of nature is favourable in influencing affective variance and enjoyment when compared to exercising in an indoor environment (4). Correspondingly, Thompson Coon et al., reported green exercise elicited greater feelings of revitalisation, positive engagement, energy and reduction in tension, confusion, depression, and anger compared to an indoor exercise environment (27). The third, Wicks et al., researched natural exercise environments versus urban exercise environments, reporting particularly evident reductions in anxiety and fatigue, with weaker evidence for a reduction in depression in green exercise environments (11).

From the three previous reviews, (i) green exercise versus urban exercise and (ii) green exercise versus indoor exercise are the two main methodological approaches in this area. Both methodological approaches represent an ecological comparison, where individuals will often exercise in one of the two environments, thus findings using these approaches can be applied to a real-world setting (137). A recent study employing the first approach with three different groups: green walking (outdoor walk in the presence of nature), urban walking (outdoor walking in an urban area) and a control found that positive affect increased during green walking but not in the urban walking group (121). Furthermore, office workers who walked a nature route (maintained grass areas with trees) during their lunchtime break showed an improvement in self-reported mental health compared to those who walked an urban/built route (pavements and housing areas) (133). Additionally, walking in an urban downtown environment and a green botanical garden area both found improvements in directed attention, yet improvements between groups were not statistically significant (43). Yet, the main limitation of this methodological approach (i) is that often it lacks control over the exercise component, as exercise characteristics, such as intensity and duration, often influence several outcomes (137-139).

Regarding the second approach: green exercise versus indoor exercise, increased reduction in anxiety, improved positive affect and stress and greater direction attention were seen when exercising in nature compared to indoors (132, 140, 141). Yet, influences of a green outdoor environment versus an indoor environment found that there was no statistically significant effect on affect and enjoyment between the two conditions (132). This is inconsistent with other research which found both indoor and outdoor exercise resulted in improvements in pleasant affective states and enjoyment (142). It is possible that the context (social setting within the procedure) and methodological settings (duration of exercise was enough to cause fatigue in some participants) of the exercise may have predisposed characteristics of and the relative importance of certain cognitive and physiological factors, which could have caused the effect to not be statistically significant and not have been able to promote a positive exercise-affect relationship (132). The main limitation of the second approach is that it is challenging to infer respective contributions to reported outcomes of environmental and exercise differences due to the exercise component being difficult to compare (137).

2.2.2 Virtual Reality for Negating the Confounding Factors of Green Exercise

Research on green exercise faces numerous challenges, particularly in the extent to which studies can control possible confounders when comparing outdoor versus urban/indoor environments (4, 27, 91, 132, 143). For example, changing weather conditions and terrains might lead to differences in psychological and physiological effects (91). Thus, IVNs could be implemented by researchers in order to control the environmental and exercise experience (79). Moreover, IVNs could allow individuals to integrate nature experiences into their everyday lives as well as exercise promotion interventions as it is common in an urban society for individuals to not participate in green exercise regularly, for example, 80% of the population of the UK do not participate in green exercise in a regular week (57, 91). Thus, a third methodological approach has been developed that may allow participants to get closer to a full sensory experience: urban versus nature views in a laboratory setting through the use of virtual technology, often referred to as virtual green exercise (1, 137).

Virtual green exercise can be defined as any physical activity taking place while being exposed to virtual nature (58). This definition incorporates non-immersive and immersive forms of virtual nature such as monitors or virtual reality headsets displaying nature views (1). Virtual green exercise may provide additional health benefits, for example, the actual physical movement from exercise may contribute to an increased positive affect compared to sedentary exposure to virtual nature, as non-virtual physical activity is known to produce this response (27, 91, 139). Being able to move in an IVN may also create a more immersive experience as it will provide increased engagement with a virtual natural environment (91). Thus, virtual green exercise has received increased attention within both clinical and non-clinical populations (78, 144).

When paired with exercise, virtual reality might be able to augment experiences that occur during a session, such as distractions through competitive virtual characters and/or providing motivational feedback virtually (72). There is increasing research suggesting that virtual reality combined with exercise can improve an individual’s thoughts, beliefs, and enjoyment during exercise. A recent study has shown that autistic children reported higher levels of enjoyment and increased future intention to exercise when a non-immersive virtual reality game-based activity was involved (145). Furthermore, influences of non-immersive virtual reality on exercise experience after a stroke or brain injury reported that the virtual reality experience was enjoyable, exciting and challenging, with participants stating that visual and audio feedback increased their motivation to exercise (146). However, there is little research on using a virtual natural environment to influence exercise behaviours and experiences. To the best of our knowledge, one study has researched this. Calogiuri et al., found that walking in a natural virtual environment was effective in increasing curiosity to explore the natural environment, yet participants reported mixed views regarding virtual reality as a tool to promote green exercise (77).

It is imperative to consider the effect emotions have on human behaviour and predicted emotional gains elicited by experiencing nature virtually when attempting to understand the behaviour change process produced by virtual green nature experiences (77).

One possible pathway explaining exercise behaviour and experience influences associated with virtual reality use is Feedback Theory (147): emotions can provide feedback on which behaviours an individual pursues (77). Anticipated emotions are more valuable in guiding behaviour than experienced emotions yet, emotions could have a direct causal relationship with behaviours in specific situations, such as in “fight or flight” situations (77, 147). Moreover, highly developed behaviours involve the assessment of previously experienced emotions and influences from an individual’s social and cultural background (147). When related to experiences involving virtual nature exposure, experienced emotions may be related to high feelings of presence, with virtual nature exposure producing anticipated emotional gains because of previous emotional experiences of green exercise, such as enjoyment and stress reduction (77). Furthermore, the influence that virtual reality has on exercise behaviours and experiences could depend on the type of exercise behaviour being targeted. For instance, influencing motivation during exercise or influencing an individual’s affect might require different study designs such as the use of a natural environment or distractions such as another participant exercising simultaneously (72).

Calogiuri et al., proposed that virtual green exercise may provide health benefits corresponding to the green exercise concept developed by Rogerson et al., (1, 148, 149).

The Green Exercise Concept: Two Intertwining Pathways to Health and Wellbeing (148)

Rogerson et al., suggest that current research has demonstrated two pathways by which environments influence exercise outcomes (148). The first pathway states that simple exposure to nature is salutogenic (43, 77, 150), with exercise facilitating exposure to nature (4, 27, 148, 151). The second pathway states that the natural environment shapes exercise behaviours, promoting health and wellbeing (116, 117, 137, 148). According to the green exercise concept, these two pathways intertwine and support each other to promote health and wellbeing (148). As well as the natural environment creating a venue for exercise, their psycho-physio-social benefits can elicit increased exercise duration, intensity and long-term exercise adherence (1, 148). The concept proposed could be applied to virtual green exercise and how the benefits of physical activity can be augmented by virtual reality (1). The relatability of the green exercise concept to virtual green exercise is limited by the degree to which virtual nature can replicate real nature in terms of psychological, physiological and behavioural benefits (1, 91). The majority of published research includes less immersive forms of virtual green nature, yet there is a growing body of research on the extent to which IVNs can provide the health benefits equivalent to that of the real natural environment, including approaches involving IVNs and exercise (1, 149).

Pathway 1: Psychological and Benefits of Virtual Green Exercise (148, 149).

There is increasing research suggesting that IVN can elicit increases in psychological and physiological health factors, yet most of these studies involve sedentary conditions (1, 81-83). For example, sedentary immersion in a virtual computer-generated nature setting elicited stress restoration and increased positive affect (86). Furthermore, a recent study investigating the restorative effects of virtual settings on middle-aged and elderly adults found that viewing natural settings in virtual reality produced positive feelings, and decreased levels of depression and fatigue than that of a virtual urban environment (152). Furthermore, the use of virtual reality could motivate older adults to experience nature outdoors, consequently promoting synergistic beliefs during first virtual exposure and then exposure to a real environment (152).

Research comparing IVN with real natural environments found that the psychological benefits of a real natural environment can be obtained using a virtual environment (1, 87, 149). For example, a recent study comparing the effects of a real natural environment, with a 3-dimensional and a 360s° natural environment found that all conditions produced a reduction in negative affect, with the virtual condition producing an increase in working memory whereas the real condition did not (153).

However, the real condition produced significantly greater decreases in negative affect than the VR 360 condition (153). Furthermore, a recent meta-analysis identified six studies meeting their inclusion criteria (91, 153-157): (i) reported changes in mood before and after exposure to at least one simulated natural environment; (ii) employed a virtual simulation of a natural setting that was the same and/or similar to the real setting used in the same study; and (iii) exposure to the virtual and real settings had similar durations (93). Random effects meta-analysis of pooled effects showed that positive affect increased more in the real natural environments compared to their virtual counterparts, yet studies did generally show a reduction in negative effect for both settings (93). However, the modest number of studies limits the representation of natural settings and limits statistical power (93).

Although many studies involve sedentary conditions, there is a growing body of evidence on the psychological effects of virtual green exercise (78, 144). Yet, the combination of exercise and IVNs has not produced consistent results (1, 149). A recent study comparing walking in a virtual reality green environment on a treadmill, a walk in real nature and a sedentary virtual reality replica of the same outdoor walk found that the nature walk elicited high levels of enjoyment and increased positive affect, whereas, both virtual green conditions elicited increased negative affect and were perceived as less enjoyable by participants (91). However, an IVN combined with exercise has been shown to significantly improve stress compared to exercise without the use of virtual reality (158). Moreover, a systematic review revealed inconclusive evidence regarding the extent to which virtual green exercise can provide similar psychological health benefits to real green exercise (4). The review revealed studies that favoured the real natural environment (91); and favoured a virtual natural environment (89); while others found no difference between virtual and real (88) for positive affect (4). Furthermore, one study (89) revealed statistically greater attention scores (via Necker Cube Pattern Control task) with an outdoor nature walk versus a virtual nature walk, conversely, whereas, another (88) observed no statistical main effects between real green exercise and virtual green exercise in attention (via Backwards Digit Span task and symbol digit modalities test) (4).

The inconsistent results of previous research on virtual green exercise may be due to the difference in exercise intensity, duration, type and the natural environments used ranged from university campuses to open natural landscapes (106). Furthermore, some studies manipulated mood and stress levels through the use of a pre-stressor experience (158, 159), while others may have experienced issues with cybersickness (160).

Pathway 2: Virtual Green Exercise Shapes Individual Behaviours (148, 149)

Virtual technology, such as monitors and screens, have been used extensively by researchers to explore how virtual environments can affect an individual's exercise behaviours (1). This type of technology for influencing exercise behaviours has been used since before the turn of the millennia (1, 161). A study from 1997 researching whether virtual reality-enhanced equipment influenced adherence and induced feeling states found adherence to exercise was highest in the virtual reality bicycle group (161). Yet, post-exercise feelings of positive engagement, revitalisation, tranquillity and physical exhaustion did not differ between the virtual reality and condition without virtual reality (161). However, there have been few studies researching how using immersive virtual reality technology combined with exercise influences exercise behaviours (1). One study researching the latter found exposure to IVN combined with walking resulted in high levels of intent to visit the area represented virtually (77). Furthermore, significant pre-to-post increases in future green exercise intentions were found after exposure to IVN and exercise (77). Open-ended qualitative questions revealed the impact of virtual reality exposure on behaviour regulation and highlighted the crucial role of anticipated emotional benefits (77). Although participants reported scepticism regarding virtual reality use and exercise, IVN was effective in stimulating curiosity to explore nature (77).

Performing exercise in the natural environment can impact an individual's activity behaviours, such as a reduction in perceived effort, thus increasing the amount of time an individual can exercise for and/or at a higher intensity (1, 4). The natural environment may provide a distraction from feelings of fatigue; thus, individuals can exercise for longer and at higher intensities (162, 163). A recent study on the acute effects of outdoor vs. indoor exercise on feelings of energy revealed that exercise (both outdoor and indoor) resulted in improvements in feelings of energy compared to a sedentary condition, yet there was no significant difference between exercise conditions and feelings of energy (163). However, this study was on individuals with depressive symptoms, where it has been shown that exercise in general is beneficial for both physiological and psychological factors for individuals with depression (163-165). Furthermore, walking in nature elicited significant increases in energy levels and positive affect compared to indoor exercise (88). When related to the use of virtual reality and exercise, virtual reality in combination with exercise could provide beneficial behavioural benefits seen by that of real natural environments (1). When virtual reality is compared with exercise, enjoyment and energy levels increase, as well as a reduction in tiredness (166). Moreover, using virtual reality as an aid to promote green exercise is effective in increasing future green exercise intention following virtual reality exposure consisting of a green environment (77).

2.2.3 What is the optimal dose of green and IVN exercise?

It has been suggested that to maximise the benefits of exercising within nature, it is necessary to know the optimal dose of the environment (41). Dose of green exercise represents the association between the duration of exposure, intensity of activity and the type of greenspace (3). A dose-response approach can be used to develop minimum or optimal dose recommendations for the amount of time spent in a natural environment to ensure a positive change in health outcomes (167). Yet, the exposure duration of an IVN exercise environment must be cautiously evaluated, as this can influence the effect size of the psychophysiological response to the environments and influence cyber sickness (58). Five-minute bouts of real nature experience have been associated with large effect sizes on mood, while benefits of physiological indicators of stress, such as blood pressure, peak at ten minutes of exposure (168). Furthermore, a large-scale meta-analysis by Barton et al., revealed dose-response curves for the optimal duration of green exercise on mood (Figure 2.2); showing a U-shaped relationship, with effect size peaking at five minutes, with the lowest change at 10-60 minutes of exercise (3). Conversely, in IVN research, it is important to consider the possible impact of IVN exposure and cybersickness (58). A recent review revealed that sedentary exposure to IVN shows that cybersickness symptoms increase with time up until a 75-minute threshold (169). Thus, there may be a trade-off between the optimal exposure duration to induce psychophysiological effects and the optimal duration to reduce the impact of cybersickness (58).

Barton et al., also revealed dose-response relationships between green exercise intensity and mood (Figure 2.3); the greatest change is seen at light intensity, decreasing to the lowest at moderate and then increasing again for vigorous activity (3). Yet, the results of this analysis represent differences in activity type as this research focuses on a wide range of different activities, such as walking, cycling, gardening and fishing, thus, the different activity types have not been differentiated to assess the true optimal level of exposure of the different activities (137). Nevertheless, the analysis found that every green environment improved mood (3). Dose-response relationships have also been researched for exercise and affect; greater positive affect is often experienced by individuals when the exercise intensity is less than the lactate threshold (137). Yet, to the best of the author's knowledge, there is no research on the dose-response relationship between exercise and affect while using an IVN.

