Respiratory Biofeedback based Virtual Environment to Increase Subjective Vitality and Reduce Stress in International Students: Usability, Feasibility and Effectiveness pilot study.

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30EC thesis

University of Twente

31-10-2022

Acknowledgements

I could not have undertaken this journey without the BMS faculty and University of Twente for generously awarding me with University of Twente Scholarship by enabling me with the financial means to pursue this masters. Words cannot express my gratitude to my first supervisor, Dr.Christina Bode for her invaluable patience, feedback, offering advice and encouragement with a perfect blend of insight and humour. I must also thank my second supervisor, Dr. Stans Drossaert for helping me structure my thesis and encouraging me to do better. Additionally, this endeavour would not have been possible without Luci Rabago Mayer, who supervised and helped me translate the designs into the virtual world to develop what we now call Biofeedback Based 'Walk in Nature' Prototype. I also had the pleasure of working with Psychology, Health and Technology intern, Laura Korporaal, who graciously managed the project by reminding me of my responsibilities and helped me stay on track.

I would also like to thank all the participants for being a part of this intervention. I would also like to thank Ahmed Momin for being the voice behind the exercise and for always supporting me. Finally, I am very grateful to my mother for having faith in me, to my father who reassured me and reminded to take breaks when required, to my friends who always offered to lend an ear about my experiences and offer moral support.

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Abstract

Virtual Reality has been used in various well-being based interventions. Based on publicly available studies, an intervention focusing on physical and psychological exercises within the same virtual environment was very limited in number. Therefore, subjective vitality was used as a concept to make a prototype of an intervention to make a more holistic approach towards fostering well-being. Subjective vitality is a state of feeling alive and having an energy available to oneself. This study has made further developments to the already existing Prototype developed by Bareišytė (2021) which was developed for improving Subjective Vitality. Additionally, biofeedback based virtual environments are majorly used to alleviate physical pains or mental stress. Although, this study utilized this technology to explore its impact not only on stress but also, on subjective vitality. The focus group of this intervention were international students. Many research studies have observed high levels of stress in this population, specifically rooting from acculturation processes and academic experiences which were somatised leading to adverse physical effects. Furthermore, usability and feasibility of this newly developed prototype was examined. As result, higher presence and immersive tendencies were observed. Additionally, an effectiveness study was conducted to measure any differences in the levels of subjective vitality, acculturative stress and academic stress using one-group pre-test post-test design. The results showed significant increase in subjective vitality, increase in acculturative and academic stress.

In conclusion, the developed biofeedback based virtual reality environment was effective in increasing subjective vitality and decreasing acculturative and academic stress. Also, the prototype was perceived to be usable and feasible by the participants.

1. Introduction

The ability of technology to promote well-being in effective, scalable, and ethical ways has led to its identification as a well-being enabler (Downey & Cohen, 2018; Sander, 2010; Vidyarthi & Riecke, 2014). The internet, virtual reality, multimedia computing and specialized applications are few of the varied technological advancements to foster well-being (Downey & Cohen, 2018; Riva et al., 2012). This study employed Virtual Reality, it has been referred to in behavioral science as an advanced type of human-computer interaction (HCI) that enables the user to engage with and become fully immersed in a computer-generated environment in a realistic way (Riva, 2005; Ventura et al., 2018). Traditionally, VR has been used to treat a few severe conditions, such as posttraumatic stress disorder, substance abuse disorder, anxiety, and phobias (Kruzan & Won, 2019). Moreover, VR has emerged as an effective medium whose immersive virtual environments can elicit emotional states and behaviors resembling those experienced in reality, HCI research has begun to investigate the application of VR for well-being support (Wagener et al., 2021). However, the peer-reviewed clinical psychology literature exploring VR applications to mental health is still in its infancy (Frewen et al., 2020).

In a study conducted by Baños et al. (2012), discovered gains in vigor after exposing cancer patients to VR featuring pleasant landscapes. Correspondingly, the development of virtual environments inclusive of physical activity, also known as Exergames, are said to have experienced similar mood benefits on individuals to those compared to outdoor activities (Plante et al.,2003). Exergaming research is paying more attention to the value of enjoyment, as it has been discovered that increased enjoyment of physical activity is crucial for cognitive benefits, which are therefore believed to have a good impact on academic attainment (Benzing & Schmidt, 2018). It has been noted that people who exercise in an atmosphere that is rich in stimulating visual and aural stimuli report larger improvements in mood and self-efficacy (Plante et al., 2003). Exergaming promotes flow, immersion, and enjoyment in addition to increased exercise drive (Benzing & Schmidt, 2018). Despite such advantages on mood and physical health, positive psychological interventions using virtual reality lack physical activity. On the other hand, the majority of VR applications focus on using technology to prevent adverse health conditions, rehabilitation, psychotherapy and physical fitness which have been designed for populations like older people, clinical patients, children, high-school students, etc; healthy university students have been scarcely studied.

Psychological distress is becoming more widely recognized as a concern among university students around the world (Sharp & Theiler, 2018). Amongst the university students, international students face multitude of academic and social adjustment problems, there are also differences in the engagement levels in educational activities between local and international students (Andrade, 2006). According to a recent German study, "international students had significantly higher stress levels, more traumatic life events, and higher scores of negative life experiences," putting them at "higher risk for MDD (major depressive disorder), somatoform disorder, anxiety disorder, and more severe depressive, somatic, and anxiety symptoms" (Rückert, 2015; Nat, 2012). Furthermore, international students from non-Western cultures have a propensity to somatise their psychological experiences (e.g., stress, homesickness), increasing the chance of seeking medical rather than psychological care (Poyrazli, 2015), such practices have been detrimental to physical health as well. Prior research indicates that language and cultural limitations, academic and financial issues, interpersonal problems, racial discrimination, loss of social support, alienation, and homesickness can all pose significant challenges for international students (Sherry et al., 2010). These problems have been acculturative in nature. Acculturation is defined as a cultural transformation process that occurs as a result of repeated, direct interaction between two separate cultural groups (Poyrazli et al., 2004). Acculturative stress is a possible side effect of the acculturation process; it includes physiological, psychological, and social components that are directly linked to the acculturation process and international students had similar acculturative stress when compared to refugees (Poyrazli et al., 2004). Researchers have highlighted academic stress as a specific source of acculturative stress for foreign students due to the learning difficulties these students have as a result of shifting to a new language and school system (Liao & Wei, 2014). There is also a gap in scientific evidence focusing on detrimental effects of acculturation and academic stress in international students residing in the Netherlands, the existing literature is predominantly focused on English speaking countries like the USA, UK and Australia. Excessive academic stress can lead to depression and physical illness, both of which can have a negative influence on academic performance (DeDeyn, 2008). As a result, it was vital to focus on a construct which focuses on physical and psychological manifestations. Researchers discovered that subjective vitality is related to both psychological and physical health aspects (Fini et al., 2010).

Subjective vitality is defined as a sense of energy and aliveness, and it is an inner force that promotes mental and physical wellness (Ju, 2017;Ryan & Frederick, 1997). Subjective vitality has a positive correlation with self-realization, mental health, positive emotions, and stronger self-motivation, whereas distress, negative emotions, and external locus of control have a weaker relationship (Ryan & Deci, n.d.). Subjective vitality is associated with the eudaimonic approach, which emphasizes meaning and self-realization and defines well-being in terms of an individual's level of functioning (Ryan & Frederick, 1997). It is drawn from an internal source rather than particular risks in the environment, and it varies from mania in that vitality is not forced or compelled. As a result, it is predicted that the sense of subjective vitality will explicitly relate to energy thought to emerge from the self, implying that it has an internal perceived locus of causality (Akın, 2012). Psychological energy is a crucial resource for subjective vitality required to make actions, and a high degree of vitality promotes improved psychological health and wellbeing. As a result, subjective vitality improves psychological health and well-being by regulating purposeful behaviors and actions (Arslan, 2021). Subjective vitality was shown to be substantially linked to increasing subjective well-being and flourishing as well as subjective happiness, while reducing addictive behaviors, psychological discomfort and school burnout (Salama-Younes & Hashim, 2017).

Previous research has shown that students with high levels of subjective vitality are more likely to engage in constructive study behaviors, such as less homework procrastination, than students with low levels of vitality (Mavilidi et al., 2020). Subjective vitality may be an important indication of human well-being due to its favorable connection with physical and psychological characteristics. Evidence demonstrating the favorable impacts of physical exercise on subjective vitality and on-task behavior might serve as an unique 'hook' for universities to employ physical activity programs with the long-term objective of increasing academic performance (Mavilidi et al., 2020). The high physical-activity group of university students had higher subjective vitality than the low physical-activity group (Molina-García et al., 2011). Yet, interventions focusing on increasing subjective vitality are a handful. The nature of the subjective vitality based interventions were varied, such as, on increasing intensive physical training to enhance subjective vitality (Mavilidi et al., 2020), examining the role of subjective vitality and other factors for yoga based practices to build altruistic behavior (Dagar et al., 2020), exploring the associations between subjective vitality with autonomous self-regulation, depressive symptoms and tobacco abstinence, for health behavior change (Niemiec et al., 2010), and many others. Additionally, three studies using Virtual Reality explored subjective vitality similarly. A restorative virtual environment (VE) was built and it significantly enhanced subjective vitality as well as mood (Mattila et al., 2020), another study focused on comparing physical urban nature with virtual environment by measuring differences in subjective vitality, affect and stress (Reese et al., 2022), although no significant differences in both the settings were discovered. This suggests that such interventions aimed for psychological or physical changes by studying subjective vitality as a contributing factor, but lacked to explore the development of interventions focusing on solely improving subjective vitality.