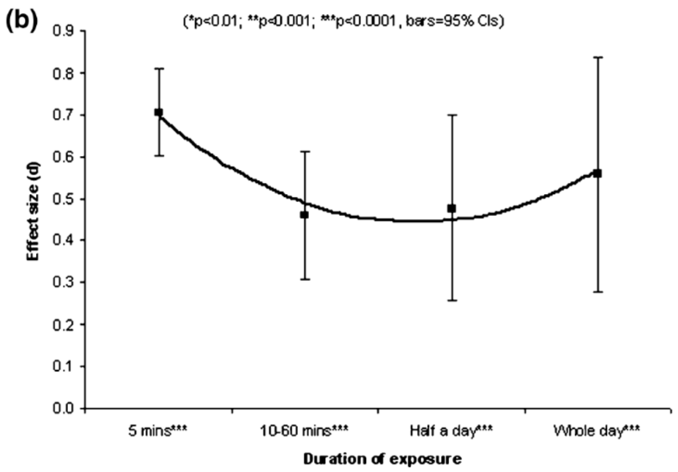


Figure 2.2: Barton et al ., dose-response relationship for the effect of exercise duration on mood (3).

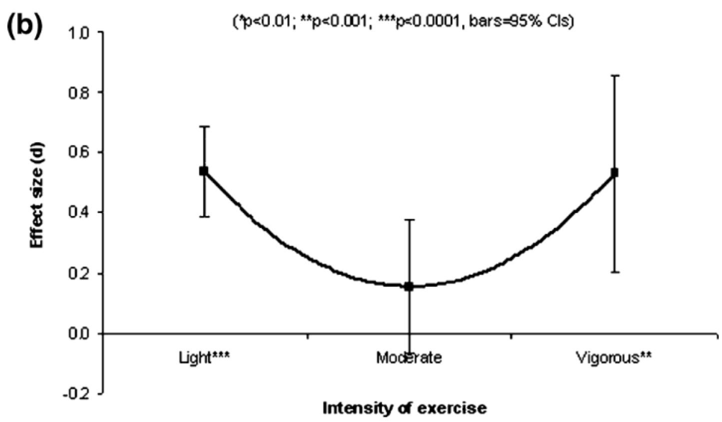


Figure 2.3: Barton et al ., dose-response relationship for the effect of exercise intensity on mood (3).

Green exercise has been shown to offer additional psychophysiological benefits (4, 137). However, the opportunity for nature interactions during exercise is declining due to barriers such as increasing urbanisation (13). Virtual reality has been suggested as a potential alternative to simulate natural environments, providing a means for nature exposure to individuals who may be unable to exercise in natural settings due to obstacles like urbanisation or medical constraints world (58, 77, 78). Virtual reality has gained increased attention in recent research due to its ability to enhance exercise experiences, potentially yielding additional benefits such as mood and cognitive enhancement as well as overall improved exercise experience (27, 91, 139).

2.3 Thesis Aims

This thesis' goal was two-fold; a) to examine how immersive virtual environments can influence an individual's psychological and physiological outcomes of exercise, and b) to explore individual expectations and reactions to using immersive virtual reality exercise. These goals were addressed via two original studies:

***Study 1*: Influences of immersive virtual exercise environments on psychological and physiological outcomes of a prescribed exercise.

> *Specific study aim:* To address the methodological gap by comparing a range of previously reported and physiological outcomes of exercising in an immersive virtual green environment versus an immersive virtual urban environment, whilst using a prescribed intensity.

***Study 2*:** A qualitative exploration of expectations and reactions to immersive virtual reality cycling.

> *Specific study aim:* To understand expectations of immersive virtual reality before use and reactions after exercising in all conditions.

3.0 Influences of immersive virtual environments on psychological and physiological outcomes of a controlled exercise.

3.1 Introduction

Exercise can provide a wide range of physiological and psychological health benefits (4, 170). Regular exercise can decrease the risks of morbidity and mortality from numerous non-communicable diseases such as coronary heart disease and stroke (5). Furthermore, exercise is often prescribed to treat and prevent mental health problems such as anxiety and depression (8). It has become apparent that an individual's environment has an impact on the beneficial effects of exercise (106). For instance, compared to exercising indoors or outdoors/built environments, engaging in exercise whilst surrounded by a natural environment is suggested to enhance exercise outcomes including stress reduction, enhanced mental wellbeing, improved cognitive functioning, and directed attention (1, 4, 40, 43, 51). The combination of exercise while simultaneously being exposed to nature is often termed "green exercise" (12, 132). It has been suggested that an individual can achieve the benefits of nature exposure, while also achieving the health benefits of exercise by performing green exercise (124, 148). Yet, many individuals find it challenging to engage in green exercise, due to barriers such as poor health, lack of time, perceived safety, and accessibility (106, 124, 141, 171, 172).

3.1.1 Virtual Green Exercise

With recent technological advancements, virtual reality has been suggested as a possible solution to barriers to engaging in green exercise (173). Virtual reality is a medium composed of interactive computer simulation that senses the user's position and actions and augments the feedback to one or more senses, giving the user a feeling of being mentally immersed or present in a simulation or a virtual environment (71). Recently, the application of virtual reality to create virtual simulations of the natural environment has generated greater attention as an opportunity to deliver nature exposure to those who cannot access the natural environment for medical reasons or other barriers or to reconnect individuals with the natural world and allow individuals to engage in green exercise virtually (58, 77, 78).

Virtual green exercise can be defined as any physical activity taking place while being exposed to virtual nature (1). This definition incorporates non-immersive forms of virtual nature such as monitors displaying nature views (1). Immersive virtual nature consists of synthetic sensory information that provides a surrounding and continuous stream of stimuli, creating the virtual perception of being enclosed within and interacting with a natural environment (79, 91). Immersive virtual nature is often achieved in the form of head-mounted devices (HMDs), more commonly known as VR goggles (1). HMDs present virtual environments through single or multiple displays placed immediately in front of an individual’s eyes; with the intent to occupy as much of an individual’s field of view as possible from the displays (79). The recent increase in the popularity of immersive virtual technology follows the introduction of affordable HMDs allowing individuals to immerse themselves in a virtual environment through the use of their smartphones and these devices (1, 91). Virtual green exercise has been proposed as an alternative method to real nature and may have the capacity to reconnect individuals with real nature (34, 154), especially for those who may be unable to engage in real green exercise (173)

3.1.2 Exercise-Environments and Affect

Previous research has suggested that green exercise increases affect compared to exercising in an urban environment (11, 25, 43, 47, 174). Affect, often related to mood (175), is a psychological outcome that can be influenced by different exercise environments (4). Studies have often used the Positive and Negative Affect Schedule (PANAS) or the Zuckerman Inventory of Personal Reactions (ZIPERS) when measuring self-reported affect in response to an environment (1, 118, 119). Negative affect is often linked with the development of psychological disorders such as anxiety, depression and other mood disorders (120). Positive affect describes a pleasant emotional state that includes the feeling of joy, enthusiasm and amusement (121). Positive affect has been linked with numerous health-related benefits such as stress resilience and overall mental health and wellbeing (121-123). Negative and positive affect are not opposites but are independent concepts not always correlated (121).

A recent study on the role of the natural environment in a workplace, where office workers undertook two lunchtime walks per week for eight weeks using either a nature route (walk centred around tress, grass and public footpaths) or a build/urban route (pavement routes through housing estates and industrial areas revealed self-reported mental health improved in the natural walk condition, with no change found in the urban/build condition (133). Moreover, a 2010 systematic review which analysed 25 studies comparing responses to exercise in a natural environment compared to urban/built environments found that the natural environment was associated with reduced anxiety, fatigue and increased energy (24). Yet, this review may have overlooked negative emotional responses, triggered by elements such as street traffic, or acute psychophysiological response to exercise, as well as confounding factors by combining urban/built environments with indoor environments and exercise with non-exercise conditions (4).

Engaging in exercise while being exposed to virtual nature (virtual green exercise) may also provide the benefits seen by real nature (1). Previous research into virtual green exercise has mainly adopted the use of less immersive forms of virtual technology, such as TV screens or projections on a flat wall (106). One study on post-menopausal women that compared non-immersive green exercise to an indoor group and non-immersive virtual urban exercise revealed that green simulated environment led to an increase in positive affect, whereas the urban and control conditions, although still improving positive affect, caused less of an effect on positive affect (176). Furthermore, mood assessed via the use of the shortened version of the Profile of Mood States questionnaire, in fifty healthy participants, revealed that exercising whilst viewing non-immersive virtual nature was beneficial for an individual's mood and stress levels compared to indoor exercise and no exercise (158).

A recent integrative analysis by Calogiuri et al., (149) suggested that more immersive HMD-based virtual green exercise may provide the health benefits corresponding with the green exercise concept proposed by Rogerson et al., (144, 148). Calogiuri et al., proposed that adding nature exposure to virtual exercise (virtual green exercise) would provide psychophysiological benefits above that of indoor and immersive virtual urban exercise (144, 149).

Studies more specifically using HMD-based virtual reality have provided inconsistent results relating to affect (149). For instance, in an early study, Plante et al., found that although virtual green exercise improved psychological state to a greater extent than treadmill walking with no virtual stimulus, a walk through a real outdoor environment had the greatest positive affect (177). More recently, Caloguiri et al., reported that virtual green treadmill walking increased negative affect and was perceived as less enjoyable than walking in a real green environment, which also increased positive affect (91). However, Gatersleben et al., reported that walking in a virtual natural environment was more restorative for positive affect, following mentally fatiguing task (Stroop test) than areal outdoor natural walk (89). The inconsistency in findings in previous research could be accredited to different studies performed exercises with different durations and intensities; the natural environments used ranged from open natural environments to university campuses (12, 177), some manipulated stress and mood levels through the use of a pre-stressor experience (158, 159) and the immersion levels of the HMD used varied (177, 178).

A recent systematic review revealed that four of the studies identified to research heart rate (51, 176, 179, 180), found that three trials (51, 176, 179) observed no statistically significant difference in heart rate between virtual green and indoor exercise (4). Two trials used cycle ergometer-based exercise (176, 179) and one used treadmill running (51). The three trials observing no statistical difference between conditions controlled the exercise via percentage of VO2 max (51), percentage of maximal heart rate adjusted for age (176) and, cycling speed and rotations per minute (179). Validating that exercise intensity was identical between conditions. The trial that reported a significant difference in heart rate allowed participants to run at a self-selected pace on a treadmill (180). Heart rate and distance ran were higher during self-selected entertainment (e.g. music and pictures of friends) compared to views of nature (180). Yet, the previous studies used less immersive forms of virtual green exercise, such as TV monitors and projections onto a wall. One study that used immersive HMD virtual exercise and self-selected exercise intensity revealed no significant difference between virtual green treadmill walking and indoor treadmill walking (144). Moreover, another study using self-selected walking comparing a real outdoor environment and an immersive HMD virtual green environment found no statistical difference in heart across conditions (91).

3.1.3 Attention Restoration Theory and Directed Attention

Attention restoration theory suggests that spending time in environments that provide an abundance of natural stimuli promotes the restoration of depleted attentional resources (49, 55). It suggests that to attend to stimuli that require relatively more cognitive processing, one uses ‘directed attention’, which is defined as Directed attention can be defined as the effortful cognitive ability to avoid being distracted by competing stimuli (51, 53, 54). Prolonged engagement in tasks that require mental effort, attention, and cognitive control can fatigue over time in corresponding brain regions, with this depletion being termed directed attention fatigue (51, 54). The ability to subdue distractors is a core cognitive subprocess within the directed attention mechanism, this ability to suppress distractors has been termed inhibitory control (181, 182). Furthermore, the voluntary control of distractors is prone to causing directed attention fatigue (51, 54, 181). Within an urban environment, many unwanted stimuli require mental effort and cognitive control to inhibit incoming distractions while maintaining focus on a specific task (181). Thus, causes directed attention fatigue and reductions in inhibitory control, which may cause declines in focus, loss of efficiency and other attention-related adverse effects (181, 183). Conversely, in natural environments, directed attention is not required as natural stimuli are intrinsically “fascinating”, so involuntary (“effortless”) attention can be used; involuntary attention involves significantly less cognitive effort, thereby providing an opportunity for restoration of depleted attentional resources and, in turn, mood states (49, 51, 54, 55, 184). For example, engaging in an hour of rest in an outdoor garden has been shown to facilitate improvements in directed attention among the elderly compared to an equivalent period of rest in an indoor room (185). As well as at rest, environmental influences on directed attention occurs during exercise. (43, 51, 136, 174). Cycling in an outdoor environment increased directed attention compared to an indoor environment, which found a detrimental effect (132). Similar findings have been found in treadmill-based exercise (51).

3.1.4 Exercise and Directed Attention (Transient Hypofrontality)

In addition to environmental influences, evidence suggests a pathway linking attention restoration with exercise (51, 186). Exercise enables prefrontal cortex restoration through transient hypofrontality; decreases in prefrontal cortex activity occur in conjunction with increased motor cortex activity (51, 186, 187). During exercise, the reduction in prefrontal cortex activity may be detrimental to cognitive performance, this is due to exercise deactivating brain structures involved in memory function, such as brainstem nuclei and the hypothalamus (188). Yet, this affords prefrontal cortex restoration, thereby improving post-exercise cognitive performance (51).

3.1.5 Directed Attention Virtual Research

Studies that have compared immersive HMD virtual exercise environments on directed attention have yielded inconsistent results. One study found statistically greater attention scores, via the use of the Necker Cube Pattern Control task, with an outdoor nature walk compared to a virtual nature walk (89). Conversely, in a much larger trial, walking in a virtual natural environment and a real natural environment reported similar benefits in cognitive effects, via backwards digit span task (88). Additionally, attentional focus, via the Attentional Focus Scale (189), is significantly higher when cycling in a virtual natural environment compared to a control condition (190). These confounding results could be due to the difference in directed attention measures used, yet more research is needed to understand the reasons for these mixed findings.

3.1.6 Gap in Research

Although virtual reality exercise research has mainly compared virtual environments to real environments, traditional laboratory based green exercise studies have typically compared green vs. urban vs. control conditions, as discussed in Chapter One. It appears that only one study to date has compared immersive virtual green exercise and immersive virtual urban exercise on affect. The study observed no significant changes in positive affect after the nature condition, yet positive affect significantly decreased following the urban conditions (178). Conversely, negative affect significantly reduced in the nature condition, whereas no change was observed in the urban condition (178). Concurrently, to date, no research has used this study design and immersive HMD technology to examine exercise environmental influences on directed attention, although non-immersive virtual green exercise has elicited greater directed attention, via backwards digit span test, compared to a non-immersive virtual urban environment (51).

The present study aimed to address this methodological gap by comparing a range of previously reported psychological (directed attention and affect) and physiological (heart rate) outcomes of exercising in an immersive HMD virtual green environment versus an immersive virtual urban environment, whilst using a prescribed exercise intensity (132).

The hypotheses were that: (i) all exercise environments would facilitate improvements in affect and (ii) directed attention from pre- to post-exercise; (iii) immersive virtual green exercise would facilitate improvements in affect from pre- to post-exercise to a greater extent than immersive virtual urban exercise and a control condition; (iv) immersive virtual green exercise would facilitate improvements in directed attention from pre- to post-exercise to a greater extent than immersive virtual urban exercise and a control condition; (v) heart rate and distance travelled would be similar during all conditions due to exercise intensity being controlled in the present study.