Based on limited publicly available studies and resources, only one study conducted by Bareišytė (2021) stood out, the nature VE based intervention was developed to improve subjective vitality. This VE consisted of tasks which focused on physical and psychological stimulation which were developed to improve subjective vitality, and the study showed an improvement in the subjective vitality. There were four tasks : *Walking in Nature*, *Breathing Tree*, *Butterfly Task* and *Yoga*. These tasks were placed in a restorative environment, while walking in nature and yoga did what the title entails. The butterfly task was inspired by butterfly parks and the participants were instructed to make the butterflies fly away inside the arch. For the breathing tree exercise, it was inspired by a study conducted by Patibanda et al. (2017), in which the participants were shown a sickly-looking tree and instructed to perform a breathing exercise to help the tree recuperate. Voice instructions also guided the individual through the task. The tree represented the participant's lungs: with each inhalation, the tree expanded, and with each exhalation, it constricted. They were asked to breathe according to the tree movements.

Breathing exercises are a practical, effective, and evidence-based method for reducing stress-related symptoms and improving psychophysiological health (Hopper et al., 2019). Slow breathing has both psychological and physiological impacts that interact in a bidirectional feedback loop. Slow, regular breathing soothes the body and increases parasympathetic nervous system activation, which leads to mental relaxation (Blum et al., 2020). Although focused breathing is a free and low-effort technique to improve psychophysiological health, consistent practice is difficult. People typically struggle to maintain motivation, keep their concentration on the breath, or lack sufficient self-awareness when practicing breathing meditation or focused breathing exercises (Pisa et al., 2017). To increase engagement in breathing exercises and give additional direction for continued practice, respiratory biofeedback can be used to make the individual immediately aware of their breathing condition (Blum et al., 2020). Biofeedback is based on measuring physiological changes related with psychological states to aid in the monitoring of bodily functions influenced by psychological reactions (Alneyadi et al., 2021).

A research investigated the efficacy of integrating biofeedback with didactic training for students enrolled in a university stress management course; the findings revealed substantial reductions in anxiety (Ratanasiripong et al., 2012). According to Gaume et al (2016), Biofeedback can serve numerous purposes. For starters, it can increase awareness of one's own breathing movements and changes, which are instantly and plainly visible. Second, respiratory feedback may be utilized to assess the user's present breathing pattern, alert them of it, and, if required, encourage the ideal breathing style (e.g., slow and even respiration). Third, feedback is frequently meant to be appealing and rewarding, allowing for reinforcement learning. Respiratory signals (inhalation and exhalation) can be monitored using various sensors and sent back to the user in real time, often as visual or audio stimulation. VR has two key advantages in the context of respiratory biofeedback exercises. First, high immersion via stereoscopic, six degrees of freedom, head-mounted VR can aid in the creation and implementation of vivid and visually attractive feedback stimuli, which have been demonstrated to boost motivation and engagement (Rockstroh et al., 2019). Current study used Biofeedback technology as an addition to the VE developed by Bareišytė (2021). The usability and feasibility of this technology was examined. Followed by, the study of the effectiveness of the developed biofeedback VE intervention. Based on these aspects, the study was conducted in two parts. The aims of the Part 1 were:

1. To further develop the 'Walk in Nature' VE to a Biofeedback based 'Walk in Nature' VE

   1.1. To examine the usability of the biofeedback based VE.

1.2. To examine feasibility of the biofeedback based VE.

Part 2 was a pilot effectiveness study to examine the potential effects of biofeedback based VE on the international students. The research questions were:

2.1. Do international students report an increase in subjective vitality after using the biofeedback based VE?

2.2. Do international students report a decrease in acculturative stress and academic stress after using the biofeedback based VE?

2. Material and Methods

This section proposed a pilot study that briefly discussed the development of the 'Biofeedback based Walk in Nature' VE, also known as BWN prototype which consisted of new additions to the existing 'Walk in Nature' VE, also known as WN prototype developed by Bareišytė (2021). Following this, usability and feasibility study for the BWN prototype was discussed by outlining the sample group, procedures, measures and planned interpretation of the data. Second part of the study measured effectiveness of the prototype BWN by briefly discussing design, procedure, participants, instruments and data analysis. (A very in-depth information on design and development can be read in Appendix H)

2.1 Design and Development of 'Biofeedback based Walk in Nature' VE (BWN Prototype)

The development and design of BWN Prototype was conducted by the researcher with support of a multidisciplinary team. The design and development were guided by Luci Rabago Mayer from BMS lab at the University of Twente, with support provided by Health and Technology intern Laura Korporaal. This was supervised by Dr. Christina Bode and Dr. Stans Drossaert.

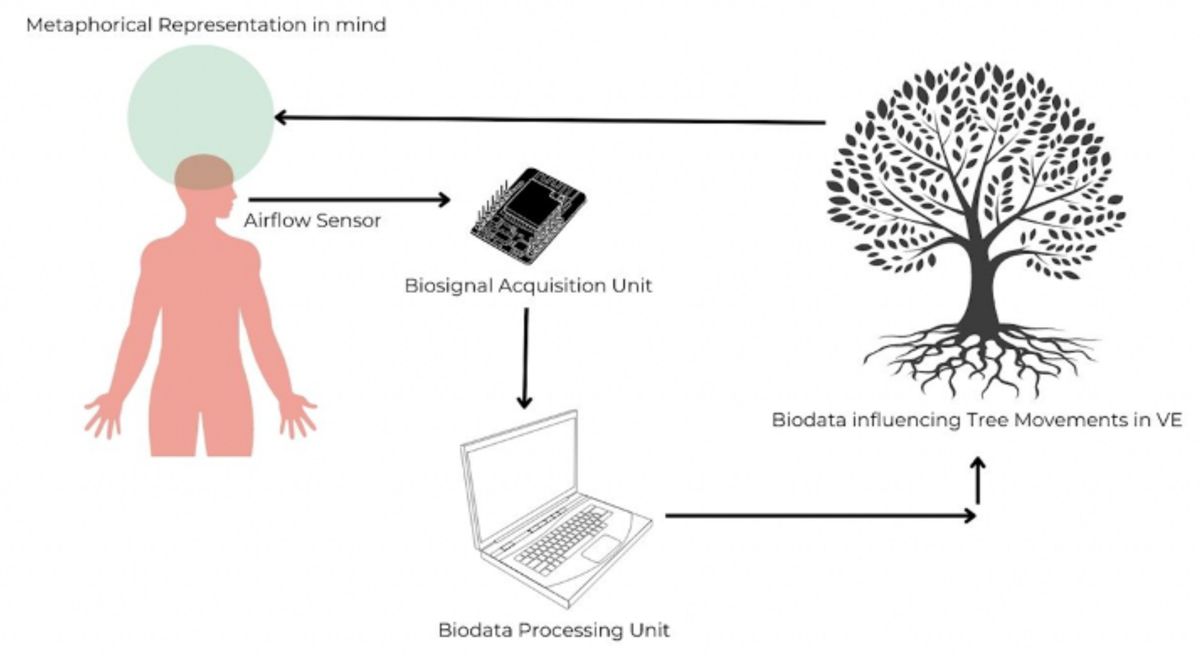
2.1.1. Programming of the Respiratory Biofeedback in BWN Prototype

The *Breathing Tree* task from WN Prototype was the main focus point to make the addition of biofeedback technology. In the WN Prototype, the tree changed from gray to green while participants practiced mindful breathing. This transition was automatic and it had no inputs from the participants, although they were asked to press a button when they inhale and release the button when they exhale. These presses were not responsible for any movement of the tree. The main goal for BWN Prototype was to design a real time interaction between the participant and the tree in VE. As previously studied, biofeedback based studies showed an improvement in relaxedness as well as reduction in anxiety and hypertension (Gardl et al., 2018), deep breathing can reduce perceived stress and improve mood (Perciavalle et al.,2016), similarly, in 2007 significant improvement in academic performance in university students by practicing deep breathing was discovered by Paul et al. Therefore, understanding the effects of biofeedback within a VE on international students was vital.

Acquiring the correct sensors was critical for developing biofeedback technology. The MySignals Airflow sensor was used in this study. The Airflow sensor consisted of a flexible thread that went behind the ears and two prongs were inserted into the nostrils. These prongs were used to determine the breathing rate. The Airflow sensor measured respiration rate and transferred the data to the biosignal acquisition unit. The data was converted into understandable breathing readings which were sent to the Biodata Processing Unit. This unit consisted of Arduino Software which interpreted the readings, while Unity Hub Software used these readings to create a real-time connection within the VE. The biodata had an immediate impact on the tree movements leading to a meaningful metaphorical representation of the tree movements to the movements of human lungs during breathing in the participant's mind. A visualization of this mechanism is shown in Figure 1.

Figure 1

Illustration of the Mechanism of Biofeedback Technology



2.1.2. The Final Structure of BWN Prototype

The first task was *Walking in Nature*. The layout of this task was changed by the researcher to the size of the room where the experiment was conducted, to enable the participants to get familiar with the physical world while exploring the VE through the headset. This was followed by the *Butterfly* Task. It was physiological in nature, the participants were asked to make the butterflies fly away as fast as they can, this fostered moving fast, jumping and quick hand movements. To conclude the Prototype in a restorative note, the psychological task also known as, *Breathing Tree* task was performed. The participants were seated comfortably in a chair and followed voice instructions within the VE to initiate and motivate them to practice slow and deep breathing. Their breathing data was used to manipulate the tree movements. One each exhale, the tree expanded while on each inhale, the tree contracted. It started with a dead looking tree which turned into a bigger green-lushful tree by the end of the exercise.

2.1.3 Usability and Feasibility of BWN Prototype

To test if the above mentioned designs and development are usable for a larger population, this study conducted usability testing. The two characteristics which are considered to be more prevalent in VR than in any other type of information systems are immersion and presence (Mütterlein & Hess, 2017). Immersion is the objective level of sensory realism provided by a VR system (Bowman & McMahan, 2007). Presence is defined as, "a psychological state or subjective perception in which, despite the fact that part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience" (Krijn et al., 2004). More advanced technology is frequently assumed to result in greater presence. To examine if the added biofeedback technology in BWN Prototype made any difference, the levels of presence was compared between Prototype WN and Prototype BWN in the same group of participants. Before the intervention, immersion levels were also measured of the same participants. Because, research comparing different levels of immersion reveals that more immersive VR systems have a stronger presence experienced by the individuals (Diemer et al., 2015).

A feasibility study evaluates the viability of a proposed project or system. It is used to determine if an intervention should be tested further and to assess its efficacy (Quintana et al., 2020). The practicality is determined by first-hand observation of the user's experiences, as well as the obstacles encountered during or after implementation. Virtual worlds are very adaptable and configurable. They allow the researcher to provide a wide range of controlled stimuli as well as assess and monitor a wide range of user reactions (Riva, 2002). This adaptability may be utilized to deliver systematic restorative training that maximizes the degree of training transfer or generalization of learning to the individual's real-world environment (Riva, 2002). In Prototype BWN, biofeedback technology focused on training of slow paced and deep breathing. Therefore, it was also crucial to examine if this transfer of training happened or there were any obstacles experienced by the participants. Feasibility studies are performed to establish if an intervention is suitable for future testing, or whether the concepts and findings may be adjusted to be meaningful (Spreij et al., 2020).

Additionally, a background questionnaire on familiarity with VR was administered and user experiences were collected through open ended questions to gain more insightful knowledge on the participant's experiences. Feasibility study was aimed only on Prototype BWN, it was not compared with Prototype WN.

Participants

The study recruited 18 participants for Part 1. The participants were recruited using availability sampling. The inclusion criteria for this study were : 1. A student at the University of Twente, 2. An international student (outside of EU nationality), 3. They do not have a hearing, sight (sensitivities to rapidly changing light), and physical problems (epilepsy, motion sickness), 4. They are proficient in using the English language. In the beginning of the intervention, an informed consent form was introduced informing about data collection, potential risks, and procedure as well as that participation is voluntary and that participants can withdraw from the study at any time without giving a valid reason to do so (see Appendix A). The study was reviewed and approved by the BMS ethics committee at the University of Twente.

Experimental Set-up and Materials:

The Experiment took place in ManouVR lab at the BMS lab, University of Twente. The room had designated seating space which was used to fill up questionnaires in a comfortable sitting position and lab area for free body movement in the room to freely interact with the virtual environment. The questionnaires were represented using iPad 4 Air by Qualtrics Software (https://utwentebs.eu.qualtrics.com). Qualtrics is a survey tool meant to create, collect, and analyze data. The equipment used to simulate the VE was comprised of Oculus Rift S, Alienware monitor, and Oculus Link wire. The VR system consisted of a HMD and a set of controllers. The HMD lets the user see and explore the VE from all angles in 360 degrees, while the controllers allow the participant to interact with the environment by pressing buttons. Additionally, to measure respiratory biofeedback the MySignals Airflow sensor was used.

Measures

Background questionnaire

A background check on a five-point Likert scale (ranging from “not at all” to “very much”) regarding previous experiences with VR (“To what extent are you familiar with virtual reality environments?”), nature (“Do you like walking in nature?”), and current stress levels (“To what extent do you feel stressed right now?”) was first conducted. It was meant to get a better understanding about the background of participants.

Immersive Tendencies Questionnaire (ITQ)

To comprehend presence, it is necessary to first assess individuals' ability to immerse themselves in an area (Witmer & Singer, 1998). Witmer and Singer (1998) developed the original ITQ, which was amended and translated by Robillard, Bouchard, Renaud, and Cournoyer (2002). ITQ is a questionnaire that assesses one's capacity to immerse oneself in diverse settings. It consists of 18 items on a range of 1 (never) to 7 (frequently) (see Appendix B). The ITQ elements are divided into four subscales - *Focus, Involvement, Emotions* and *Game.*

Presence Questionnaire (PQ)

A translated French-Canadian PQ (original by Witmer and Singer (1998); amended and translated by Robillard et al. (2002)) was used to evaluate presence perceived during the gamified nature VE (see Appendix C). The PQ consists of 24 elements about the VE experience that are assessed on a scale of 1 (not at all) to 7 (totally). The PQ items are divided into seven subscales - *Realism, Possibility to Act, Quality of Interface, Possibility to Examine, Self-Evaluation of Performance, Sound* and *Haptic*. Robillard et al. (2002) offered the PQ norms for comparison, however they did not include Sound and Haptic subscales. As a result, data from another research utilizing the same questionnaire with a healthy population conducted by Robillard, Bouchard, Fournier, and Renaud (2003) were also included.

Open Ended Questions

Open-ended questions adapted from Foronda et al. (2016) were used to measure user experiences in this study. As a result, rather than inquiring about one's simulation experiences, the questions pertain to the VE or gamified walk in nature. The questions were divided into five major categories: initial impressions of the VE ("What are your initial impressions, thoughts, and feelings about the virtual environment?"), parts that participants enjoyed ("What did you enjoy during the gamified walk in the nature?"), parts that participants did not enjoy ("What did you not enjoy during the gamified walk in the nature?"). Would participants suggest the experienced VE to promote subjective vitality? Why or why not?"), and whether motion sickness occurred ("Did you feel any motion sickness during the virtual walk?"). Another domain was added to compare the environments of Prototype A and Prototype B (“Did you notice any difference in both environments?” “Which one would you prefer using to increase Subjective Vitality? Why?”). All of the questions touched on many issues and allowed participants to express their feelings on the environment.

System Usability Questionnaire

This scale was carefully examined for use of technology and has been proved to be valid, reliable, and sensitive (Bangor et al., 2008). Ten statements are assessed on a five-point Likert scale. The SUS delivers a percentage usability estimate in the form of a point estimate. Ratings above 85 are regarded as outstanding, while scores below 50 suggest extremely poor levels of usefulness. Scores between 50 and 70 are deemed marginal/OK (See appendix D). The norms for data analysis will be used from the study conducted by Maarsingh et al., 2019, as they had employed the SUS to measure usability in a biofeedback based VE to decrease stress levels, hence it was better suited for the population of the current study.

Satisfaction Survey for Feasibility testing:

The Satisfaction Survey was employed by the study conducted by Migoya-Borja et al., 2020. In this study, the questionnaire was adapted for using biofeedback based virtual reality and feasibility of the same. This scale focused on easy usage of the technology, whether the virtual environment was engaging or interesting, expectations of the users were met or not, changes in the perspectives on deep breathing, overall satisfaction, usefulness and recommendation of the biofeedback based virtual environment to others (See Appendix G).

Data Analysis

The *Background Questionnaire* was scored by subscales – familiarity with VR, affinity towards walking in nature and current stress state. The mean and standard deviations were calculated and interpreted based on score ranges. *Immersive Tendencies Questionnaire* and *Presence Questionnaire* scores were checked for normality by conducting Shapiro Wilk normality test, based on the results a *t*-test was conducted for ITQ and a paired *t*-test was conducted for PQ scores to measure differences in presence in WN and BWN prototypes. If it was not normally distributed, a suitable non-parametric test was selected. *Satisfaction Survey* (SS) and *System Usability Questionnaire* (SUS) was given to the same sample of participants but only after exposing them to Prototype BWN. The SUS and SS were checked for normality. If it was not normally distributed, a suitable non-parametric test was selected. If normally distributed, the mean *(M)* and standard deviations *(SD)* of the scores were compared to the mean *(M)* and standard deviations *(SD)* of the norms in a study conducted by Maarsingh et al., 2019. The means (M) and standard deviations were calculated for Satisfaction Survey and compared to the norms by Migoya-Borja et.,al 2020. The data analysis for the questionnaires was done using IBM Statistical Package for Social Sciences version 28. Responses to open-ended questions were analyzed qualitatively, summarizing and classifying participants' views, most common viewpoints, or suggestions. Responses were also cited and supplemented with contextual information from the researcher.

2.2. Effectiveness of the BWN Prototype

The goal was to examine if the BWN Prototype impacted subjective vitality, acculturative stress and academic stress. An effectiveness study gave the researcher an insight into whether this intervention worked in the real-life setting by focusing on applicability of the intervention in the international student population. The intervention used the fully functional version of BWN Prototype (as described in Section 2.1.2) created with physiological and psychological factors in mind to promote subjective vitality and exploring further impacts on acculturative stress and academic stress. Studies focusing on increasing subjective vitality were less in numbers as discussed before, although the nature of the majority of studies were similar but different in approaches and applicability. The subjective vitality was either studied as an assessing factor to check if an intervention fostered positive well-being or correlations studies which discovered subjective vitality in terms of enhancing or diminishing the variable in focus in a study ,for example, a study conducted by Korpela and Ylén (2019) highlighted how visiting favorite place of the given individual increased restorative experiences and subjective vitality was one of the multiple assessing factors. Another mediational model based study conducted by Ju (2017) explored the link between physical activity, meaning in life and subjective vitality. This study successfully showed positive correlations within all the three constructs. A significant positive correlation was discovered between flow experiences and subjective vitality (Chang, 2020). Prevalence of psychological and social factors in physical exercises also contributed to increasing subjective vitality (Özkara et al., 2017). A study explored a relationship between performance anxiety and subjective vitality, and their impact on motivational performance (Chu et al., 2018). This showed a lack of focus in studies aimed at increasing subjective vitality through exercises focused on physical and psychological. After developing such an intervention, it was vital to examine the effects of the same. Similarly, subjective vitality is negative correlated to depressive symptoms, anxiety and stress (Uysal et al., 2014) which was also one of the aims of this study i.e, to examine the intervention developed to foster subjective vitality also had an impact on the stress. This constituted Part 2 of the study. This part of the study was concise and brief compared to Part 1. The reasons were twofold. First, the development and workings of the Prototype BWN were demonstrated as well as the usability testing employed multiple instruments to examine different aspects of the Prototype BWN, accompanied by feasibility and user experiences of the same. Second, instruments in the Part 2 were previously developed specialized to measure the constructs which contributed in making it concise. This section further discussed the above mentioned aspects in depth -

2.2.1. Design of the Effectiveness Study

Current study used One-Group Pretest-Posttest Design. This quasi-experimental design was used to measure any differences in the levels of subjective vitality, acculturative and academic stress for pre and post biofeedback based VE (BWN Prototype) intervention. In sum, the objective was to evaluate the size of effect of the intervention on the international students. As it was a quasi-experiment, the sample group was non-randomized by employing international students through availability sampling.