3.2 Methods

Twelve participants (3 females, 9 males; age range 19 - 33 years (22.17 ± 3.59 years); stature = 1.70 ± 0.15 m, mass = 71.37 ± 7.66 kg) were recruited from students at the University of Essex. Participants responded to written and verbal recruitment advertisements. All participants stated that they were familiar with cycle-ergometer-based exercise. The physical activity background of each participant was not obtained.

3.2.1 Design and Procedure

A within-participants repeated measure design was utilised, whereby every participant completed all three of the exercise conditions: virtual green outdoors, virtual urban outdoors; and an indoor control condition in a random counterbalanced order for 10 minutes at rate of perceived exertion (RPE) 12. Studies have shown that 10-15 minutes of exercise is sufficient to produce psychological effects (107).

Experimental conditions differed only by the environment (two virtual and one real) in which the exercise session took place. The conditions were completed on separate days to eliminate any carryover and fatigue effects from each condition.

A Wattbike Pro ergometer was used in all conditions. An Oculus (Meta) Quest 2 virtual reality headset (HMD), with an elite strap was used in the virtual green condition and the virtual urban condition.

3.2.2 Description of Environment Settings

In both virtual environments, the application VZ fit was used in conjunction with an HMD (Oculus Meta Quest 2 Virtual Reality Headset) that allowed for first-person bike rides. In the virtual green outdoors condition located in Iceland, exercise was performed inside in a virtual environment depicting an outdoors green environment, which showed mountains, a body of water, interspersed trees, and grassland (Figure 2.1). The virtual urban outdoor condition depicted a route in downtown Detroit, Michigan, USA, with buildings, a little greenery and moving cars (Figure 2.2). In both the green and urban conditions, as imaging was ultimately from the Google streetcar driving along roads, other cars are present within the virtual environments. In the urban condition, there were many cars, in proximity, throughout the ride whereas in the green condition, there were no cars, whereby cars were not visible for any of the ride. In the control condition, exercise was performed indoors, in a laboratory, where participants viewed neutral grey blinds. The cycle ergometer was placed approximately in the centre front of the laboratory for each condition.

Figure 3.1: Virtual Green Outdoors Condition

Figure 3.2: Virtual Urban Outdoor Condition

Figure 3.3: Control Condition

3.2.3 Measures

Directed Attention

The backwards digit span task was used to measure directed attention (191). The task requires individuals to mentally hold, track and rearrange digits within their short-term memory (43, 132, 192). Participants viewed strings of digits displayed on a computer screen before typing their answer into the computer. Each digit was presented for a duration of one second consecutively (132). Instructions were given out to participants verbally by the researcher and visually on the computer screen before each testing (132).

In a standard backwards digit span task, the length of the number string increases by 1 each time a participant correctly types the string and continues until participants fail two consecutive attempts at reciting strings of a given length. (51, 191). Participants attempted to recite as many strings of digits as possible with the max number of digits in a string being 10. Participants scored one mark for each successfully recited backwards string (132).

Mood

The brief measures of positive and negative affect: The PANAS scale was used to measure mood (118). Participants were asked to indicate how they felt "*right now*" in response to single-word mood descriptors (118, 132). Participants were asked to rate on a 5-point Likert-type scale the extent to which they experienced each mood descriptor at that exact point in time (118). The points of the scale were labelled: 1, "*very slightly or not at all*", 2, "*a little*", 3, "*moderately*", 4, "*quite a bit*", 5, "*very much*" (118).

Cronbach's alpha values of 0.86 to 0.90 for positive affect and 0.84 to 0.87 for negative affect have been reported indicating acceptable internal consistency (118). The reliability of the scale is also unaffected by the time instructions were used (118). Positive and negative affect are assumed to be stable characteristics of individuals over time, whereby, individuals generally have consistent tendencies to experience positive and negative emotions regardless of the specific time frame being considered (118). Moreover, Watson et al., reported the PANAS scale to have high test-retest reliability over a two-week interval, with test-retest reliability coefficients ranging from 0.68 to 0.84 for positive affect and 0.71 to 0.87 for negative affect (118).

Perceived Exertion

The rate of perceived exertion scale (RPE) was used to prescribe perceived exertion (132, 193, 194). The scale consists of a fifteen-point vertical list of numbers, certain numbers are accompanied by a descriptor word, from 6 “*no exertion*” to 20 “*maximal exertion*”. Participants were asked to exercise at an RPE of 12, between 11, “*light exertion*” to 13, “*somewhat hard exertion*”.

The reliability of a fixed perceived effort cycling has positive results. Eston et al., reported using RPE as a useful and reliable method for regulating exercise in healthy men and women during cycling, between-trial correlations for oxygen uptake were high for all RPE levels measured: RPE level 9 (r = 0.83), RPE level 13 (r=0.94) and RPE level 17 (r=0.92) (195). Similarly, Kaston et al., reported consistent heart rate responses at given RPE levels during cycling: participants adjusted work rates to correspond to RPE levels 11,12, and 15 within three minutes, revealing no significant differences in mean heart rate responses across trials, with mode-specific estimates for heart rate intraclass correlation coefficient and coefficient of variation ranging from between 0.80 and 0.91m and 5.6% and 8.3% respectively (196).

Heart Rate

Heart rate was recorded as a single observed value every two minutes continuously during all cycling conditions via a heart rate monitor (Fitbit Sense) and extracted as beats per minute (bpm). Recording of heart rate started at four minutes to allow for participants to reach a steady state of exercise (197).

3.2.4 Procedure

Virtual Green Outdoor Condition

On arriving at the laboratory, participants sat at a table, were given a verbal briefing and overview of the contents of the study. If this was the participants’ first session, they read a Participant Information Document and completed a Physical Activity

Readiness Questionnaire (Par-Q) and an informed consent document. The Par-Q functioned as a screening measure for each participant's suitability to perform exercise (no participants were excluded). Participants' stature and mass were measured. The participants were invited to return to the table by the researcher and familiarized with the RPE scale (132). Participants then put on the Fitbit watch. The participants then completed the pre-exercise backwards digits span task (directed attention), followed by the pre-exercise PANAS mood questionnaire. After this and ensuring the seat and handlebar heights were comfortable and correct, participants sat on the cycle ergometer, put the virtual reality headset on and entered the virtual green outdoor condition. Participants then cycled for ten minutes at an RPE of 12. Heart rate was taken every two minutes by the researcher. Upon completion of the exercise, the participants were invited to take off the virtual reality headset and were led back to the table to complete the post-exercise PANAS mood questionnaire and the post-exercise backwards digits span task (direct attention).

The following script was read to the participants before initiation of the cycle: "*OK, we are going to start your 10 minutes of cycling now, so please just cycle at an RPE of 12, meaning a 'moderate' intensity for you. You can see the white dots in front of you – these just show you the path that you will be following, so you know when the video will turn a corner or move across the road. Please always hold onto the handlebars – they don't move so don't worry about turning them to go around corners, the video will do this automatically, which can feel a little bit strange to start with, but if your hands are on the bars then you should feel nice and stable. I am now going to refrain from talking to you during your cycling, because I just want you to immerse yourself in the experience and really take in your surroundings, imagining you are in that place. Of course, if you do need or want to ask me anything then* *please do, but otherwise, I will leave you to it*." Participants then completed 10 minutes of cycling at RPE 12. Every 2 minutes the participant's heart rate was collected.

Virtual Urban Condition

The procedure of the virtual urban outdoor condition was identical to the virtual green outdoor condition, except the virtual environment was of an urban environment (Detroit). The same script was used with an addition at the end: "You *will see some cars during your ride, and because of how the photos are taken, sometimes it looks like you are cycling into oncoming traffic, however, you are of course safe here in virtual reality*."

Control Condition

The control condition was identical to the virtual urban and virtual green outdoor condition apart from no virtual reality HMD was used and thus no related script was used. Participants were still instructed to cycle at an RPE 12 for ten minutes.

3.2.5 Statistical Analysis

IBM SPSS Statistic for Windows, version 27 was used for statistical analysis. Following checks of violations of the relevant assumptions, Paired Samples T-tests and two-way repeated measures ANOVA were performed to identify any time-by-condition interaction effect on (i) Positive Affect scores (ii) Negative Affect scores and (iii) backwards digits span task scores. One-way repeated-measures ANOVAs were performed to check for differences in (iv) mean heart rate values between conditions and (v) mean distance travelled between conditions. If significance was achieved, a *post hoc* analysis with Bonferroni's adjustment of alpha was used to examine differences across conditions for all variables. An alpha level of 0.05 was used to indicate statistical significance.

3.3 Results

For all measures, mean and standard deviation values are presented in Table 3.1 and 3.2.

Table 3.1: Mean pre- and post-exercise (±1 SD) values by condition.

Measure	Pre-Exercise Values by Condition			Post-Exercise Values by Condition		
	Green	**Urban**	**Control**	**Green**	**Urban**	**Control**
Positive Affect	32.5 ± 10.2	31.92	31.8	40 ± 8.8	33.25 ± 8.6	29.4 ± 7.2
Negative Affect	14 ± 5.6	13.7 ± 4.1	12.5 ± 3	12.5 ± 5.1	12.8 ± 3.6	12.25 ± 2.7
Directed Attention (number of strings successfully recited backwards)	7.2 ± 3	7.6 ±3.4	7.8 ± 3.2	8.9 ± 3.9	8.8 ± 3.1	9.1 ±3.1
Heart Rate				123.3 ± 12.77	127.9 ± 14.37	143.6 ± 14.6
Distance Cycled (m)				4733.1 ± 881.1	4678.5 ± 672.4	5053.9 ± 658

Table 3.2: Mean pre- and post-exercise (±1 SD) by visit.

Measure	Pre-Exercise Values by Visit			Post-Exercise Values by Visit		
	Visit 1	**Visit 2**	**Visit 3**	**Visit 1**	**Visit 2**	**Visit 3**
Directed Attention (number of strings successfully recited backwards)	6.4 ± 2.8	7.8 ±3.7	8.3 ± 2.7	8.3 ± 3.3	8.9 ± 3.5	9.6 ±3.2

3.3.1 Psychological Measures

Positive Affect

Results of a two-way repeated measures ANOVA indicated a significant interaction effect for time by condition on Positive Affect scores ($F_{2,22} = 20.33$, $p < 0.001$, $\eta p^2 = 0.65$); Figure 3.4. Post hoc analysis with Bonferroni adjustment revealed: (i) there was a statistically significant difference in Positive Affect scores between the green and control conditions (5.67, 95%CI 0.69 to 10.64, p = 0.03); (ii) no statistically significant difference was seen between green and urban conditions (p = 0.42) and (iii) urban and control conditions (p = 1); (iv) no significant difference in positive affect scores between all conditions before exercise (p = 1); (v) there was a statistically significant difference between green and control conditions after exercise (10.58, 95%CI 6.54 to 14.62, p < 0.001); (vi) there was no statistically significant difference between green and urban conditions (p = 0.06) and urban and control conditions (p = 0.61) after exercise.

Results of a paired samples T-test revealed that: positive affect was significantly higher after exercise in the green condition (t (11) = 7.47, p < 0.001); there was no significant change in positive affect after exercise in the urban (p = 0.25) and the control (p = 0.11) conditions.

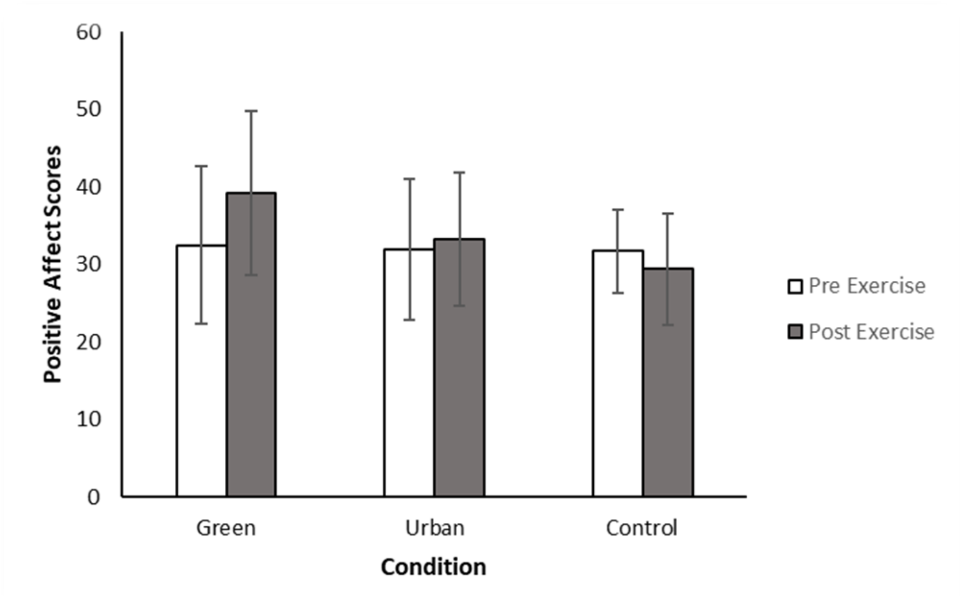


Figure 3.4: Mean (±SD) pre- and post-exercise Positive Affect scores by condition; higher scores represent a greater level of positive affect.

Negative Affect

Results of a two-way repeated measures ANOVA indicated that there was no significant interaction effect for time by condition on Negative Affect scores ($F_{2,22}$ = 0.56, p = 0.58, ηp^2 = 0.48; Figure 3.5).

Results of a Paired Samples T-test revealed that: negative affect was significantly lower after exercise in the green condition (t (11) = -2.42, p = 0.03); there was no significant change in negative affect after exercise in the urban (p = 0.48) and the control (p = 0.68) conditions.

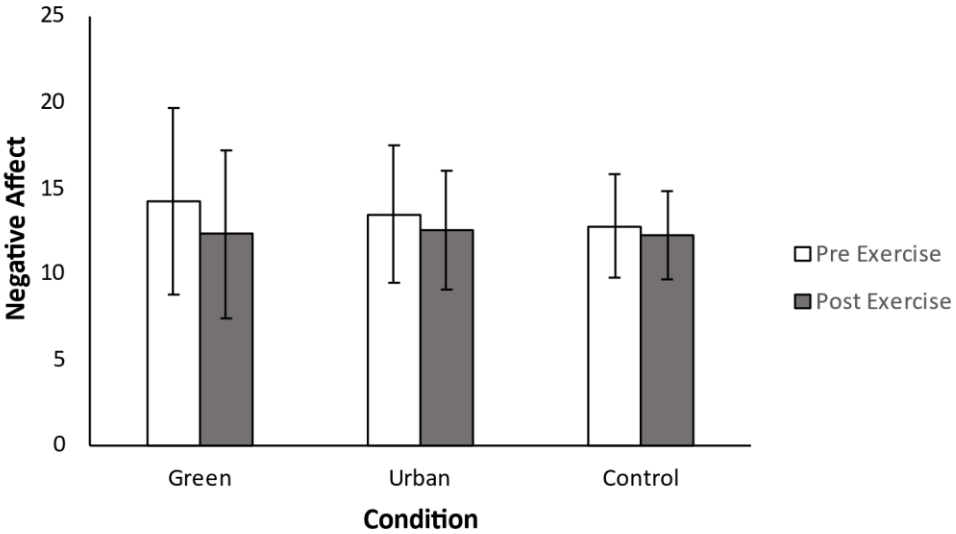


Figure 3.5: Mean (±SD) pre- and post-exercise Negative Affect scores by condition; higher scores represent a greater level of negative affect.