2.2.2. Intervention and Instruments

The intervention consisted of exposing the participants to the Prototype BWN. As discussed above, it consisted of three tasks. Namely, *Walking in Nature, Butterfly Task* and *Breathing Tree Task.* To measure the differences in the pre and post-tests, following instruments were used:

Subjective Vitality Scale (SVS)

The 7-item SVS assesses “energy and aliveness” (Ryan & Frederick, 1997, p. 530; see Appendix E). It combines both psychological well-being and one’s ability to function or physical well-being (Castillo, Tomás, & Balaguer, 2017). It consists of six positively phrased items (e.g. “I look forward to each new day”) and one negatively phrased (“I don’t feel very energetic”) item. Each statement within the measure is evaluated on a Likert scale from 1 = “not at all” to 7 = “very true”. The minimum score one could receive for the SVS was 7 and the maximum was 49. The SVS has shown good construct validity, with all items showing high factor loadings (loadings > 0.60) (Bostic, Rubio, & Hood, 2000).

Acculturative Stress Scale for International Students

The Acculturative Stress Scale for International Students (ASSIS) developed by Sandhu and Asrabadi (1994) was used because it was designed to measure the difficulties experienced by international students with personal, social, and environmental changes upon arrival in a new country, also known as cultural shock or acculturative stress. The Acculturative Stress Scale for International Students (Sandhu & Asrabadi, 1994) was designed to assess the acculturative stress levels of international students and consists of 36 items on a 5-point Likert-type scale ranging from 1 = "Strongly Disagree," 2 = "Disagree," 3 = "Not Sure," 4 = "Agree," to 5 = "Strongly Agree." "People from different ethnic groups exhibit animosity against me by their acts," for example, or "I find trouble adjusting to new cultural beliefs" (see Appendix F).

Perceived Academic Stress Scale

The items pertaining to academic stressors were transformed into an 18-item, 5-point Likert-type questionnaire. The scale consisted of three subscales - *the academic expectations subscale* (four items), *workload and examinations subscale* (eight items), and s*tudents' academic self-perceptions subscale* (six items). This instrument had adequate internal consistency reliability, as well as indications of face, content, and convergent validity (Bedewy & Gabriel, 2015). Examples of the items were "Competition with my peers for grades is quite intense", "The examination questions are usually difficult", "I can make academic decisions easily" and "I fear failing courses this year".

2.2.3. Participants

The study recruited 30 participants for Phase 2. The sample consisted of 8 different nationalities (Shown in Table 1). The participants were recruited using availability sampling. The inclusion criteria for this study were – 1. A student at the University of Twente, 2. An international student (outside of EU nationality), 3. They did not have hearing, sight (sensitivities to rapidly changing light), and physical problems (epilepsy, motion sickness), 4. They were proficient in using the English language. In the beginning of the intervention, an informed consent was introduced informing about data collection, potential risks, and procedure as well as that participation was voluntary and that participants can withdraw from the study at any time without giving a valid reason to do so (see Appendix A). The study was reviewed and approved by the BMS ethics committee from the University of Twente.

Table 1.

Demographic Representation of the sample (N=30).

Sr.no	Country	No. of Participants
1.	India	18

2.	Indonesia	5
3.	Mexico	2
4.	Egypt	1
5.	Turkey	1
6.	China	1
7	Sri Lanka	1
8.	Surinam	1

2.2.4. Data Analysis

Data were analyzed using SPSS for each questionnaire, as in Part 1. A Shapiro-Wilk normality test was done, and an appropriate analytic approach was chosen based on the findings. If the data were normally distributed ($p > 0.05$), a paired samples t-test comparing before and after VR conditions was performed. The Wilcoxon signed rank test was applied if it varied from a normal distribution ($p < 0.05$). For *Subjective Vitality*, in SPSS, the scale's negatively stated item ("I don't feel very energetic") was inverted. Then, before and after applying the VE, means and standard deviations were computed and presented, along with the t-value and significance of the change in means. To test effect size, Cohen's *d* was measured for normally distributed data. In case of unequal distributed data, matched pairs rank-biserial correlation was conducted. To calculate it, the data from Wilcoxon signed rank test was used. First, the sum of total ranks was calculated i.e., positive and negative ranks. This sum was used to divide with the sum of positive and negative ranks. Followed by subtracting the positive outcome from the negative outcome. For *Perceived Academic Stress Scale,* the items were reversed 1-5 and the scoring was conducted. For *Acculturative Stress Scale for International Students,* mean of all the subscales were calculated. Furthermore, to measure how large the effect was between the pre and post-test, Cohen's *d* was conducted if the data was normally distributed for Acculturative Stress and Academic Stress.

3. Results

This section has demonstrated differences in the levels of presence in two prototypes i.e, WN and BWN. Followed by, examination of the feasibility and user experiences. The data analysis of the above mentioned constructs have answered the aims of Part 1. Furthermore, differences in subjective vitality, acculturative stress and academic stress on pre and post-tests was also discovered. The results of these constructs have answered the research questions of Part 2.

3.1 Analysis of Usability and Feasibility for Prototype BWN

Background Questionnaire

The results from the background questionnaire are presented below in Table 2. Familiarity with VR shows average mean score with quite deviations between the scores, enjoying walks in nature had a high mean score with fewer deviations. Lastly, the stress question produced an average mean with quite deviations as well.

Table 2.

Results from the background questionnaire (N=18)

	M	*SD*	Score Range*
Familiarity with VR	2.44	1.24	1 – 5
Enjoyment of walking in nature	4.55	0.65	3 – 5

Current Stress Level	2.05	1.39	1 – 5

**Possible range: 1 – 5*

Immersive Tendencies Questionnaire

The results for imaginative immersion before exposure to the prototypes of VEs are presented in Table 3. When compared to the norms by Robillard et al. (2002), the majority of the subscales – *Involvement, Emotion* and *Game* are higher. Except for subscale *Focus*, the mean for this subscale is lower than the norm which entails the participants will get distracted easily when compared to the norm. The total ITQ mean was significantly higher than the norm.

Table 3.

Imaginative immersion scores before the VE exposure (N = 18) and the norm group by Robillard et al. (2002).

	Sample			Norm Group		
	M	*SD*	Score range	*M*	*SD*	*t*-test
Focus	23.44	4.56	12-31	24.81	7.54	-1.26
Involvement	21.00	5.16	8-31	15.33	8.67	4.65*
Emotion	16.16	5.34	7-24	14.25	6.70	1.52
Game	11.22	4.27	3-19	6.56	4.95	4.62
Total	71.83	13.15	36-100	64.11	13.11	2.49*

*$p<0.05$

Presence Questionnaire

The Presence Questionnaire was administered after exposing the participants (*N*=18) to Prototype WN and it was also administered after exposing the Prototype BWN to check if there was any difference in presence between the prototypes (See Table 4). According to the results, there was higher presence in Prototype BWN. However, based on subscale scores, possibility to examine have lower scores compared to the norms for both prototypes. Similarly, within the prototypes, Prototype WN has higher haptic and possibility to examine higher than Prototype BWN. It means that Prototype WN had better points of examination with multiple viewpoints and participants were able to concentrate more on the tasks rather than the mechanisms of the given tasks as well as auditory stimulation was better. On the other hand, subscales – realism, possibility to act, quality of interface, self-evaluation of the performance, sounds and the total for the presence was higher in Prototype BWN.

Table 4.

Presence scores after the VE exposure (N = 18),the norm group by Robillard et al. (2003) and Paired t-test.

	Prototype A		Prototype B				Norms	
	M	*SD*	*M*	*SD*	Paired *t*-test	Score Range	*M*	*SD*
Realism	35.66	5.78	37.94	4.98	-1.130	24 – 44	28.9	5.5
Possibility to Act	19.61	4.85	21.38	4.40	-1.277	11 – 25	22.2	4.6
Quality of Interface	10.61	5.37	14.22	4.09	-3.111*	12 – 21	16.2	3.0
Possibility to Examine	15.50	3.41	15.05	2.60	.517	8 – 20	15.7	2.1

Self-Evaluation of Performance	11.05	2.55	11.44	1.19	-.534	7 – 14	11.5	2.1
Sounds	16.16	2.72	16.27	2.78	-.179	9 – 21	13.3	5.5
Haptic	9.88	2.63	9.66	2.49	.337	2 – 14	5.8	3.5
Total	118.50	18.45	126.00	13.01	-1.641	96 – 153	93.7	11.2

**Note. $p < 0.05$*

System Usability Scale

The results from the System Usability Scale for BWN Prototype show the mean and standard deviations are significantly higher than the norm (see Table 5). The norms were taken from a study conducted by Maarsingh et al., 2019. A score of 51.0 is regarded as low, a number between 51.0 and 80.3 is considered adequate but improvable, and a score more than 80.3 is considered excellent. A high score implies that participants are likely to actively discuss the tested technology (Maarsingh et al., 2019). The mean score is 87.08 which indicates a high score in the sample population.

Table 5.

System Usability Scale scores (N=18) and norms provided by Maarsingh et al, 2019.

	Sample		Norm		
	M	*SD*	*M*	*SD*	*t*-test
System Usability Scale	87.08	13.48	80.50	10.60	2.07*

**$p<0.05$*

Satisfaction Survey for Feasibility

The results from this survey showed higher mean values with fewer deviations when compared to norms provided by Migoya-Borja et al., 2020 (see Table 6). Except for item no.1, the mean value was lower than the norm. It means the sample found it a bit complicated to use the virtual environment for Prototype B. On the other hand, it scored higher in VE being engaging, matching the expectations of the sample group, higher satisfaction, higher usefulness and sample group scored higher in recommending the VE to others.

Table 6.

Satisfaction Survey scores (N =18) with norms provided by Migoya-Borja et.,al 2020.

Items	Sample		Norms	
	M	*SD*	*M*	*SD*
1. Was the VE easy to use?	0.94	0.23	0.96	0.19
2. Was the VE engaging/interesting?	1.00	0.00	0.89	0.31
3. Did the VE do what you expected?	0.94	0.23	0.84	0.37
4. Has VE changed the way you perceive deep and slow breathing?*	-	-	-	-
5. I find this breathing exercise enjoyable.*	-	-	-	-
6. I was able to focus on breathing without any distractions.*	-	-	-	-
7. Did you find it relaxing?*	-	-	-	-
8. Please rate your overall satisfaction with VE	4.33	0.68	3.92	1.02

9.	Please rate the usefulness of VE	4.33	0.68	3.74	1.24
10.	How much would you recommend this VE to others?	4.27	0.66	4.18	1.10

Items were added to make it more applicable to the sample and virtual reality technology, hence they do not have norms provided by Migoya-Borja et.,al 2020.

User Experiences

The overall impression of the VE prototypes was favorable, some of the examples were “beauty of nature, mountain, sunshine, loved the details like flowers and butterflies” (P1), “light breeze and ambient sounds along with it” (P3), “realistic views and dimensions then expected” (P15), “walking around in the nature and watching the sky especially” (P5), “very beautiful and calming” (P6). The VE as a whole had been well approved. It was described as realistic, soothing, peaceful, engaging, interesting, immersive, and stimulating. It was also described as a good representation of actual nature. The activities were described as enjoyable, intriguing, beneficial, engaging, and thrilling. Four participants preferred the butterfly activity, whereas three preferred the breathing exercises.

The key element most of the participants did not appreciate was the restricted room. Some participants recommended that the VR eyewear be more stable and clear. The biofeedback-based breathing tree task was disliked by one participant (Prototype BWN). 15 of the 18 participants. agreed that the VE promoted Subjective Vitality, one of them expressed it as “means for an individual to have their time of reality to feel better “ (P4), . Three participants disagree with VE enhancing subjective vitality because it requires improvement, real-life alternatives are superior, and realism is lacking.

Ten participants picked Prototype BWN for several reasons: it was more participatory than Prototype WN, and they liked the real-time feedback they received during the task. Eight participants chose Prototype WN because it took more time to get used to the tree's workings and controlling your breath to influence the tree's movements took away the enjoyment element. For some, it helped with the biofeedback technology because it made them focus more on breathing and it further enhanced their experience of relaxation. Furthermore, because of the real-time interaction, several respondents felt more connected and involved within the VE. (See Appendix H for more information on User Experiences).

3.2. Analysis of the Effectiveness Study

Subjective Vitality Scale

Owing to the non-normal distribution of the data, Wilcoxon signed rank test was used. As shown in Table 7, there was a significant increase in Subjective Vitality after exposure to Prototype BWN, 21 participants experienced increase in Subjective Vitality as compared to their pre-test. On the other hand, 7 participants experienced a decrease in Subjective Vitality as compared to the pre-test. Two participants scored similarly in the pre-posttest. Similarly, to examine the effect size, matched paired rank-biserial correlation was calculated. The effect size of Subjective Vitality was 0.53. The effect size falls under the moderate to large category, which means Prototype BWN had practical significance by enhancing subjective vitality in the international students when compared to pre-test conditions.

Table 7.

Scores of Subjective Vitality based on pre and post tests.

	Sum of Positive Ranks (W+)	Sum of Negative Ranks (W-)	Ties	*p* value
Subjective Vitality	21	7	2	0.01*

* *P<0.05*

Acculturative Stress Scale for International students

The data was normally distributed, hence Paired Samples *t*-test was conducted. There were drop in the mean scores of the subscales and total after the sample was exposed to Prototype BWN. Subscales like *Perceived Discrimination, Homesickness, Perceived Hate, Fear and Stress due to change*s scored lower than pre-test. Additionally, the total score of Acculturative Stress Scale also scored significantly lower than pre-test. This signifies a drop in acculturative stress in the international students after they were exposed to Prototype BWN. Although, there is an increase in subscale Guilt after exposure to Prototype BWN. Cohen's *d* was calculated and the point estimate value was 0.45, which shows a small effect size. In conclusion, Prototype BWN helped in alleviating acculturative stress in the international students when compared to pre-test conditions (see Table 8).

Table 8.

Scores of Acculturative Stress Scale for International students (N=30) and paired samples t-test between both Prototype A & B.

	Pre-test		Post-test		
	M	*SD*	*M*	*SD*	Paired Samples *t*-test
Perceived Discrimination	75.64	17.50	68.72	21.52	1.92
Homesickness	10.37	2.85	9.66	3.34	1.92
Perceived Hate	9.12	3.19	8.08	3.09	1.80
Fear	6.33	2.01	5.58	2.50	1.77*
Stress due to change	6.91	2.37	6.16	2.33	1.64
Guilt	4.50	1.58	4.62	0.40	-0.31
Miscellaneous	21.08	6.56	19.20	7.66	1.72
Total	75.64	17.05	68.72	21.52	2.27*

*$p<0.05$

Perceived Academic Stress Scale

The paired *t*-test was conducted on the normally distributed data. The results were *N* = 30, *M*= 60.55, *SD*= 14.27 for before exposing Prototype BWN, similarly for after exposing to

Prototype BWN *M*= 55.46, *SD* = 12.31 and the results of *t*-test were 1.79 ($p < 0.05$). The effect size was 0.32 calculated by Cohen's *d.* The effect size was small, but the scores are lower for post-test scores when compared to pre-test scores. In conclusion, Prototype BWN had a positive impact on perceived academic stress by reducing it when compared to pre-test conditions.

4. Discussion

This section was divided based on the aims and research questions of the current study for a better insightful understanding and comprehension of the results. Starting with:

Confirmation of the Aim: To further develop the 'Walk in Nature' VE to a Biofeedback based 'Walk in Nature' VE

Regarding the first aim of the study, developing an already existing prototype had saved lead times and costs associated with a new product development (Gibson, 2006). As said by Stoimenova et.(2022), "Prototypes should provide help in discovering new aspects of the problem at hand and support the invention of design requirements." The development process gave birth to a fully functional respiratory biofeedback virtual environment. The environment had successfully installed a real-time interaction between the participant and breathing tree in the VE. Although, there was still a need to develop a more refined and smooth biofeedback loop due to reasons such as, first, the sensitivity of the nasal sensor. The sensitivity contributed to baseline drifts and inconsistent measurements of the airflow values. This made the tree movements abrupt and fast when the measurements were out of the preliminary tested values, even when some participants indulged in deep breathing it was not translated into the system which caused inconsistencies. Second, the nasal sensor was displaced from its optimum position after wearing the VR headset and it had to be adjusted if measurements were inconsistent which resulted in tree movements being slow. This also contributed to disruption in their gamified experience. Additionally, the chair was placed within the virtual environment parameters for the breathing tree exercise and the participants had to be guided, so they could sit on the chair which again disrupted their experience. The nasal sensor was connected to the MySignals hardware with a wire, which was also a contributing factor for the breathing exercise to be conducted while sitting to avoid tripping on the wires.

Confirmation of the Aim: To examine the usability of the biofeedback based VE

The usability of the prototype BWN was examined based on the aspects of immersive tendencies of the sample, followed by a comparative study that measured differences in the levels of sense of Presence in Prototypes, BWN and WN. The Immersive tendencies showed higher immersion tendencies in the sample compared to the norms provided by Robillard et.al.(2002). A participant who had highly immersive tendencies felt more present in the virtual environment and enjoyed the experience more than a participant who does not often become immersed in activities (Wang et al., 2015). Having a highly immersive sample gave them an upper hand, in experiencing a higher sense of presence, as the ability to feel immersed is tied to the ability to feel present (Khashe et al., 2018). This also explained higher sense of presence levels in the sample compared not only to norms provided by Robillard et al. (2003), but also to the scores of prototype WN. Amongst which the Quality of Interface was improved in Prototype BWN based on the significantly higher scores on the same subscale. This also added further evidence on the benefits of using biofeedback technology to help with increased presence within the VE. To add more to this evidence, the System Usability Scale scores were high (87.08%), indicating a high degree of acceptability, ease of use, learnability, and confidence when using the system.

Confirmation of the Aim: To examine feasibility of the biofeedback based VE

Based on Satisfaction Survey for Feasibility, users were quite satisfied with the biofeedback based VR intervention. It was deemed beneficial and user-friendly by participants. The response from participants shows that the VE is a potentially beneficial tool for increasing subjective vitality and reducing stress levels in university students. Additionally based on user experiences, 15 participants out of 18 found the VE to be effective in enhancing Subjective Vitality. Based on the feedback, 10 participants found Prototype BWN to be more effective in increasing subjective vitality due to its real-time breathing feedback. While eight participants chose Prototype WN, as they took time to get accustomed to the mechanism of biofeedback and erratic movements of the tree made it difficult to relax in Prototype BWN. A fundamental disadvantage of all existing clinical VR research has been the lack of meaningful end user involvement from intervention design through adoption and deployment of VR technology (Tennant et al., 2020), current study had the goal of involving users in the process of development and design. This was inculcated by employing the prototyping system and each prototype was aimed at improving based on user experiences and scientific evidence. Although, the problem of limited space still remained unsolved and this problem was highlighted yet again in the user experiences, as they wished to explore virtual nature, move around freely without being consciously aware about their surroundings or bumping into a wall or an object.

Results to the Research Question: Do international students report an increase in subjective vitality after using the biofeedback based VE?