Backwards Digit Span Test

Results of a two-way repeated measures ANOVA indicated that there was no significant interaction effect for time by condition on Backwards Digit Span Test scores ($F_{2,22}$ = 0.27, p = 0.62, ηp^2 = 0.02; Figure 3.6).

Results of a Paired Samples T-test revealed that: Backwards Digit Span test scores were significantly higher after exercise in the green condition (t (11) = 2.55, p = 0.03) and control condition (t (11) = 2.8, p = 0.02; there was no significant change in Backwards Digit Span test scores after exercise in the urban condition (p = 0.06).

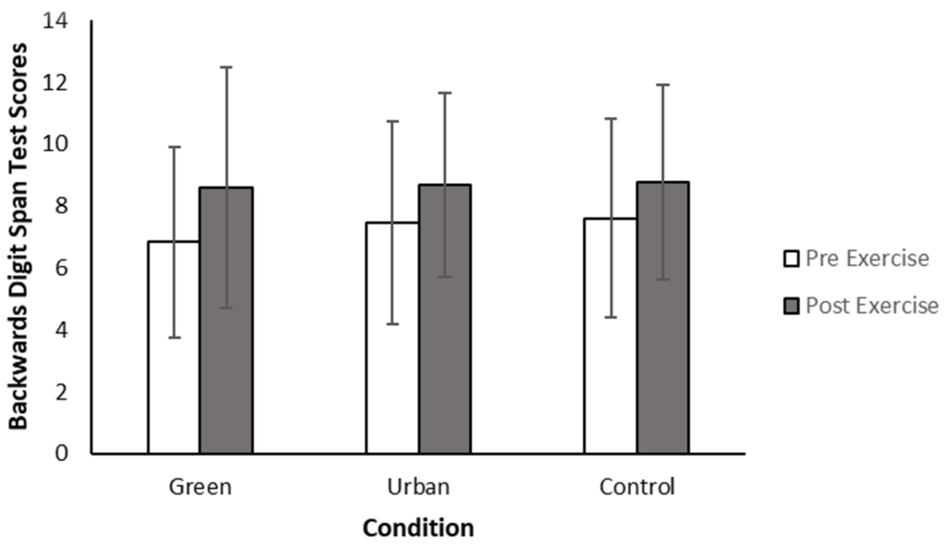


Figure 3.6: Mean (±SD) pre- and post-exercise Backwards Digit Span test scores by condition; higher scores represent a greater level of backwards digit span test scores.

A two-way repeated measures ANOVA was employed to examine the presence of a learning effect across successive visits to the laboratory. Results revealed there was not a significant effect for visit on pre-exercise Backwards Digit Span test scores ($F_{2,22}$ = 3.89, p = 0.06, ηp^2 = 18.49; Figure 3.7). Post hoc analysis with Bonferroni adjustment revealed there was a statistically significant difference between pre-exercise visit one and visit three (1.92, 95%CI, 0.35 to 3.49, p = 0.02); there was no significant difference between pre-exercise visit one and visit two (p=0.09) and visit two and visit three (p = 1). For post-exercise visits, results indicated no significant effect for visit on Backwards Digit Span test scores ($F_{2,22}$ = 2.04, p = 0.15, ηp^2 = 4.69; Figure 3.8).

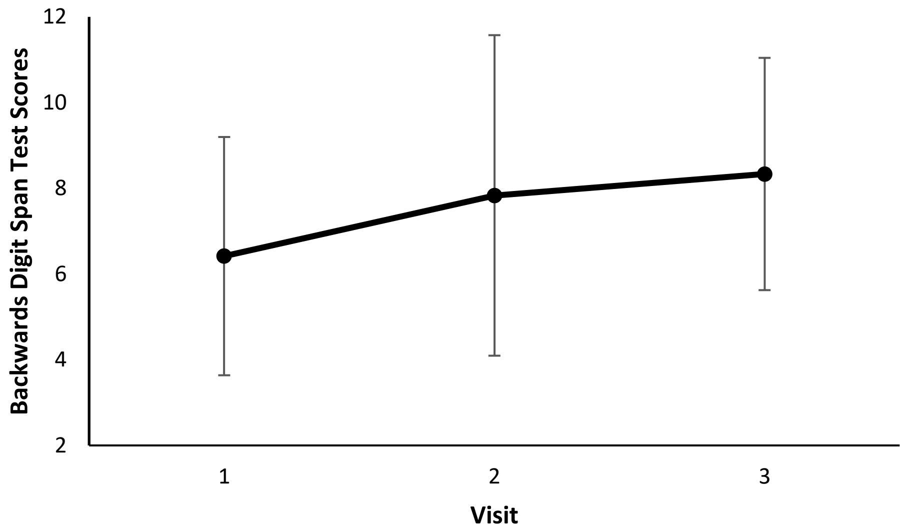


Figure 3.7:Mean (±SD) pre-exercise Backwards Digit Span test scores by visit; higher scores represent a greater level of backwards digit span test scores.

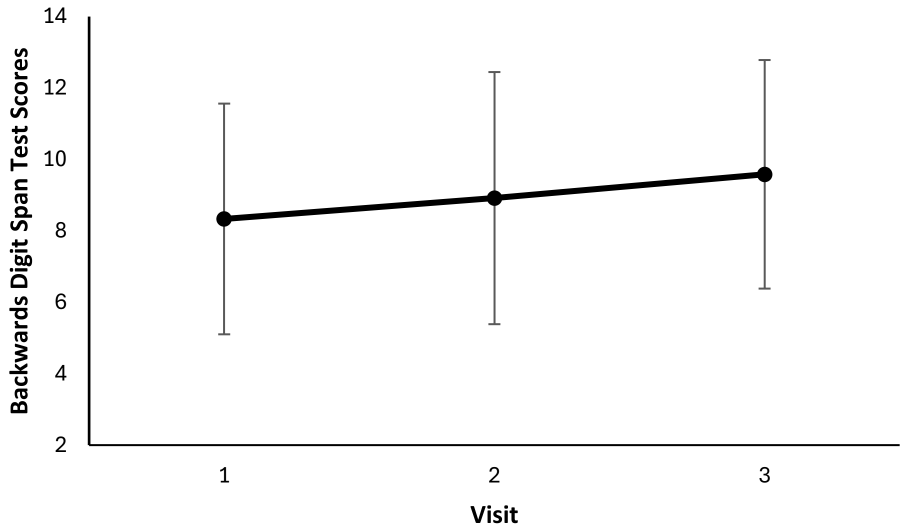


Figure 3.8:Mean (±SD) post-exercise Backwards Digit Span test scores by visit; higher scores represent a greater level of backwards digit span test scores.

3.3.2 Physiological Measures

Heart Rate

One-way repeated measures ANOVA indicated a significant effect for condition on mean heart rate scores ($F_{2,22} = 12.04$, $p = 0.002$, $\eta p^2 = 0.71$); Figure 3.7. Post hoc analysis with Bonferroni adjustment revealed that there was a statistically significant difference in mean heart rate scores between control and green conditions (19.82, 95%CI, 4.49 to 35.15, $p = 0.012$) and control and urban conditions (15.17, 95% CI, 6.83 to 23.51, $p < 0.001$); no statistically significant difference between green and urban conditions ($p = 0.704$).

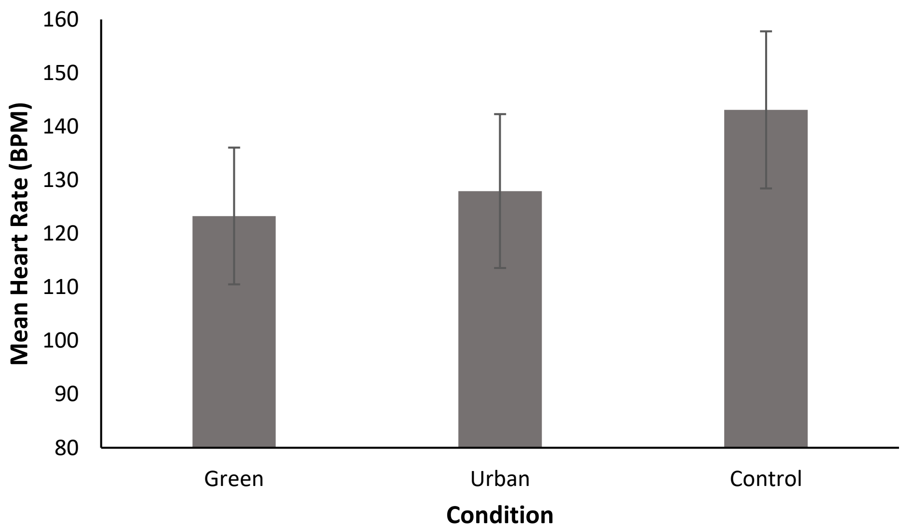


Figure 3.9: Mean (±SD) exercise Heart Rate by condition; higher scores represent a greater level of heart rate.

Figure 3.10:Mean (±SD) post-exercise Distance by condition; higher scores represent a greater distance cycled.Figure 3.9: Mean (±SD) exercise Heart Rate by condition; higher scores represent a greater level of heart rate.

Distance

One-way repeated measures ANOVA indicated a significant effect for condition on distance scores ($F_{2,22} = 5.51$, $p = 0.01$, $\eta p^2 = 0.03$); Figure 3.8. Post hoc analysis with Bonferroni adjustment revealed there was a statistically significant difference in distance between urban and control conditions (-0.44, 95% CI, -0.72 to -0.16, p = 0.003); there was no statistically significant difference between green and urban condition (p = 1) and, green and control condition (p = 0.19).

Figure 3.9 refers to heart rate and distance cycled across all three conditions.

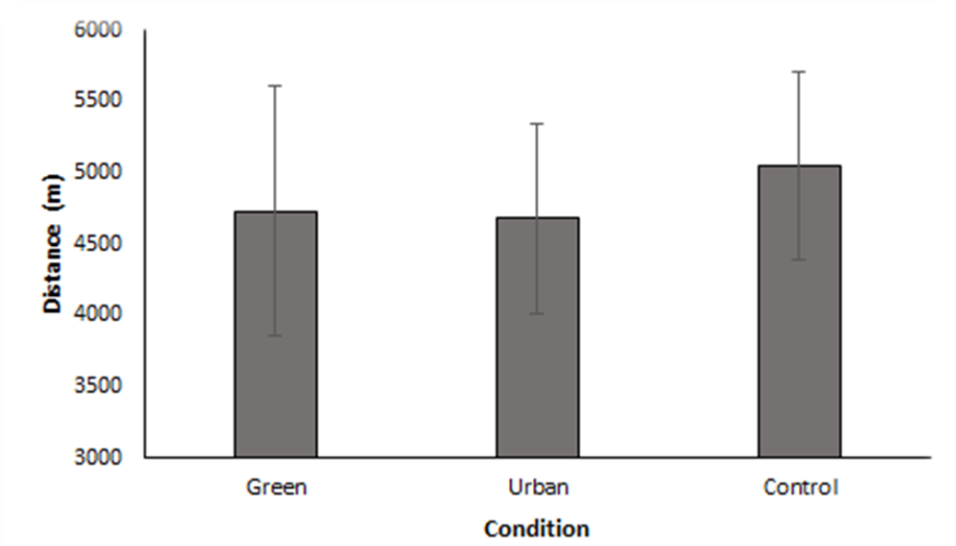


Figure 3.10:Mean (±SD) post-exercise Distance by condition; higher scores represent a greater distance cycled.

Figure 3.11: Mean post-exercise Heart Rate and Distance Cycled (m); higher scores represent a greater level of heart rate.Figure 3.10:Mean (±SD) post-exercise Distance by condition; higher scores represent a greater distance cycled.

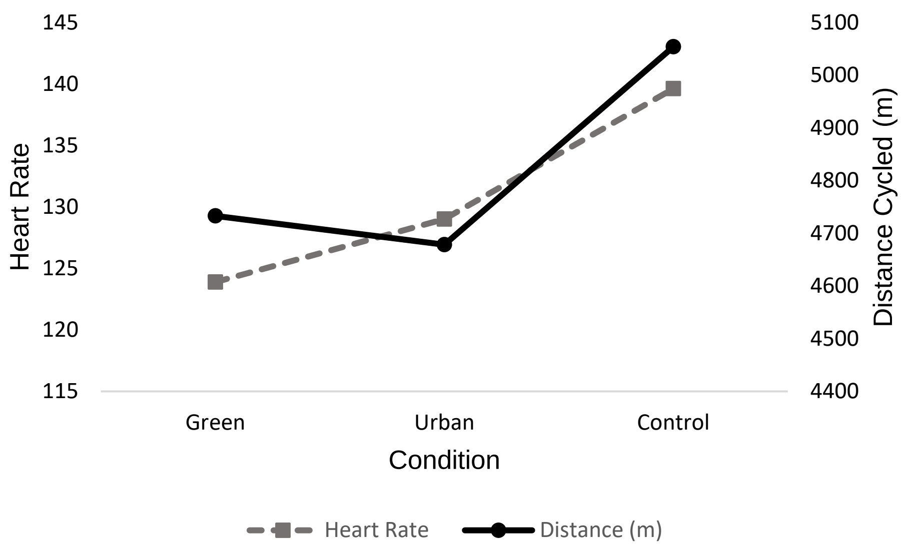


Figure 3.11: Mean post-exercise Heart Rate and Distance Cycled (m); higher scores represent a greater level of heart rate.

Figure 4.1: Dimensions and Themes of Expectations of Immersive Virtual ExerciseFigure 3.11: Mean post-exercise Heart Rate and Distance Cycled (m); higher scores represent a greater level of heart rate.

3.4 Discussion

The current study aimed to address the methodological gap in existing research by comparing a range of previously reported psychological and physiological outcomes of exercising in an immersive HMD virtual green environment versus an immersive virtual urban environment, whilst using a prescribed intensity. Results revealed that immersive HMD virtual green exercise environments can be beneficial for some psychological outcomes yet the extent to which can vary. Furthermore, the control condition (indoor cycling) causes an increase in exercise intensity (measured by heart rate and distance cycled) compared to both immersive HMD virtual green and urban exercise environments.

Hypothesis (i) that all exercise environments would facilitate improvements in affect was not supported. The hypothesis (ii) that all exercise environments would facilitate improvements in directed attention from pre- to post-exercise was partially supported. Hypothesis (iii) that immersive virtual green exercise would facilitate improvements in affect from pre- to post-exercise to a greater extent than immersive virtual urban exercise and the control condition was not supported. Hypothesis (iv) that immersive virtual green exercise would facilitate improvements in directed attention from pre- to post-exercise to a greater extent than immersive virtual urban exercise and a control condition was not supported. Hypothesis (v) that heart rate and distance travelled would be similar during all conditions due to exercise intensity being controlled in the present study was not supported.