The results depicted a significant increase in subjective vitality after biofeed based intervention using the Prototype BWN when compared to the pretest values. It also adds to the existing literature which says parks and forests offer restorative experiences that boost psychological and physiological health, facilitate attentional fatigue recovery, reduce psychophysiological stress, and enhance good emotional states (Hartig et al., 2003; Tyrväinen et al., 2014). Multiple participants expressed feeling away from their daily activities and thoughts momentarily which helped them relax and restore their mental state. It was also consistent with the finding of study conducted by Bareišytė (2021), although this prototype used to make developmental changes which were aimed at improving the presence by addition of Biofeedback technology in the breathing exercise. This technology has also contributed to an increase of subjective vitality, as feelings of vitality are assumed to be impacted not just by bodily experience, but also by how the incident is interpreted as beneficial or detrimental to the self (Ryan and Frederick 1997). In this study, participants perceived biofeedback technology as beneficial and meaningful which helped them relax and restore by practicing in deep and slow breathing. Furthermore, international students have fewer time resources which leads to negligence of physical activity. In this intervention, physical activity was instilled in the participants which also resulted in an increase in subjective vitality. This was consistent with previous empirical findings by Hurtig-Wennlof et al. (2014) that suggested physical activity had a positive impact on subjective vitality. The documented increase in vitality made VR technology appealing, especially applicality on a study or work day: significant benefits were acquired quickly without leaving the room. This intervention was also focused on healthy university students, it was short and effective in providing results which is the best solution for university students with limited resources to practice in the physical world.

Results to the Research Question: Do international students report a decrease in acculturative stress and academic stress after using the biofeedback based VE?

The results show a significant decrease in acculturative stress and perceived academic stress in the sample. Adding evidence to the existing literature, which examined VR research that compared the objective and subjective benefits of relaxing and reduction in stress via VR with nature scenes versus ones with interior settings (Anderson et al.2017). Additionally, a study conducted by Jo et al. (2021) discovered that watching forest videos in VR gave college students a state of immersion and focus, i.e. attention, as well as a physiologically favorable influence on stress. Reduced levels of acculturative stress, also in subscales of perceived discrimination, homesickness, percieved hate, fear and stress due to changes. This study showed a gamified walk in nature can contribute to reduction of acculturative stress in international students. Although an increase in the subscale of guilt was observed, the guilt subscale focused on differences in the quality of lifestyle, resources, environment and materials compared to the foriegn country the person is residing versus their home country which leads to feelings of guilt if their friends and family fail to experience the similar quality of the above mentioned factors in their home country.. According to the researcher, such an increase might have stemmed from feeling guilty to experience the beautiful and restorative landscapes, while their family and friends are not enabled to experience the same.

Furthermore, various studies have discovered that natural elements such as grass, shrubs, and natural plants have a great potential to be incorporated as one of the components to aid in the stress reduction process (Jerčić & Sundstedt, 2019). The perceived academic stress was also reduced. Slow and deep breathing has a positive impact on stress caused by academics, using biofeedback to foster this breathing has been proven beneficial. Additionally, Biofeedback techniques are becoming a learning tool that ordinary people may use to manage everyday stress, rather than only a therapy for medical conditions (Yu et al., 2018).

Strengths and Limitations

This study was an impactful advancement towards integrating not only VR in the mental and physical well-being sphere, but also, introducing biofeedback technology. Firstly, this study depicts the iterative process from designing to the development i.e., improvements and new technological additions to Prototype WN which transformed into Prototype BWN. Secondly, this prototyping technology has led to a formation of a pipeline for all the improvements, requiring hours to complete the additions to VE, focus points, solutions and arguments, settings and equipment. This streamlining led to a collaborative environment for the technical professionals to translate these visions into real life to assist healthcare professionals. Thirdly, this study showcased how a multidisciplinary team can achieve more technological milestones benefiting human wellness. Fourthly, the developed Prototype BWN had more sense of presence compared to Prototype WN, highlighting the improvements were made in the right direction. These improvements were also largely perceived as usable and feasible. The study proved to increase Subjective Vitality, reduce acculturative stress and perceived academic stress in the international students, adding more to the limited available literature on using biofeedback based VE for holistic wellness. The developed VE also replicates real nature environments, participants enjoyed taking the initial walk in the VE based on user experiences. This might have also contributed to the restorative effect. Similarly, Reese et al. (2022) believed that exposure to virtual nature and emphasizing the importance of nature for well-being may create the perception that nature requires preservation. Similarly, (actual and virtual) nature encounters can boost connectivity to nature, which is strongly linked to both well-being and pro-environmental behavior. To increase pro-environmental behavior in the university students can lead to greater benefits to society as well. Finally, one of the biggest strengths was developing an intervention solely for fostering subjective vitality which was rare. Additionally, an intervention which was developed using VR and biofeedback technology makes this study one of its kind.

This study came with some limitations. Starting with the Biofeedback technology, the nasal sensor can be replaced with better equipment like chest belts which helps in filtering out inconsistent data in-put and precisely measures diaphragmatic movements by helping the movements of the tree within the VE to run smoothly. Furthermore, the mathematical model can also have an addition of a calibration function to further smoothen the animations of the tree by automatically setting the preliminary breathing values per participant. Furthermore, these strategies teach self-regulation in peaceful, controlled settings, which may not translate to real-world stressors (Jerčić & Sundstedt, 2019). Lastly, Biofeedback technology can be foreign to individuals with no past experience with it, hence an introductory training with this technology will help participants get habituated and use it efficiently. On the other hand, the study can also employ participants with intermediate level of experience with VR and biofeedback. Furthermore, SUS are majorly used in industrial engineering to give a rapid and reliable evaluation of users' perceived utility of a technical system (Apostolidis et al., 2021). There needs to be a tool developed for biofeedback technology for behavioral sciences in the field of virtual reality to give us more in-depth analysis of the usability. The Acculturative Stress Scale for International Students is 36 item scale with complex scoring system, as well as Perceived Academic Scale is 18 item scale. A smaller scale would be efficient for the participants to answer pre and post. These scales are also chronic states measurements, a momentary state measurement of stress would also be beneficial to examine any immediate effect on the stress levels. The sample group can be larger including more diversified nationalities to explore different outcomes. Despite the practicality of using respiratory biofeedback to improve breath awareness, practical and cost restrictions have limited the use of respiratory biofeedback to clinical or laboratory settings thus far (Blum et al., 2020). Sensors, interfaces, and software setup and integration are all expensive. Furthermore, the measurement is frequently intrusive (e.g., facial mask for airflow monitoring, nose sensors) and may scare the user, undermining the exercise's relaxing aims. This study also did not use a control group, although this limitation might have been overcome due to following reasons: the study conditions were under control (for example, a designated room with proper equipments and sensors were used), these conditions were such that they were isolated from the outside environment and the pretest posttest were conducted in a very short period of time i.e, 15 minutes difference in them.

Future Directions

VR technology provides inherent benefits for improving mental health, with high ecological validity in scenario presentation, data collecting, evaluation and intervention of physical and mental states, and so on (Wang et al., 2022). Furthermore, physical and mental states would be tested in interactive VR situations, resulting in multimodal indications and rich complete models of humans, technologies, and environments (Wang et al., 2022). Additionally, the spatial arrangement for room-scale tracking must be considered (Rockstroh et al., 2020). For example, walking in a circle rather than back and forth might provide a better sense of continuity and so coherence. It must be determined whether this possible impact outperforms the possibly distracting demand for navigation as well as the requirement for wider real-world environments with curves rather than simple straight lines. Similarly, current technologies which address limited space mobility with VR are Redirected walking, Walk-in-place, Stepper Machines like Virtualizer, Point & Teleport and Flying. In walk-in-place, the user marches in the same spot without moving forward or backward, the locomotion direction is either the torso direction or the head direction, and the walking pace is determined by the frequency of the steps (Slater et al., 1995). This could be a good adaptation in the next prototype, as it is said to be very similar to real-life walking (Bozgeyikli et al., 2019). As discussed, the sensitivity of the nasal sensor caused abrupt movements, this could be avoided with installation of a band pass filter; it allows signals within a specific frequency range to be heard or decoded while blocking signals at undesirable frequencies (Contributor, 2006). To rectify this issue, using wireless connection would be beneficial. It is mostly used to improve the quality of healthcare systems, as they offer various benefits over typical wired systems, including the following: simplicity of use, decreased risk of failure, decreased user pain, increased mobility, and decreased cost of care delivery (Zubiete et al., 2011). To improve the virtual experience, one can also use chest belts that measure chest extraction and contractions, they also use multiple filters to smoothen the signals received by removing baseline drifts and inconsistent measurements (Lux et al., 2018). The current study used wired technology, both for sensors and VR headset. Making biofeedback sensors bluetooth or Wifi based will increase mobility in participants, similarly with HMD, currently Oculus devices can run wireless on Wifi. This should further be explored. Using different physiological parameters for biofeedback can also be considered, for example, Galvanic Skin Response can be used to study responses throughout the intervention. Additionally, these inputs can be used to manipulate weather inside the VE and examine the perceived effect on the mood, stress level and subjective vitality. Recruiting participants having experience with VR will help in getting insights and suggestions in technological improvements and better user experiences. This study's participants had no prior experience with biofeedback. A more in-depth instructional training session before treatment, as well as frequent practice, may help to resolve this difficulty. Furthermore, whether MySignal Airflow as a biofeedback sensor, as well as the particular protocol and computing technique, is the ideal choice for the examination of physiological data for restorative purposes remains debatable. Different biosensors must be explored.

A study can be conducted to explore with and without biofeedback VE, to examine if biofeedback has any impact on subjective vitality. In conclusion, this research shows how biofeedback may be incorporated into realistic restorative VR simulations. The design decisions were influenced by the goal of providing a realistic and healing environment with meaningful opportunities to incorporate physiological data. Finally, although this study does not convey that VR technology can or should replace actual encounters in nature, but it offers up opportunities for new groups of people to reap similar advantages. Providing good and memorable experiences may enable people to connect with nature and real-world situations. It is not desirable for people to travel indefinitely, but VR technology might provide experiences of many places and natural environments on a sustainable basis (Mavilidi et al., 2020). Long term effects of this environment on subjective vitality and stress should also be explored. Another intriguing study option is personalization of VR environments: there have been several studies on people's favorite locations, and it is possible that the reported advantages of the VR forest might be much more significant if the users' particular preferences were taken into account (Mattila et al., 2020).