3.4.1 Psychological Measures

Affect

The immersive HMD virtual green condition significantly improved positive affect from pre- to post-exercise, whereas the immersive HMD virtual urban condition and the control condition did not significantly improve positive affect. This is consistent with a similar study by White et al., yet, the study used less immersive forms of virtual reality exercise environments and was on post-menopausal women (176). Previous research has suggested that exercise as a whole significantly increases an individual's mood/affect (4). Analysis from the control condition does not support this claim, as positive affect did not significantly increase from pre- to post-exercise.

The present study revealed that immersive HMD virtual environments did not significantly increase positive affect to a significantly greater extent than immersive HMD virtual urban exercise. The finding of the present study is inconsistent with previous research using immersive HMD virtual exercise environments. For instance, Chan et al., revealed that there was a significant difference in positive affect scores pre- to post-exercise between a green environment and an urban environment (178). Yet, unlike the present study, positive affect decreased in the urban environment and showed no significant increase in the green environment, thus causing the significant time-by-condition interaction (178). The present study reported a significant reduction in negative affect scores during immersive HMD virtual green exercise environments but not in the urban and control exercise environments. This is consistent with Chan et al., who reported a significant reduction in negative affect scores for the green exercise environment yet did reveal a significant reduction in the urban environment, with negative affect significantly decreasing in the green condition compared to the urban condition. The inconsistency in affect findings could be accredited to the different exercise methods used: Chan et al., implemented a less intense immersive virtual exercise environment, whereby participants walked on a spot while holding onto fixed handlebars (178) – which also may have limited how immersed participants felt within the immersive virtual exercise environments. Compared to the present study where participants exercise on a stationary bike at a higher intensity, with a virtual replica represented in the immersive virtual environments. Thus, the differences in methodological approach are attributed to difficulties in pinpointing the best practical use for virtual green exercise research, especially when using immersive virtual reality (106). Furthermore, future research is needed on how different exercise intensities and types can impact affect whilst using immersive HMD virtual environments.

The lack of a significant interaction effect for time by condition on negative affect and reduction in positive affect in the control was unexpected given that exercise is frequently suggested to significantly improve affective state (132, 198, 199). Dual mode theory postulates that the interplay between cognitive processes, including the frontal cortex's cognitive appraisal and context of exercise, and physiological elements, such as acidosis and core temperature, influence the exercise-affect relationship (72, 132, 200). It is possible that the intensity and type of exercise used in the present study caused fatigue in some participants and context (immersive virtual reality use). Thus, may have predisposed characteristics of and the relative importance of particular cognitive and physiological elements; which in turn may have not been able to create a significant positive exercise-affect relationship (132).

Directed Attention

Concurrent with transient hypofrontality, post-exercise-directed attention scores were higher in all conditions compared to pre-exercise scores, yet the increase was not statistically significant in the urban condition. Agreeing with previous findings, both the immersive HMD virtual green environment and the control condition improved directed attention from pre- to post-exercise (51, 186-188). Yet, due to the absence of a non-exercise control condition in the present study, it is not possible to establish the mechanism responsible; the observed improvements could be attributed to short-term learning or motivation effects (51). Yet, inconsistent with previous research, the immersive HMD virtual urban exercise environment did not elicit a significant improvement in directed attention (186-188). The urban environment could impair the ability to ignore contextual information because the environment exerts higher cognitive loads than natural environments (43). Thus, urban environments deplete working memory/cognitive resources, compared to green environments which allow these resources to replenish and restore cognitive control (201).

The finding Immersive virtual green exercise did not facilitate improvements in directed attention compared to the immersive virtual urban and control condition is inconsistent with Rogerson et al., which revealed that directed attention improved after exercise while viewing footage of a natural environment, compared to viewing an urban environment or a blank screen (control). The inconsistent results could be accredited to Rogerson et al., employing a longer exposure (15 minutes) to all exercise environments compared to the present study (10 minutes). A recent study revealed a significant main effect for exercise duration on cognitive performance (measured via a Stroop test), with response time being significantly shorter (i.e. better) after 20 minutes of exercise compared to 10 minutes (202). Yet, to the best of the author's knowledge, there is no previous research comparing a 10-minute and 15-minute exposure. Attention restoration theory suggests that spending time in environments that provide an abundance of natural stimuli promotes restoration of depleted attentional resources (49, 55). The results of the current study (immersive HMD virtual green environment significantly improved directed attention) support this possibility.

Absence of a familiarisation session might have led to a potential learning or carryover effect during the administration of the backwards digit span task (directed attention task). Participants may have demonstrated improved performance in later visits due to increased familiarity and practice with the task (203). It was observed that compared to visit one, participants had significantly higher pre-exercise backwards digit span task scores than visit three. Thus, a learning effect may have occurred from visit one to visit three for pre-exercise backwards digit span task scores. However, no statistically significant effects were observed between pre-exercise visits one and two, as well as visits two and three. Moreover, there was no statistically significant effect found in post-exercise backwards digit span task scores across visits.

3.4.2 Physiological Measures

The present study revealed mean heart rate was significantly higher in the control exercise condition compared to the immersive HMD virtual green and urban exercise environment with no significant difference between the green and urban conditions. This finding is unexpected as previous research using a controlled exercise observed no significant difference in heart rate between virtual green and indoor (control) conditions and all participants in the present study cycled at the same RPE across all conditions (51, 176, 179). Yet, these studies used less immersive forms of virtual green exercise, such as TV monitors and projections onto a screen. Thus, more immersive forms of virtual reality, such as HMD virtual reality, may augment people's perceptions and/or regulation of exercise intensity. This can be corroborated by an early study by Plante et al., where participants cycled at a controlled intensity (60 – 70% max heart rate), reporting higher levels of exertion when cycling with immersive virtual reality compared to cycling without (166). Yet, one study that used immersive HMD virtual exercise and self-selected exercise intensity revealed no significant difference in heart rate between virtual green exercise and indoor exercise, suggesting that immersive virtual reality does not augment exercise intensity (144). However, the study used treadmill walking compared to Plante et al., and the present study where participants cycled. Thus, immersive virtual reality may only augment intensity in certain exercises, such as cycling. Furthermore, no significant difference in distance cycled was observed between the green condition compared to the urban and control conditions. Concurrent with this finding, Abernathy et al., revealed distance cycled and heart were similar during an immersive HMD virtual green and urban cycling environment, yet participants were able to select their exercise intensity (204). The present study reporting no significant difference in distance cycled between the control condition and the green condition is interesting considering heart rate was significantly higher in the control condition compared to the green condition. This could suggest that virtual reality mediated nature may only influence heart rate and not distance cycled. Yet, more research is needed on this relationship.

Overall and in line with previous research, the present study found limited evidence of other additional benefits of virtual green exercise compared to control/indoor exercise (4, 144). Apart from positive affect, no additional psychological benefits of immersive HMD virtual green exercise compared to a control were observed, including negative affect, and directed attention. These findings challenge the belief that synergistic benefits occur when combining exercise and (virtual) nature exposure (144, 149). Thus, it is important to consider the issue of whether immersive HMD virtual green exercise can produce the same benefits seen by real green exercise. Some research reported that immersive HMD virtual green exercise increased negative affect and was perceived as less enjoyable compared to exercising in a real green environment (91), while others show that exercising in a virtual green environment is more restorative for positive affect, following a mentally fatiguing task than a real outdoor green walk (89). The inconsistency in findings can again be accredited to different methodological approaches used as some research manipulated mood levels through the use of a pre-stressor experience (89).

3.4.3 Strengths and limitations

A strength of this study is its rigorous experimental procedure, robust within-subject design and counter-balanced blinded trial, which enabled control over confounding factors such as carryover effects and noise (205). Another strength of this study is that it is one of the few to use an HMD in combination with exercise (i.e., cycling), and the very first to use such technology to compare green versus urban exercise environments (91). Furthermore, the duration of immersive virtual reality exposure in all studies was 10 minutes, a time span chosen as it has been previously found to be a minimum bout for achieving health and wellbeing benefits in relation to both nature exposure and physical activity (77). Immersive virtual reality offers methodological benefits that are closer to real life compared to pictures or videos, thus providing whilst allowing for a higher level of experimental control (206). Another strength of this study was the inclusion of heart rate and distance cycled. This allows assessment of whether exercise was truly identical between conditions. Thus, examination of whether regulation of RPE prescribed intensity was influenced by environmental condition. In the case of the present study, the prescribed intensity was influenced by the exercise environment.

A limitation of the current study was that it examined the immediate effects of exercise; thus, it is not possible to conclude that the psychological benefits previously reported are long-lasting (166). Yet, previous research has reported that the mood effects of exercise can last for a least two hours (207). Furthermore, the immersive virtual exercise environment used may not have been compelling enough to create a credible replica of a real environment, causing the psychophysiological benefits to be limited. Future research should use a larger sample size and evaluate the long-term psychophysiological effect of immersive virtual reality exercise. The sample size of the current study (N = 12) may have been too small to obtain adequate power for measures included in this study (205). The lack of a familiarisation session may have contributed to a learning effect observed during administration of the backwards digit span task. Future studies could consider implementing a familiarisation session to mitigate potential learning effects observed during the task. The generalizability of findings may be limited as the participants in the present study were healthy adults; thus, it is uncertain whether findings can be applied to individuals with clinical conditions, such as sight deficiencies, infections of the vestibular system, or other health problems (205). The lack of an experimental condition applying a real natural environment limits the ability to attribute this finding to the environment and not the virtual reality technology alone (144). Furthermore, the virtual reality application used in this study is quite novel, the application (VZFit) used may not have been able to produce a likewise virtual replica of a real natural environment. VZFit used Google Earth to produce virtual replica routes of real places. Thus, the video of the route could often feel unstable. The researchers chose the green and urban environments from Google Earth to be represented in virtual reality. Hence, different Google Earth routes may produce different results.

Immersive virtual green environments provide a source of nature exposure for those unable to access the natural environment. The relative ease of setting up a virtual reality system could make it a viable solution for healthcare settings involving clinical populations. Yet, there has been little work researching the use of immersive virtual reality to influence outcomes during exercise in clinical populations (72). Given evidence in the present study suggesting the beneficial effects of immersive virtual green exercise environments on affect, investigations on clinical populations seem warranted. Furthermore, low-cost systems like the Google Cardboard enable users to experience virtual nature using their smartphones (178).

3.5 Conclusion

This was the first study to demonstrate the effects of exercise conducted in different immersive virtual exercise environments on affect and directed attention. Although immersive virtual green exercise significantly improved affect and directed attention, compared to an immersive virtual urban environment the difference was not significant. Yet, immersive virtual green exercise significantly improved positive affect compared to indoor exercise (control condition). Furthermore, directed attention scores revealed no significant difference between indoor exercise and immersive virtual green exercise. Heart rate was significantly higher in the control condition compared to both immersive virtual conditions. Yet, there was no significant difference in distance cycled between immersive virtual green exercise and indoor exercise as well as urban exercise.

4.0 A Qualitative Exploration of Expectations and Reactions to Immersive Virtual Reality Cycling

4.1 Introduction

Chapter 3 showed how immersive virtual environments can influence difference psychological and physiological measures. Yet, it does not address participants' thoughts and beliefs regarding this technology.

There has been growing interest in using virtual environments to enhance not only overall health but also an individual's experience of exercise (18). Virtual reality has been proposed as one way to improve exercise experiences (72). With the recent development of affordable and user-friendly virtual reality technology, human-nature interactions could transition to the virtual environment, thus decreasing the disconnect between humanity and nature (1, 208). Virtual reality can be defined as a computer simulation that senses the participant's positions and actions and replaces or arguments the feedback to more than one or more senses, giving the user a feeling of being immersed or present in a virtual world (71). It is important to understand the components of virtual reality that can influence individual expectations and reactions to virtual reality-mediated exercise.

4.1.1 Immersion

One component that plays an important role in the effectiveness of virtual reality-mediated exercise is the concept of immersion (77). Immersion describes the extent to which virtual reality technology is capable of delivering inclusive (the extent to which reality is shut out), extensive (range of sensory modalities accommodated) and vivid (resolution and quality of displays) illusions of reality to one or more senses (97). A subjective correlate of immersion is presence (98). Presence is an individual's sense of being in a virtual environment (97). Presence depends on the technology's ability to augment sensory input from the physical reality. When the sensory feedback creates a believable virtual environment, it contributes to increased levels of place illusion (77, 98, 99). When a virtual environment responds to an individual's actions, incorporates personal references, and aligns with expectations of how objects and people should behave, plausibility illusion emerges; this illusion convinces individuals that the events occurring in the virtual environment are genuinely happening (98). These components of illusion within a virtual environment are believed to increase an individual's level of presence and immersion (77). This translates to immersive virtual nature's ability to create similar responses seen by a real natural environment (58). For example, increased stress reduction and positive affect are seen when using a virtual reality head-mounted display (HMD) was used compared to a non-immersive virtual desktop experience of an underwater environment (83).

Immersion levels can differ by what type of virtual reality technology is used; immersion levels can be defined as high if an HMD with real-time tracking of movement was used, whereas, low immersion involves using projections, monitors/television or an HMD that does not have real-time motion (72). Immersion levels of virtual technology have been shown to influence an individual's beliefs about exercise. For example, a recent study found that highly immersive virtual reality was perceived as significantly more enjoyable than cycling without virtual reality (209). Moreover, incorporating more immersive virtual reality features, such as sound, results in significantly higher enjoyment and motivation than vision alone (210). Research on an individual's beliefs about exercise in natural environments has mainly adopted low immersive virtual reality (72). One such study found that low immersive virtual reality involving walking in nature consistently showed enjoyment benefits and increased positive affect compared to the real nature walking group (87). Yet, one study comparing an immersive virtual natural exercise environment to an urban environment revealed that there was no statistically significant effect between the virtual environments on immersion and enjoyment (204). Yet, participants' end-of-study comments regarding their preference of environments revealed that 66.7% found the natural environment more relaxing, 54.2% found the natural environment more enjoyable and 58.3% found the natural environment more immersive (204).

4.1.2 Cyber Sickness

Increasing immersion and presence are not the only aspects that affect the efficacy of a virtual environment but reducing the impact that negative aspects (1). High immersive virtual reality technology has been documented to cause cyber sickness among users (58). Cyber sickness has been reported to occur in as many as 100% of users depending on the virtual reality technology used, the period spent immersed and the content of the virtual environment (72, 100, 101). Furthermore, a recent study reported that 19 out of 26 participants had experienced cyber sickness while using highly immersive virtual technology (91). Cyber sickness is a specific type of visually induced motion sickness that can cause dizziness, nausea and general discomfort (79, 211). Sickness induced by highly immersive virtual technology will likely influence an individual's experience of a virtual environment (1). A recent review found that cyber and sickness and presence are negatively related, with increased cyber sickness causing a reduction in presence (102). It has been suggested that cyber sickness distracts and suppresses an individual's attention away from a virtual environment that is required for presence to occur, thus causing the inverse association (102). Due to the technological developments of virtual reality technology causing visual displays to become more immersive, such as HMDs, are more prone to induce high levels of cyber sickness, the issue of cyber sickness has become more relevant (103). This paradox must be solved in order to increase the benefits that could be seen by immersive virtual natural environments, as the most immersive displays are needed to provide a sufficient level of presence (58).