Conclusion

This study started with improvements and additions to an already existing Walk in Nature VE. This Prototype WN was the foundation on which improvements and additions were built on. This prototyping technology has been proved to be beneficial in developing a VE more effective, usable and feasible. The aims of Part 1 had been successfully achieved and delivered. The usability testing led to discovery of higher presence in Prototype BWN. Although, user experiences were mixed. Inputs from these user experiences can lead to better technological improvements towards the development of a more effective intervention to increase subjective vitality. Similarly, this technology also contributed to increasing presence. The Part 2 of the study was to study the effectiveness of Prototype BWN in impacting subjective vitality and stress. According to the results, there was an increase in subjective vitality after the intervention and decrease in acculturative stress and perceived academic stress. The research questions of this part were examined and answered in a positive outcome.

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Appendix A

PARTICIPANT INFORMATION SHEET

PURPOSE OF THIS STUDY:

The study focuses on improving the subjective vitality in the international students using biofeedback based virtual nature environment. Subjective vitality refers to the state of feeling alive and alert–to having energy available to oneself. Biofeedback involves using painless sensors to measure certain bodily functions, these measures will be represented to you and you will be guided to enhance the measures.

BENEFITS OF THIS STUDY:

A previously conducted study by Lina Bareistye at University of Twente on subjective vitality and virtual environment has been proven effective to improve the sujective vitality. This study will be using the same virtual environment with further improvements.
One of the tasks in this intervention also includes diaphragmatic breathing, it promotes relaxation, increases oxygen in blood, reduces blood pressure and improves stability in the core muscles.

RISKS OF PARTICIPATING:

This project has been reviewed and approved by the BMS Ethics Committee (Domain Humanities & Social Sciences). Although, it is better to inform the researcher if you experience motion sickness, epilepsy, special sensitivities to rapidly changing light, or if you are pregnant.

WITHDRAWAL FROM THE STUDY:

To withdraw from this study, you should inform the researcher by email or verbally. Your participation is voluntary and you can withdraw from the study up to the point of completion, without having to give a reason and without any consequences.

DATA USAGE AND PERSONAL INFORMATION:

The personal information will be stored anonymously and will be confidential. This information will be processed and retained anonymously in University of Twente, there are no external recipients. The information collected during this study will be taken in a form of questionnaires and bodily measurements, primarily breathing. The participant has the right to request access to and rectification or erasure of personal data.

Study contact details for further information:
Divya Ahire, d.ahire@student.utwente.nl
Contact Information for Questions about Your Rights as a Research Participant
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities &

Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves data collected from me in terms of questionnaires and bodily measurements, such as breathing. I am also aware about the painless sensor which will be used on me during this study. I am also aware that I will be answering the questionnaires to the best of my ability.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for only for research outputs	☐	☐
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted in research outputs.	☐	☐
Future use and reuse of the information by others		
I give permission for the information gathered from questionnaires and body sensors that I provide to be archived in University of Twente so it can be used for future research and learning.	☐	☐

Signatures

________________________ ________________________

Name of participant Signature

Date:

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

___________________________ ____________________ _________

Researcher name Signature Date

Appendix B

Immersive Tendencies Questionnaire original by Witmer & Singer (1998), revised and translated by Robillard et al. (2002).

Indicate your preferred answer by marking an "X" in the appropriate box of the seven-point scale. Please consider the entire scale when making your responses, as the intermediate levels may apply. For example, if your response is once or twice, the second box from the left should be marked. If your response is many times but not extremely often, then the sixth (or second box from the right) should be marked.

1. Do you easily become deeply involved in movies or tv dramas?

   |________|________|________|________|________|________|________|
   NEVER OCCASIONALLY OFTEN

2. Do you ever become so involved in a television program or book that people have problems getting your attention?

   |________|________|________|________|________|________|________|
   NEVER OCCASIONALLY OFTEN

3. How mentally alert do you feel at the present time?

   |________|________|________|________|________|________|________|
   NOT ALERT MODERATELY FULLY ALERT

4. Do you ever become so involved in a movie that you are not aware of things happening around you?

   |________|________|________|________|________|________|________|
   NEVER OCCASIONALLY OFTEN

5. How frequently do you find yourself closely identifying with the characters in a storyline?

   |________|________|________|________|________|________|________|
   NEVER OCCASIONALLY OFTEN

6. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?

   |________|________|________|________|________|________|________|
   NEVER OCCASIONALLY OFTEN

7. How physically fit do you feel today?

|________|________|________|________|________|________|________|
NOT FIT MODERATELY FIT EXTREMELY FIT

8. How good are you at blocking out external distractions when you are involved in something?

|________|________|________|________|________|________|________|
NOT VERY GOOD SOMEWHAT GOOD VERY GOOD

9. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

10. Do you ever become so involved in a daydream that you are not aware of things happening around you?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

11. Do you ever have dreams that are so real that you feel disoriented when you awake?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

12. When playing sports, do you become so involved in the game that you lose track of time?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

13. How well do you concentrate on enjoyable activities?

|________|________|________|________|________|________|________|
NOT AT ALL MODERATELY WELL VERY WELL

14. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

15. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

16. Have you ever gotten scared by something happening on a TV show or in a movie?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

17. Have you ever remained apprehensive or fearful long after watching a scary movie?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

18. Do you ever become so involved in doing something that you lose all track of time?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

Appendix C

Presence Questionnaire original by Witmer & Singer (1998), revised and translated by Robillard et al. (2002).

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT:

1. How much were you able to control events?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

|________|________|________|________|________|________|________|

NOT RESPONSIVE MODERATELY RESPONSIVE COMPLETELY RESPONSIVE

3. How natural did your intentions with the environment seem?

|________|________|________|________|________|________|________|

EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

4. How much did the visual aspects of the environment involve you?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

5. How natural was the mechanism which controlled movement through the environment?

|________|________|________|________|________|________|________|

EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

6. How compelling was your sense of objects moving through space?

|________|________|________|________|________|________|________|

NOT AT ALL MODERATELY COMPELLING VERY COMPELLING

7. How much did your experiences in the virtual environment seem consistent with your real world experiences?

|________|________|________|________|________|________|________|
NOT MODERATELY CONSISTENT VERY CONSISTENT

8. Were you able to anticipate what would happen next in response to the actions that you performed?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

9. How completely were you able to actively survey or search the environment using vision?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

10. How compelling was your sense of moving around inside the virtual environment?

|________|________|________|________|________|________|________|
NOT AT ALL MODERATELY COMPELLING VERY COMPELLING

11. How closely were you able to examine objects?

|________|________|________|________|________|________|________|
NOT AT ALL PRETTY CLOSELY VERY CLOSELY

12. How well could you examine objects from multiple viewpoints?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

13. How involved were you in the virtual environment experience?

|________|________|________|________|________|________|________|
NOT INVOLVED MILDLY INVOLVED COMPLETELY INVOLVED

14. How much delay did you experience between your actions and expected outcomes?

|________|________|________|________|________|________|________|
NO DELAYS MODERATE DELAYS LONG DELAYS

15. How quickly did you adjust to the virtual environment experience?

|________|________|________|________|________|________|________|
NOT AT ALL SLOWLY LESS THAN ONE MINUTE

16. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

|________|________|________|________|________|________|________|
NOT PROFICIENT REASONABLY PROFICIENT VERY PROFICIENT

17. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|________|________|________|________|________|________|________|
NOT AT ALL INTERFERED SOMEWHAT PREVENTED TASK PERFORMANCE

18. How much did the control devices interfere with the performance of assigned tasks or with other activities?

|________|________|________|________|________|________|________|
NOT AT ALL INTERFERED SOMEWHAT INTERFERED GREATLY

19. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED SOUNDS:

20. How much did the auditory aspects of the environment involve you?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

21. How well could you identify sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

22. How well could you localize sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED HAPTIC (SENSE OF TOUCH)

23. How well could you actively survey or search the virtual environment using touch?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

24. How well could you move or manipulate objects in the virtual environment?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

Appendix D

System Usability Questionnaire

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system					

Appendix E

Subjective Vitality Scale by Ryan and Frederick (1997).

On a scale from 1 = “not at all true” to 7 = “very true” describe your feelings at this moment.

1. I feel alive and vital
2. I don’t feel very energetic*
3. Sometimes I am so alive I just want to burst
4. I have energy and spirit
5. I look forward to each new day
6. I nearly always feel awake and alert
7. I feel energized

*Reversed item

Appendix F

<u>Acculturative Stress Scale for International Students</u>

As foreign students have to make a number of personal, social, and environmental changes upon arrival in a strange land, this *cultural-shock* experience might cause them acculturative stress. This scale is designed to assess such acculturative stress you personally might have experienced. There are no right or wrong answers. However, for the data to be meaningful, you must answer each statement given below as honestly as possible.

For each of the following statements, please circle the number that BEST describes your response. 1= Strongly Disagree, 2= Disagree, 3= Not Sure, 4= Agree, 5= Strongly Agree.