Combining exercise and immersive virtual natural environments, referred to as virtual green exercise (i.e., exercising whilst in the presence of technological nature), creates additional challenges, mainly associated with maintaining balance, and thus, causing the sensory conflict that leads to cyber sickness (58). A recent study revealed that cyber sickness had a detrimental impact on participants' emotional responses in a virtual green exercise environment compared to a real green exercise environment, with participants also reporting difficulty in maintaining balance whilst walking in immersive virtual reality (91). furthermore, cyber sickness is generally seen the more time an individual is immersed in a virtual environment (1, 169). Research combining exercise immersive virtual natural environments have utilised exposure durations ranging from 10-30 minutes (77, 87, 91, 166, 177). Yet, briefer sessions, such as 5 minutes, have been associated with increases in emotional responses (3). Therefore, an exposure duration of 5-10 minutes is recommended to decrease the risk of cyber sickness and allow for time for emotional responses (1).

One possible pathway explaining an individual’s behaviour related to virtual reality is Feedback Theory: emotions provide feedback on which behaviours individuals should or should not follow (77, 147). Thus, anticipated emotions are more vital than real experienced emotions in guiding behaviour (147). Yet, in certain situations emotions could have a direct causation on behaviours, such as the fight or flight response; in more complex behaviours, the decision-making process involves the evaluation of past experienced emotions, as well as influences from an individual's personal and cultural settings (77). Regarding exposure to a virtual natural environment, high levels of presence and immersion facilitate an individual to experience powerful emotional outcomes (77, 147). Furthermore, virtual environments may elicit anticipated emotional benefits due to an individual's generalised previous experiences of green exercise, such as increased enjoyment, motivation and relaxation (77, 147).

4.1.3 Expectations and Reactions to Virtual Reality Exercise

There is an increasing body of evidence suggesting that virtual reality use during exercise might improve experiences within the exercise session itself (72). A recent study revealed that using virtual reality during exercise increases enjoyment, energy and affect (212). Furthermore, walking on a treadmill in a virtual outdoor natural environment increased relaxation, energy and enjoyment compared to watching projected footage of walking outside while sedentary (87). Yet, recent work comparing walking in an immersive natural environment, a real natural environment and a sedentary replica in immersive virtual reality found both virtual conditions were perceived as less enjoyable (91). Furthermore, a recent study suggested that participants became more active and engaged in the exercise more in an immersive HMD virtual reality environment compared to a simulated environment displayed on a monitor (213). Correspondingly, Pyae et al., reported that over a two-week period, users of immersive HMD virtual reality were more engaged in exercise and had increased enjoyment while exercising than those who exercised conventionally (214). Immersive virtual reality may also be a solution to barriers faced in engaging in exercise (173). A recent study in which an immersive HMD virtual reality exercise game (VRun) was used to allow participants to run on the spot and move through a virtual environment suggested that it could allow individuals to engage in exercise, particularly for those who cannot attend a gym and exercise regularly (215).

There is limited research regarding participant expectations prior to using virtual reality. To the best of the author's knowledge, only one previous study has explored participants' expectations of virtual reality. McMichael et al., explored parents of adolescent's perspective of physical activity and virtual reality (216). Qualitative data revealed most participants (83%) had a limited understanding of virtual reality; all cited the cost of virtual reality systems as a barrier and, 50% felt strongly that physical activity in the real world would provide greater benefits to virtual reality exercise (216).

Qualitative insight was gathered from participants at the start and end of the previously reported study (Chapter 2). Chapter 2 provided analysis of quantitative outcomes, yet the understanding of immersive virtual reality experience itself is unknown. Thus, qualitative information will allow exploration of this. The aim of the current study is to explore qualitative insights to understand participant expectations and reactions to immersive virtual reality exercise.

4.2 Methods

Participants and Design

The same participants from Chapter 2 provided qualitative insights.

Design and Procedure

The design and procedure were identical to that described in Study 1 (Chapter 2).

Qualitative information was collected using two different series of open-ended questions. The first series of questions were presented to participants prior to completing any of the three conditions. The second series of questions were presented to participants after completing all three conditions. The participants responded in a face-to-face interview format.

Pre-Study Questions:

1. What do you currently know, or what is your current impression of using virtual reality during exercise?
2. What are your thoughts and/or expectations about using virtual reality combined with exercise?
    a. Do you think that exercising in virtual reality might make a difference in how we experience exercise?
    b. This study involves cycling in virtual reality, what are your thoughts and/or expectations about this specifically?
3. What are your thoughts on using a virtual reality environment to replace a real environment?
4. Is there any virtual environment that you can think of that you might be cycling in?
    a. If so, how do you think this environment will make you feel?
    b. Where would you like it to be?

Post-Study Questions:

1. What are your thoughts on using virtual reality combined with/ during exercise?
2. What are your thoughts on using a virtual reality environment to replace a real environment?

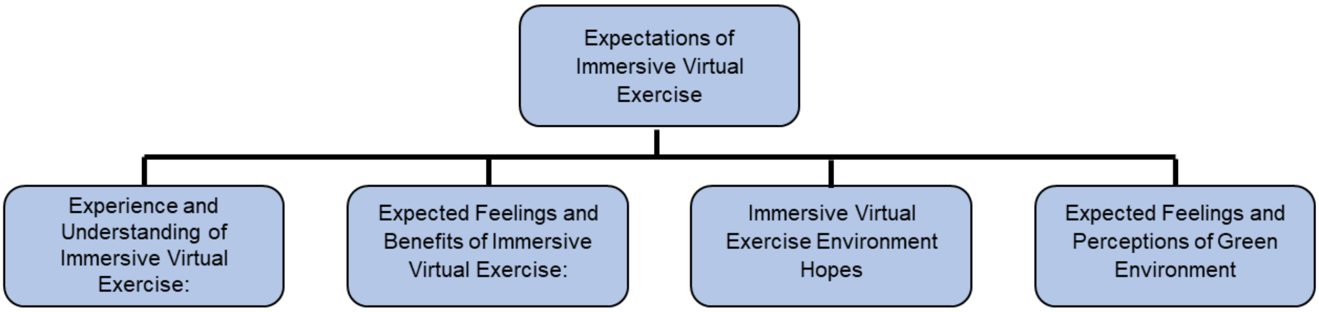
3. How do you feel after using virtual reality as an aid or addition to exercising?
4. Do you have any thoughts on the 2 different virtual environments that you exercised in?
    a. Which environment did you prefer exercising in?
    b. What did you prefer more about that environment than the other one?
5. Did you feel more immersed in one environment more than another?
    a. Why did you feel more immersed in one environment than the other one?
6. What bodily sensations occurred during different parts of the ride?
    a. What did you feel when you turned a corner?
    b. Did it feel like you sped up at all at different points?
7. Did you feel any motion sickness, more commonly referred to as cyber sickness, during any points of both virtual reality rides?
8. Did you have any thoughts on what the study was investigating?
    a. Once you knew that you would be cycling in virtual environments, did you have any expectations/ ideas of what environments you could have been put in?
    b. Once you knew that you would be cycling in virtual environments, did you have any hopes of what environment you might have been put in?

4.3 Data Analysis

Participants' answers to the items were coded using inductive qualitative content analysis, adhering to Braun and Clarke's guidelines (217) to identify themes in the data. NVivo 14 (218) was used for all qualitative analyses.

4.4 Results

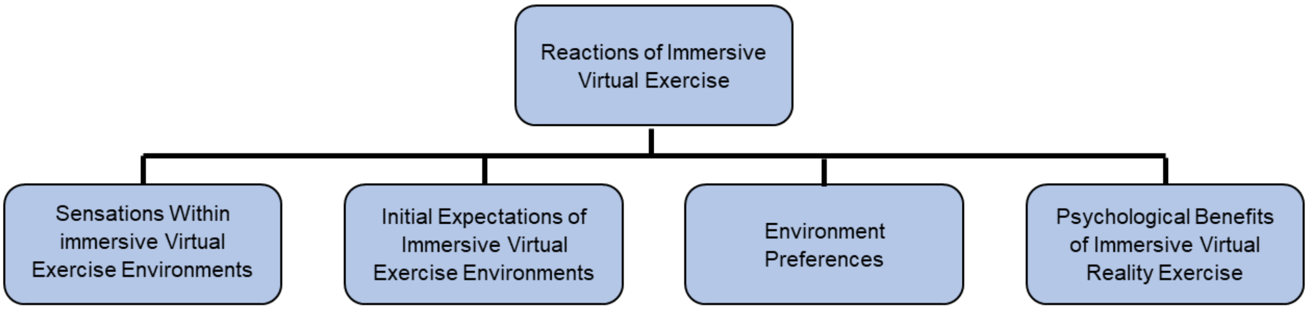
Following thematic analysis, the researcher identified 11 themes from the pre-study questions and 20 themes from the post-study questions. These themes were categorised into four general dimensions of expectations of immersive virtual reality exercise: Experience and Understanding of Immersive Virtual Exercise; Expected Feelings and Benefits of Immersive Virtual Exercise; Immersive Virtual Exercise Environment Hopes and Expected Feelings and Perceptions of Green Environment and four general dimensions of reactions to immersive virtual reality exercise: sensation within Immersive Virtual Reality Exercise Environments, Initial Expectations of Exercise Environment, Environment Preferences, and Perceived Benefits of Immersive Virtual reality Exercise. Figure 4.1 and 4.2 illustrates the content of these dimensions and their corresponding themes. Each general dimension will be elaborated upon using quotes from participants. Table 4.1 and 4.2 refers to the frequency of participants who referenced each theme.



• Limited Experience • General Understanding • Scepticism	• Expected Benefits of Immersive Virtual Reality Exercise • Overcoming Barriers	• Hopes for Green Environment	• Connectedness with Nature • Positive Psychological Effects

Figure 4.1: Dimensions and Themes of Expectations of Immersive Virtual Exercise

Figure 4.2: Dimension and Themes of Reactions of Immersive Virtual ExerciseFigure 4.1: Dimensions and Themes of Expectations of Immersive Virtual Exercise



• Sensations of Speed in Immersive Virtual Exercise Environments • Cyber Sickness • Immersion and Presence	• Anticipation of the Green Environment • Unexpected Urban Environment	• Green Environment Preference • Urban Environment Preference • Boredom in Control Condition • Real Exercise Environment Preference	• *Increase Enjoyment* • *Decreased Perceived Effort* • *Increased Motivation* • *Relaxing and Calming in Immersive Virtual Environment* • *Psychological and Accessibility Assistance*

Figure 4.2: Dimension and Themes of Reactions of Immersive Virtual Exercise

Figure 4.2: Dimension and Themes of Reactions of Immersive Virtual Exercise

4.4.1 Expectations of Immersive Virtual Reality Exercise (Pre-Study Question Answers)

Experience and Understanding of Immersive Virtual Reality:

Limited Experience

Most participants had limited experience of immersive virtual reality combined with exercise and most had never used it.

> *I've never used the virtual reality system before, particularly during exercise (Participant 7).*

> *I've never done it before, so I guess it's all hypothetical, but the concept is good, especially if it like feels realistic (Participant 12).*

General Understanding

Although participants expressed limited experience, some had a general understanding of immersive virtual reality exercise.

> *I know that virtual reality is used to enhance the exercise experience by altering the reality of what someone is doing or where they're exercising (Participant 1).*

> *I know what virtual reality is. I can imagine how it's used but I've never used it myself (Participant 11).*

Scepticism

Only one participant was sceptical about immersive virtual reality due to their preference for the real world.

> *But my initial impression would be that I'm sceptical because it's virtual. It's not reality (Participant 12).*

Expected Feelings and Benefits of Immersive Virtual Reality Exercise:

Expected Benefits of Immersive Virtual Reality Exercise (Enjoyment, motivation, exercise intensity, and fatigue)

Participants suggested that immersive virtual reality could have positive impacts on the exercise experience such as increased enjoyment, motivation, and exercise intensity, and distract from fatigue.

> *It will increase enjoyment because you're seeing more things than you've just seen on a wall (Participant 4).*

> *I feel like it could be used as a motivational point because you could implement yourself into any environment like we're going to do today. And it could potentially increase motivation. Placing you in interesting scenarios (Participant 5).*

> *I feel like it might remove some of the mental strain on your exercise, thus making it easier for you to perform (Participant 5).*

> *It could potentially distract people from fatigue, especially in less intense workouts (Participant 1).*

Overcoming Barriers

Participants suggested that immersive virtual reality exercise could aid in overcoming barriers to exercising such as accessibility issues for the elderly and disabled, and aid individuals in building confidence to transition to real-world exercise.

> *Virtual reality can be a stepping stone for those who feel unsafe or lack confidence, providing them with a controlled environment to build confidence before transitioning to real-world exercise (Participant 2).*

> *Older people and disabled individuals could also benefit from the accessibility and experiences virtual reality offers (Participant 1).*

Another barrier to exercise participants suggested immersive virtual reality could aid in anxiety when exercising. It was suggested that this technology can be used in the comfort of their own home, reducing the stress of other people's perceptions of them.

> *100% for people with anxiety. For example, my girlfriend hates going out and maybe getting seen by other people gives girls anxiety especially when they're exercising. So, if you could do it in your living room where no one can see you could have no anxiety and no stress about people watching you. (Participant 9).*

> *One pro is that no one can see you exercise so stress and anxiety go away from that (Participant 6).*

Immersive Virtual Exercise Environments Hopes

Hopes for Green Environment

Interestingly, without informing the participants of the virtual exercise environments that they would be exercising in, participants stated that they would expect to be exercising in a green/natural environment.

> *I think cycling in the countryside would be ideal (Participant 1).*

> *I imagine it could be a green setting, such as a woodland track surrounded by trees and nature. It might include an audio element, like birds chirping, to enhance the immersive experience (Participant 2).*

Expected Feelings and Perceptions of Green Environment

Participants who stated that they could be exercising in a green environment also gave insights on their expected feelings and perceptions of it.

Connectedness with Nature

Only one participant suggested that immersive virtual green exercise could increase an individual's connectedness with nature.

> *I think cycling in the countryside would be ideal. It would create a more enjoyable and serene experience, making me feel happier and more connected to nature (Participant 3).*

Positive Psychological Effects (anxiety and stress)

Participants suggested that immersive virtual green exercise could elicit positive psychological effects such as decreased anxiety and reduced stress.

> *Exercising in a pleasant environment like that would also alleviate any anxiety I might have about being observed while working out (Participant 8).*

> *It would have positive psychological effects. It may also reduce stress especially if we're not working at an RPE that is too taxing (Participant 2).*

4.4.3 Reactions of Immersive Virtual Reality Exercise (Post-Study Question Answers)

Sensations Within Immersive Virtual Reality Exercise Environments

Sensations of Speed in Immersive Virtual Exercise Environments

Participants suggested they sped up when cycling downhill in the virtual green exercise environment even though the incline of the cycle ergometer remained neutral throughout the ride.

> *In the Iceland one, it's like a nice straight road. But I felt myself speeding up when I was going downhill as well (Participant 5).*

> *In the green environment, whilst it was mostly straight roads there were deviations in the road such as downhills which were able to trick your body like it is real life. When I was going down the hill it felt easier on the legs, and I thought I was spinning quicker (Participant 2).*

Participants also mentioned that the virtual elements with the urban setting resulted in different perceptions of speed.

> *There were more reasons for speeding up in the urban. I was trying to be competitive with other things that I was seeing like cars (Participant 1).*

> *Yeah, so especially when there are cars around, I feel like you would in real life you tend to speed up to get across the crossing or past the car (Participant 8).*

Cyber Sickness

Cyber sickness is an important, yet unwanted, aspect of immersive virtual reality that can negatively impact the user's experience (1). Participants stated they experienced cyber sickness symptoms when turning a corner in the immersive virtual urban environment.

> *Only when we went into that 90-degree turn that threw off my body and I felt like I was about to fall flat on my face (Participant 2).*

> *Just when I turned the corner, I felt dizzy (Participant 10).*

Yet, all participants stated that they experienced no cyber sickness symptoms in the green environment.

> *I didn't feel any sort of sickness or any nausea or any kind of motion sickness at all (Participant 1).*

> *Do you know, not at all. I thought I would at the start but because I do get travel sickness, I didn't, not at all with that (Participant 8).*

Immersion and Presence

Immersion and presence are other important aspects of virtual reality. Immersion refers to the ability of technology to deliver a vivid illusion of reality, whereas presence relates to the user's perception of the virtual environment (1). Participants suggested that the green environment was smoother, thus eliciting higher levels of presence.

> *The green environment it was a lot smoother, and you could easily forget you're in a VR session (Participant 10).*

Participants were concerned about the picture quality of the urban environment, suggesting that this decreased how immersed they were in the virtual environment. This subsequently, could decrease their levels of presence.

> *The images are very patchy on the Detroit one, so you're not completely immersed (Participant 5).*

> *The urban environment quality of the VR was not ideal and it's just you didn't really feel like you were cycling in that environment (Participant 11).*

Initial Expectations of Immersive Virtual Exercise Environments

After the study, participants were once more interviewed regarding their initial expectations of the exercise environments and whether these anticipations were fulfilled.

Anticipation of the Green Environment

Participants mentioned their anticipation of the green environment was fulfilled.

> *If I had to guess it was going to be the green environment just from my background knowledge of psychology (Participant 2).*

> *I did think of a countryside environment, maybe some hills or something like that (Participant 4).*

Unexpected Urban Environment

Moreover, the immersive virtual urban environment was unexpected by participants.

> *I wasn't really expecting the city one (Participant 12).*

> *I didn't anticipate the Detroit one (Participant 5).*

Environment Preferences

Green Environment Preference

Most participants preferred the green environment over the urban environment. Participants stated that this environment was more intriguing and relaxing compared to the urban. Moreover, participants found the urban environment too stimulating and busy to enjoy.

> *I was enjoying the green environment more. Because it just it's a bit more intriguing to me a bit more beautiful a bit more relaxing. And I just wanted to carry on going (Participant 1).*

> *I thought the green was a lot more calming compared to the one in Detroit where it's just very busy and there's lots of cars, lots of buildings around, personally I didn't enjoy it as much as I did the Icelandic route (Participant 5).*

Urban Environment Preference

Few participants preferred the urban environment over the green environment. Although these participants enjoyed the green environment, they found the rush and business of the urban environment to be positively stimulating.

I preferred the urban one because it constantly changing. Whereas the mountain one was nice, but it was almost like I was looking at the same thing the whole time (Participant 12).

I preferred the urban one because I quite like the rush. You move more like you would on a bike I think through VR in the city (Participant 10).

Boredom in Control Condition

Participants stated perceptions of boredom whilst exercising in the control condition. Participants revealed this condition dragged on and they couldn’t wait for it to finish compared to both virtual reality exercise conditions.

I found that in the third variation, which was without the VR, I was quite bored, and I just couldn't wait for it to end (Participant 7).

The time flew compared to the control session where it just felt like it was dragging a little bit (Participant 4).

Real Exercise Environment Preference

Participants stated that virtual reality exercise is a good substitution for individuals who are unable to access the real environment. However, participants would rather exercise in a real environment over a virtual counterpart.

I think it's certainly a good substitute for populations who may struggle to go into the real environment or don't have that confidence yet to go into that environment (Participant 2).

I guess I'm still a little sceptical. I would still prefer to be biking in those places (Participant 12).

Psychological Benefits of Immersive Virtual Reality Exercise

Increase Enjoyment

Participants mentioned that virtual reality exercise was more enjoyable than regular indoor exercise. Participants expressed that virtual reality exercise has the potential to mitigate the negative external factors associated with outdoor exercise for specific individuals, enhancing the overall enjoyment of exercise.

> *If someone doesn't want to go outside, they can stay inside and still get a good workout and enjoy it more compared to being worried about the external factors that are in the outdoors (Participant 1).*

Moreover, participants simply enjoyed virtual reality as they preferred it as an alternative to staring at a featureless wall.

I thought it increased enjoyment. Definitely over like staring at a wall (Participant 4).

Decreased Perceived Effort

Participants suggested that exercising in an immersive virtual environment can decrease their perceived effort of the exercise. This is interesting as participants were instructed to exercise at an RPE of 12. Thus, maybe immersive virtual reality can augment perceptions of exercise intensity.

> *It made, whilst working at the same intensity, my perception of that was probably lower (Participant 2).*

> *I perceived it as being easier or more enjoyable than just cycling in a plain environment (Participant 9).*

Increased Motivation

Participants also mentioned that virtual reality increased their motivation whilst exercising and their motivation to partake in exercise.

> *I feel virtual reality can help push people to do more and go the further mile I think virtual exercise is much more of a motivator and makes me feel better while exercising compared to just by myself (Participant 1).*
>
> *I feel like it's a good motivator for exercise (Participant 6).*

Relaxing and Calming in Immersive Virtual Environment

Although participants suggested that virtual reality increased motivation and decreased perceived effort during exercise, participants mentioned that both virtual environments were more relaxing and calming compared to the control condition (indoor exercise).

> *I found virtual reality to be a relaxing positive experience (Participant 7).*
>
> *I felt quite calm sitting there by myself just cycling as you could be anywhere (Participant 4).*

Psychological and Accessibility Assistance

Like answers from the pre-study questions, participants mentioned that immersive virtual reality can break down barriers to exercising. Participants suggested this technology can cancel any anxieties in people when exercising in a real outdoor environment or the gym. Additionally, participants pointed out that virtual reality can facilitate access to outdoor environments virtually for individuals who might otherwise be unable to physically visit such locations.

> *Exercising in virtual reality can help people with mental health issues as they may not want to go outside (Participant 10).*
>
> *I think it's good because it can get a lot of people doing exercise when they can't go outdoors (Participant 9)*

4.5 Discussion

The current study investigated the expectations and reactions of immersive virtual reality exercise. The findings offer support as to why there has been growing interest in using virtual environments to enhance not only overall health but also an individual's experience of exercise, as well as aspects of virtual reality that can influence the individual experience (18).

4.5.1 Pre-Intervention

Although participants were aware of virtual reality; a common theme was the limited knowledge and/or experience of virtual reality combined with exercise. Yet, perceptions of virtual reality were generally positive with participants as having the potential to increase enjoyment and motivation. This corroborates previous research by McMichael et al., who revealed that 83% of participants had limited understanding of virtual reality, yet described it as interesting and has potential (216).

A common theme identified among participants was the expected perceived benefits of virtual reality for exercise. Participants indicated that immersive virtual reality could increase the enjoyment of exercise. Furthermore, participants suggested that immersive virtual reality may elicit a boost in motivation, increase intensity and distract from fatigue. To the best of the author's knowledge, this is the first study to identify increased enjoyment as an expected reaction to immersive virtual reality exercise. However, previous research has revealed that participants reported immersive virtual reality exercise as an exciting and enjoyable experience post-intervention (146). Moreover, an immersive virtual reality exercise game was demonstrated to effectively motivate both children and adults to exercise (219) and virtual reality was found to be effective in distracting overweight children from physiological bodily sensations of exercise (220). Additionally, immersive virtual reality causes an increase in heart rate and can lead to more calories burnt during running (221).

Participants anticipated that their exercise environment would involve green/natural surroundings, with many suggesting these types of environments would elicit positive psychological responses, such as stress reduction. These anticipations could be due to humanity's innate relationship with nature; humans have had regular engagement with nature for thousands of years from roles as hunter-gatherers and farmers to more recently actively seeking natural spaces to reduce the stress of modern life (137).

Another theme common identified was the use of immersive virtual reality to overcome barriers to exercise. Participants suggested immersive virtual reality can aid people to exercise who may lack confidence and have increased anxiety when it comes to exercising in real outdoor and indoor spaces. In fact, immersive virtual reality has been used for the treatment of anxiety disorders (78). Yet, a systematic review revealed that pre-2012 generally suggested that immersive virtual reality was an effective treatment for mental disorders, such as anxiety, the effect was less than conventional cognitive behaviour therapy (222). However, studies post-2012 showed that immersive virtual reality can be as effective or in some cases more effective than cognitive behaviour therapy (222). This may reflect the improvements in immersive virtual reality technology during this period. Participants also suggested immersive virtual reality could benefit the elderly in overcoming barriers to exercise. A recent study implementing a manuped (chair-based indoor exercise bike) and an immersive natural virtual environment in an elderly person home revealed participants stated that the combination of immersive virtual reality and the manuped would make them want to exercise more (223). Thus, immersive virtual reality may benefit those who are unable to exercise conventionally by creating an environment they feel comfortable to exercise in.

4.5.2 Post Intervention

Participants preferred the green immersive virtual environment over the urban environment. Participants suggested the green environment was more pleasurable and relaxing compared to the urban environment which was perceived as hectic. This is not a surprising finding as individuals generally prefer natural environments over urban ones (112, 224). For instance, photographs of scenes of nature consistently receive higher ratings of liking, scenic beauty and pleasantness than photographs of urban scenes (225). Preferences for a green environment are thought to serve an adaptive purpose, aiding us in avoiding detrimental environments and approach beneficial ones (96, 226, 227). Furthermore, the present study's finding corroborates a recent study which revealed viewing immersive virtual nature settings in virtual reality was associated with more positive feelings, lower levels of fatigue and decreased depression compared to viewing an immersive virtual setting (152). Yet, participants were sedentary compared to the present study where participants exercised. The finding that participants preferred the green environment over the urban and/or control is in line with previous literature regarding the Biophilia Hypothesis: humans are innately drawn to nature and when immersed, experience positive emotions (228). Participants may have preferred the natural environment as it is attributed to the intrinsic cognitive-based human need for exploring and understanding these environments (226, 227).

Participants reported changing perceptions of speed throughout the different immersive virtual environments. Participants perceived themselves as speeding when going downhill in the green environment and when near cars in the urban environment. As a highly immersive virtual reality system was used in the present study, participants may have been more inclined to react to the different virtual stimuli in a way they would in the real world. Yet, participants stated that the immersive virtual urban environment picture quality was worse than the green environments, resulting in a feeling of not being completely immersed in the urban environment. Thereby, participants stated that they were more immersed in the green environment compared to the urban. This corroborates previous qualitative research by Abernathy et al., comparing immersive virtual green and urban exercise environments (204). Furthermore, Abernathy et al., reported that there was a strong correlation between enjoyment and interest variables and immersion, with participants who were most interested in the immersive virtual reality activity and enjoying it reporting higher levels of immersion, further explaining, why participants in the present study preferred the green environment more (204).

Cyber sickness is often related to presence (a subjective correlate of immersion) in a virtual environment. Participants stated that they felt cyber sickness when turning a corner in the immersive virtual urban environment. Thereby, participants did not feel as immersed in the urban environment of the present study. This corroborates a recent study that suggests cybersickness reduced the sense of presence in virtual environments (102). Apart from turning a corner in the urban environments, no other participants experienced cyber sickness across both virtual environment conditions. This is unlike previous research that reported as many as 100% of users reporting feeling cyber sickness symptoms (2, 16, 17). Furthermore, a recent study reported that 19 out of the 26 participants experienced cyber sickness in an immersive virtual green exercise environment (18). The finding that participants did not report any cyber sickness symptoms in the green environments is unlike previous research utilising immersive virtual green cycling which found indications of psychological distress related to cyber sickness (160). Yet, the study comprised a high intensity cycling session, compared to the present which was less intense. One strength of this study was the limited effect cyber sickness had on participants. Cyber sickness can impact individual experiences of immersive virtual reality and decrease the user's feelings of immersion and presence (91, 102, 144). Witmer et al., suggested cybersickness draws attention away from virtual reality, thus decreasing presence (229). Thus, participants felt cyber sickness in the urban environment, felt less presence, and thereby were less immersed and preferred the green environment to a greater extent. Cyber sickness determines the overall quality of user experience (91); users enjoy their virtual reality experience less when feeling discomfort from nausea or disorientation (230). Thereby, in the present study, participants preferred the urban environment less due to symptoms of cyber sickness having a detrimental impact on their experience. Moreover, the postural instability theory suggests that periods without postural control can cause cyber sickness (105). Participants may have felt a loss of postural control when turning a corner in the urban environment, causing cyber sickness symptoms. It is important to note that the green environment did not feature as many sharp turns compared to the urban environment. This raises the possibility that the camera instability during sharp turns could be a contributing factor to the onset of cyber sickness symptoms among participants. This corroborated previous research revealing that improved camera stability reduces cyber sickness symptoms among participants (205).

Although participants suggested that a virtual environment could be used as a substitution for a real environment, many still preferred exercising in a real environment. This is in line with previous research. A recent study revealed that although participants supported the use of virtual reality if there were a health benefits, half of participants felt strongly that physical activity in the real world would provide greater benefits (216). While visual and audio stimulation were employed in the virtual environments, one participant expressed the opinion that these virtual settings did not adequately incorporate a wide range of human senses to provide a beneficial experience. Furthermore, the current price of many immersive virtual reality systems may be a barrier for many groups of people, such as students. As many of the participants in this study were students, they may have been reluctant to suggest that immersive virtual reality environments could replace real environments due to these barriers. Yet, participants suggested that immersive virtual reality could eliminate barriers to exercising in a natural environment, such as accessibility issues to these environments and anxiety. Recently, virtual reality exposure therapy has become a popular treatment for anxiety with a growing body of evidence suggesting virtual reality is a successful tool for the treatment of anxiety related symptoms (222, 231-234). Yet, immersive virtual reality exercise in the treatment of anxiety and other mental health conditions are seldom reviewed (234). Thus, future research should implement virtual reality exercise for individuals with clinical mental health conditions.

Participants reported psychological and physiological benefits of immersive virtual reality like that of their expected benefits. This corroborates recent research that revealed immersive virtual reality can increase exercise motivation and physical performance (235). VZFit is rated “E for everyone-one”, thus the mechanics of the application were not very complex, and no participant had any issue with understanding the directions, allowing participants to easily enjoy the application. Consequently, the increase in motivation could be the due to the simple, yet engaging application design (219). Participants reported immersive virtual reality increases motivation and enjoyment of exercise. A recent pilot study comparing an immersive virtual reality-based exercise bike and a traditional exercise bike on physiological and psychological response revealed participants had significantly higher enjoyment and self-efficacy in the virtual reality session compared to traditional stationary bike exercise (209), implying that immersive virtual reality exercise can be an effective, enjoyable, and motivating tool for promoting exercise (236). Virtual reality combined with exercise may serve to increase motivation to engage in exercise. Enjoyment developing from immersive virtual reality-based exercise has been suggested to promote exercise participation (237). According to Self-Determination Theory, enjoyment is positively correlated with intrinsic motivation (236, 238). In the present study, participants reported increased motivation when using immersive virtual reality, and thus reported increased enjoyment.

Participants reported immersive virtual reality decreased the perceived effort of the exercise. This is interesting as participants were instructed to exercise at an RPE of 12. Thus, immersive virtual reality could augment the user’s perception of exercise intensity. This finding is similar to an early study by Plante et al., (166) in which participants' perception of exercise intensity augmented when using immersive virtual reality, as opposed to exercising without virtual reality. Notably, this occurred even though participants were cycling at a controlled intensity across all exercise conditions. The present study's finding is also similar to previous research which revealed virtual reality feedback during an indoor cycling exercise resulted in decreased levels of perceived exertion and increased levels of enjoyment of the activity compared to a regular exercise session with no virtual reality feedback (239). Yet the study used a less immersive form of virtual reality. Virtual reality may provide an individual with numerous simultaneous signals which could direct the user's attention away from painful signals of exercise (240-243). Moreover, higher levels of immersion and presence are essential components of the effectiveness of virtual reality for pain management (243). Immersion induces a state of consciousness in which the user's responsiveness to its own physical self-diminishes due to the user's involvement in the virtual environment; as the user engages strongly with this sensory experience, they may become less attentive to signals and pain of exercise (243). Thus, the perceived effort of the exercise decreased. Furthermore, participants reported increased enjoyment when using immersive virtual reality compared to the control condition. Previous research has reported immersive virtual reality when paired with exercise, enhanced enjoyment (166). In the present study, participants also reported boredom in the control condition; the control condition environment may have not been adequately stimulating to increase arousal and satisfaction in participants (244).

Combining immersive virtual reality with exercise machines, such as a cycle-ergometer used in the present study, may enhance the benefits of exercise (166).

Overall, immersive virtual reality enhanced the exercise experience compared to the control condition. This technology increased participants' enjoyment and motivation whilst creating a relaxing and calming environment. These findings build on the increasing body of research suggesting the positive impact virtual reality can have on exercise experience (72, 220, 235). The additional benefits could increase long-term adherence to exercise programmes and generally result in increased exercise enjoyment (166, 245).

4.5.3 Strengths and Limitations of the Study

The sample size was sufficient according to Braun and Clarke’s recommendation of between 10 and 20 participants (246). Furthermore, the qualitative design made the results rich, with the design of the questionnaire not limiting the content (146). Another strength of this study was the within-subject experimental design, with two different immersive virtual reality exercise environments administered in a counter-balanced order (91). The within-subject experimental design allowed for a nuanced exploration of the participants' expectations and reactions to immersive virtual reality exercise. Yet, it is not sure that the views of the participants would differ in other populations. As the mean age was 22.17±3.59 future studies could research older population expectations and reactions to immersive virtual reality exercise. The dependence on a stable internet connection for the immersive virtual reality equipment and the VZFit application could pose significant challenges in terms of broader implementation across various settings, this issue highlights the potential vulnerability of this technology to technical glitches or connectivity problems, which can disrupt the user experience and limit the feasibility of using these technologies in settings where reliable internet access cannot be guaranteed. The development of new virtual reality technology will better address these challenges, increasing the possibilities of research within this field (91).

4.6 Conclusion

Participants found immersive virtual reality combined with exercise to be a positive experience, suggesting various positive themes such as increased enjoyment and motivation. Although participants were encouraging of virtual reality, they still believed that exercising in the real world was more beneficial and that virtual reality should be used as a substitution. Participants also reported limited cyber sickness during the urban condition and no cyber sickness during the green condition. Furthermore, the majority of participants preferred the immersive virtual green environment to the urban environment, further building on previous research suggesting the positive impact nature has on humans (1, 86).

5.0 General Discussion

Research on the topic regarding the influence of immersive virtual reality green exercise is gaining traction in literature. This type of exercise has been shown to have positive effects on mood (89), directed attention (190) and individual behaviour (161). However, previous research has yet to investigate the comparative effects of an immersive HMD virtual green exercise environment and an immersive HMD virtual urban exercise environment on mood, directed attention, heart rate and distance cycled concurrently. Additionally, there has been an absence of research into participants' expectations of immersive virtual reality and their reactions to this technology simultaneously. Thus, the overall goal of this thesis was two-fold; to examine how immersive virtual environments can influence an individual's psychological and physiological outcomes. Further, to explore individual expectations and reactions to using immersive virtual reality exercise. The aims as previously stated were:

1. Address the methodological gap by comparing a range of previously reported psychological and physiological outcomes of exercising in an immersive virtual green environment versus an immersive virtual urban environment, whilst using a prescribed intensity.
2. Explore participant expectations of immersive virtual reality prior to use and their reactions after exercising in all conditions.

5.1 Main Findings of Research

The first study in this thesis (Chapter 2) investigated the influences of immersive HMD virtual environments on affect, directed attention, heart rate and distance cycled of a controlled exercise. Analysis revealed that the immersive virtual green exercise environment significantly improved participants' affect and directed attention from pre- to post-exercise. Yet, no significant difference in affect and directed attention was observed between the immersive virtual green and immersive virtual urban exercise environments. It is possible that participants did not perceive a substantial difference in emotional engagement between the two virtual environments, leading to comparable affective responses. However, compared to the control condition (indoor cycling) affect significantly improved in the immersive virtual green exercise environment. This finding could be attributed to the immersive virtual green environment eliciting positive emotional responses among participants compared to the control conditions, which in turn contributed to the observed enhancements in affect.

Distance cycled was significantly further in the control condition compared to the immersive virtual urban exercise environment. No significant difference was observed between both immersive virtual exercise environments as well as between the green and control condition and in addition, participants' heart rate was significantly higher in the control condition compared to both immersive virtual exercise environments even though participants were instructed to exercise at the same intensity across exercise conditions (RPE 12). An individual's subjective perception of effort during exercise is increasingly complex comprised of brain input, integration of information from the feed-forward centre and feedback from several central receptors such as baroreceptors, chemoreceptors and metaboreceptors, as well as auditory and visual information (124), thus immersive virtual reality exercise may provide a distraction from the sensory information above and augment perceptions of exercise intensity, causing participants to cycle at a higher intensity in the control condition, thereby heart rate was greater. Furthermore, participants may have been more familiar with traditional cycle-ergometer-based exercise and thus felt more comfortable cycling at higher intensities.

A qualitative exploratory study (Chapter 3) was conducted to investigate participants' expectations and reactions to immersive virtual reality exercise. Two sets of open-ended questions were given to the participants. The first was prior to any of the immersive virtual exercise conditions and the second was after all the conditions. A main finding from participant expectations was that the majority of participants had limited knowledge and/or experience of immersive virtual reality compared with exercise. This could be due to the cost factor of immersive virtual reality headsets being a barrier to virtual reality implementation (247). Although immersive virtual reality devices have become more affordable with the introduction of consumer-targeted devices such as the Oculus Go and Oculus Quest (248), studies have revealed that participants believed this type of technology was still too expensive (246). The operational and maintenance aspects of these devices are also to be considered; like computers and mobiles, immersive virtual reality technology may have a short product cycle with a high probability of these devices being obsolete and needing replacing within several years of initial purchase (247). Marketers often release new applications that require better graphics and computing performance, making it a persistent effort to guarantee the virtual reality equipment is up to date (247). Participants also hoped to be exercising in an immersive virtual green outdoor environment. These hopes may stem from humans' intrinsic connection with nature, a bond that has persisted throughout millennia; from the days of being hunter-gatherers and farmers to the present, where individuals deliberately seek out natural settings to alleviate the pressures of contemporary living (137).

A main theme identified from participants’ reactions to immersive virtual reality exercise was the enhancement it provided to the overall exercise experience. Participants reported immersive virtual reality increased exercise enjoyment and motivation to exercise. This finding could be due to the immersive virtual reality being a novel and engaging exercise experience. Thus, the virtual environments and interactive elements can captivate participants making the exercise more enjoyable and motivating. Interestingly, participants stated they felt a decrease in perceived effort whilst exercising, despite receiving instructions to maintain a consistent level of exercise intensity across all conditions (RPE 12). This finding may be attributed to the immersive virtual reality environment’s potential to divert participants’ attention away from the physical sensation of exercise, such as fatigue or discomfort (166, 249). Participants preferred the immersive virtual green exercise environment over the urban one. Preferences could be attributed to evolutionary processes and a cognitive basic intrinsic human need for understanding and exploring natural environments (226, 227). Participants did report feelings of cyber sickness when turning a corner in the immersive virtual urban environment. Yet, no participants reported any symptoms of cyber sickness in the green environment. This could be attributed to the absence of turns in the green environment. Another main finding from qualitative analysis was that participants suggested immersive virtual reality should be a substitute for real exercise environments, especially for populations who may not be able to access the real environment, with exercising in a real outdoor environment being the primary exercise environment.

5.2 Practical Implications

The finding that immersive virtual green exercise significantly improved participants' affect from pre- to post-exercise suggests that integrating immersive virtual green environments into exercise sessions can enhance the enjoyment of physical activity. This aligns with the findings in Chapter 3, which demonstrated that immersive virtual reality increased exercise enjoyment. Consequently, this heightened enjoyment and affect may promote exercise adherence, which, in turn, can yield positive effects on overall health and fitness. Moreover, the increased directed attention observed implies that integrating an immersive virtual green environment can reduce mental fatigue during workouts. Consequently, individuals may find it less taxing to maintain focus, particularly during longer and more challenging exercise sessions. Yet, there is little research into this area, warranting research into the impact of prolonged, high-intensity immersive virtual reality exercise sessions on directed attention. The potential for immersive virtual green exercise to improve directed attention could have broader cognitive advantages, potentially enhancing concentration and productivity in daily life and employment work tasks after using this technology.

The finding that no significant difference in affect and directed attention was observed between both immersive virtual reality exercise environments suggests that both can offer similar benefits in terms of improvements in affect and attention. Thus, exercise programs and/or interventions can provide participants with a choice of environment based on their preferences without compromising the benefits of affect and directed attention. Chapter 3 provided insight into preferences of exercise environment; the finding that participants preferred the immersive virtual green environment could increase individual connectedness with nature. This technology could promote nature connectedness in the form of psychological attachment and positive attitudes towards nature, and increase motivation to visit the natural environment, which could be a psychological construct related to increased overall health and wellbeing (76).

Participants heart rate being significantly higher in the control condition compared to both immersive virtual conditions could imply that virtual reality augments an individual’s perceptions of exercise intensity. Moreover, immersive virtual reality exercise may offer a cardiovascular advantage, allowing individuals to achieve the same perceived exercise intensity while experiencing decreased heart rate. This could be beneficial for individuals with cardiovascular issues, as it suggests a potential reduction in cardiovascular stress during exercise. Moreover, qualitative data suggests that participants did perceive a reduction in perceived effort whilst exercising in the immersive virtual reality conditions, which could explain the significant difference in heart rate seen in Chapter 2. Moreover, this calls into question whether participants consistently adhered to the prescribed intensity (RPE 12) throughout the conditions.

The finding that participants perceived cyber sickness symptoms during the immersive virtual urban exercise environment but not the green due to camera movement discomfort when turning a corner has practical implications for immersive virtual environment design. To eliminate cyber sickness symptoms, researchers should aim to increase camera stabilisation (205).

5.3 Limitations and Future Research

A limitation of findings in Chapter 2 was the relatively small sample size (N = 12). This decreased the study's statistical power and limited the generalisability of findings. Moreover, participants in the present study were healthy adults; thus, it is uncertain whether findings can be applied to individuals with clinical conditions, such as sight deficiencies, infections of the vestibular system, or other health problems (205). The lack of an experimental condition applying a real natural environment limits the ability to attribute this finding to the environment and not the virtual reality technology alone (144).

A limitation of the findings in Chapter 3 was the relatively young age of the participants, with a mean age of 22.17±3.59. Future research could explore how older populations perceive and react to immersive virtual reality exercise. Additionally, given the novelty of the immersive virtual reality equipment and the VZFit application, there were initial operational challenges. For instance, if the internet connection dropped, the entire system would stop functioning. Furthermore, the reliance on a stable internet connection for both the immersive virtual reality equipment and the VZFit application presented a significant hurdle. This issue highlights the potential susceptibility of this technology to technical glitches and connectivity issues, which can disrupt the user experience. It also underscores the limitations of using these technologies in settings where dependable internet access cannot be assured. Moreover, the novelty factor of the virtual reality technology was not explored. If novelty wears off over time, it raises the question regarding the long-term viability of this technology. Assessment of factors such as enjoyment were based on only two virtual reality cycling experiences. Thus, it is unknown if enjoyment wears off over time, highlighting the potential need for future long-term studies.

Another limitation of this study is that participants were not provided with pre-arrival dietary or exercise restrictions. Nutrient intake has been shown to influence participant perception of RPE (250). Caffeine ingestion prior to cycling has been shown to significantly lower session ratings of RPE compared to a placebo (251). Moreover, increased carbohydrate ingestion is associated with lower ratings of perceived exertion during running (252). Moreover, research has shown that fatigue levels can significantly impact RPE during exercise (253). Increased levels of self-reported fatigue can lead to higher RPE and reduced work output during self-paced exercise (254).

Future research should start to branch into clinical populations that may benefit from immersive virtual green exercise. Currently, there is little research exploring this. Clinical populations face more barriers to green exercise than non-clinical populations, such as anxiety towards exercising outside and accessibility issues during lengthy stays within hospitals. Thus, immersive virtual reality could provide a way to bring green exercise and nature interactions to them.

5.4 Conclusions

Qualitative and quantitative data within this thesis provided promising evidence for the potential of immersive virtual green exercise as a tool to promote psychological wellbeing, as well as valuable insights into expectations and reactions to immersive virtual exercise. Although this thesis focused on non-clinical populations, the information produced could be applied to numerous clinical populations who would benefit from green exercise, such as those with mental health issues or those who are unable to access green exercise typically (77). A strength of this thesis was that, to the best of the author's knowledge, the first to compare the influence of immersive virtual green and urban exercise on directed attention and explore participant's expectations of immersive virtual reality prior to use.

6.0 References

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