Because of my different cultural background as a *foreign* student, I feel that:

1) Homesickness for my country bothers me.	1	2	3	4	5
2) I feel uncomfortable to adjust to new foods and/or to new eating habits.	1	2	3	4	5
3) I am treated differently in social situations.	1	2	3	4	5
4) I feel rejected when people are sarcastic toward my cultural values.	1	2	3	4	5
5) I feel nervous to communicate in English.	1	2	3	4	5
6) I feel sad living in unfamiliar surroundings here.	1	2	3	4	5
7) I fear for my personal safety because of my different cultural background.	1	2	3	4	5
8) I feel intimidated to participate in social activities.	1	2	3	4	5
9) Others are biased toward me.	1	2	3	4	5
10) I feel guilty to leave my family and friends behind.	1	2	3	4	5
11) Many opportunities are denied to me.	1	2	3	4	5
12) I feel angry that my people are considered inferior here.	1	2	3	4	5

13) I feel overwhelmed that multiple pressures are upon me after my migration to this society.	1	2	3	4	5
14) I feel that I receive unequal treatment.	1	2	3	4	5
15) People from some ethnic groups show hatred toward me nonverbally.	1	2	3	4	5
16) It hurts when people don't understand my cultural values.	1	2	3	4	5
17) I am denied what I deserve.	1	2	3	4	5
18) I have to frequently relocate for fear of others.					
19) I feel low because of my cultural background.	1	2	3	4	5
20) I feel rejected when others don't appreciate my cultural values.	1	2	3	4	5
21) I miss the country and people of my national origin.	1	2	3	4	5
22) I feel uncomfortable to adjust to new cultural values.	1	2	3	4	5
23) I feel that my people are discriminated against.	1	2	3	4	5
24) People from some other ethnic groups show hatred toward me through their actions.	1	2	3	4	5
25) I feel that my status in this society is low due to my cultural background.	1	2	3	4	5
26) I am treated differently because of my race.	1	2	3	4	5
27) I feel insecure here.	1	2	3	4	5
28) I don't feel a sense of belonging (community) here.	1	2	3	4	5
29) I am treated differently because of my color.	1	2	3	4	5
30) I feel sad to consider my people's problems.	1	2	3	4	5
31) I generally keep a low profile due to fear from other ethnic groups.	1	2	3	4	5

32) I feel some people don’t associate with me because of my ethnicity.	1	2	3	4	5
33) People from some other ethnic groups show hatred toward me verbally.	1	2	3	4	5
34) I feel guilty that I am living a different lifestyle here.	1	2	3	4	5
35) I feel sad leaving my relatives behind.	1	2	3	4	5
36) I worry about my future for not being able to decide whether to stay here or to go back.	1	2	3	4	5

Appendix G

Adapted version of Satisfaction Scale

1. Was the virtual environment (VE) easy to use? (yes=1, no=0)
2. Was the virtual environment engaging/interesting? (yes = 1; no = 0)
3. Did the VE do what you expected? (yes = 1; no = 0)
4. Has VE changed the way you perceive deep and slow breathing? (yes = 1; no = 0) Did you find it relaxing? (scale 1–5)
5. Please rate your overall satisfaction with the session (scale 1–5)
6. Please rate the usefulness of the VE. (scale 1–5)
7. How much would you recommend this VE to others? (scale 1–5)

Appendix H

Design and Development of the Prototype BWN

**Note:* During the developmental stages, the Prototype WN was called Prototype A, while Prototype BWN was called Prototype B.
Introduction:

Design: Improvements and additions

The design of the VE was based on improvements and further additions to the existing Prototype "*Walk in Nature*" developed by Lina Bareišytė (Lina Bareišytė, 2021). This Prototype was a gamified walk in nature virtual environment and it will be called Prototype A as a point of reference. The improvements were decided based on past user experiences, results, suggestions and current researcher's personal observations and experiences. The improvements were fourfold. Starting with the Breathing Tree task, this task was psychological in nature, the participants were asked to breathe life into the death tree. The tree changed from gray to green. This transition was automatic and it had no inputs from the participants, although they were asked to press a button when they inhale and release the button when they exhale. These presses were not responsible for any movement inside the environment. The improvements for this task was to design a real time interaction between the participant and VE. Biofeedback technology was employed for this task. One of the most difficult design issues for researchers is deciding which physiological activity to employ as a source for a certain biofeedback system. They do so because of the intricate link between a psychological experience and physiological activity (e.g., cardiovascular activity as a proxy for stress), which is highly dependent on context (i.e., environmental effects) and may overlap with other phenomena (Lux et al. 2018). To increase the sense of presence and immersion, an interaction between the participant and VE through biofeedback was finalized, as biofeedback technology has been widely used to reduce stress and help in stress management (Lux et al., 2018). On the other hand, biofeedback based studies showed an improvement in relaxedness as well as reduction in anxiety and hypertension (Gardl et al., 2018). The participant's breathing inputs made a real-time interaction inside the VE by moving the tree (expanding and contracting) just like human lungs, metaphorically. While the movements are taking place the tree will grow greener and fresh by the end of the exercise. As this was a relaxation exercise, the usage of controllers were reduced to only starting the exercise to avoid any distractions. Feeling a device as embodied improves user engagement, technology acceptance, control transparency, and, as a result, human-machine system performance (Barresi et al., 2021). This was designed to enhance deep breathing in the participants. According to a study conducted in 2016 by Perciavalle et al., deep breathing can reduce perceived stress and improve mood and another comparable study conducted by Paul et al. showed significant improvement in academic performance in university students.

Second improvement was making the VE coherent to increase immersion. By coherent, it means to put all the exercises in a sequence in the same environment within the participant's reach. This improvement was crucial to eliminate outside assistance from the researcher which would make participants get back to the outer reality and outside the immersive VE. As in the previous study the researcher had to assist the participants to a certain position in the room to start each task due to limited space. The issue of limited space was solved by employing the Cyberith Virtualizer, a locomotion device which enables walking and running 360 degrees on a treadmill with belts to help individuals be at the centre while they are in a simulation like VR. Third improvement was making the instructions precise and clear for better understanding of which buttons do what function, it was very vague and unclear in the Prototype A. Lastly, the fourth improvement was to add voiceover prompts to motivate the participants in completing the tasks, as well as an addition of an arrow or indicator to help them move in the right direction of tasks.

Development: Technological requirements

A virtual reality system with highly detailed visual elements, spatialized sound, and haptic feedback (through vibrating controllers, for example) would be deemed more immersive than a scenario produced on a desktop monitor (Neo et al., 2021). This led to using the Oculus Rift S which inhibits the above mentioned factors. Biofeedback works on sensors which measure physiological changes. According to Lux et al. (2018), biofeedback is defined as the measurement of physiological activities and the generation of a feedback response that addresses at least one of a person's five senses (auditory, gustatory, olfactory, tactile, and visual) in order to cause a change in perception, behaviour, and physiological activity regulation. In this study, the primary focus is olfactory sense in the realms of deep breathing. Therefore, it will also be crucial to finalize the technology which will be employed to fulfil this function. Measuring physiological changes is just a first step in Biofeedback, the sensor provides the values which are transmitted to the hardware which depicts the measurements. These measurements are linked to the system and to create a real-time interaction, there needs to be software which will translate the incoming data into the virtual environment. Learning and assembling all the required resources is a time intensive task. The virtual environment was developed using Unity Game Engine version 2021.3.f1. The other improvements like task instructions, indicators/arrows, and putting all the exercises together was done on an existing Unity project, the Prototype A. Using the Cyberith Virtualizer came with the responsibility of getting accustomed to the technical workings of the machine, figuring out the connectivity of the machine to the computer within the Unity program along with real time connection of the biosensor.

Methods

This section describes the design process behind the improvements and additions to develop Prototype B. Followed by development of the designed blueprint using technological support.

Design

The goal of this study was to make improvements to the Prototype A. The outline of Prototype A was based on enhancing Subjective Vitality which had four tasks, starting with a walk in the nature to make participants habitual with the VE. Leading to a physiological well-being task, also known as Butterfly task, followed by a psychological well-being task i.e., Breathing tree task. Lastly, it consisted of a subjective vitality task also known as Yoga task. The current study concentrated on three tasks i.e., walk in the nature, physiological well-being and psychological well-being tasks. The additions and improvements in the VE –

Psychological Task

The psychological task was aimed to induce relaxation through breathing by visual representation of a dead-looking tree which turned greener as the participants progressed ahead with their slow-paced breathing. To make it interactive, button presses were involved by making the participants press a button while inhaling and leaving the button while exhaling. Although, these presses made no interaction in the VE. To make improvements in this task, crucial goal was to make this exercise more interactive to aid in the breathing practice. This was fulfilled by employing Biofeedback technology. It is a good way to give direction and reinforcement for emotional control to the physiological reaction by monitoring a person's measurable biological signals and communicating the information to the individual in real-time (Kotozaki et al., 2014). The measurable biological signal was respiratory inputs of the participants. These respiratory inputs were used to manipulate the tree movements in the environment. Along with the movements, the color saturation changed from grey to green based on the number of times the participants were able to create movements of expansion and contraction in the tree.

Physiological Task

The main goal of this task in Prototype A was to make all the butterflies fly away as fast as the participants can, by touching the butterflies with the controllers. This exercise was enjoyed the most by the participants in the last study which developed Prototype A. The interactive nature made this task more immersive. There two main improvements in this task. Firstly, to make the task objective more precise and concise with specific instructions on button presses of the controllers. These instructions were also pop-up in nature i.e., by pressing a button on the controller, the task objective will pop-up, irrespective of how far you are in the task. This was to eliminate any distractions from the outside variables like asking for assistance from researcher if the instructions are shown only once during the start. Minimal outer distracting stimuli was the goal. Secondly, increasing the number of butterflies within the task. This was to increase physical movement and interaction within the VE.

Other Improvements

The other goal was to make all the tasks more coherent, wherein all the tasks were placed along a route through the forest and each exercise would get activated once the participant arrived in the area of the task. This was designed to improve sense of presence within the participants, as in the Prototype A the researcher would have to take the participant to a specific position in the room to activate the task as well as be mindful of the limited space which hindered exploration of the VE. Each task was allotted specific duration. (Shown below)

Figure . *Initial Pictorial blueprint of the set-up*

Additionally, introducing arrows or indicators on this pathway to help and nudge participants 2towards the task was designed. This was like a subtle help if the participants get a bit lost in the direction. Along with this, the above discussed pop-up instructions were added to every task. (Shown below)

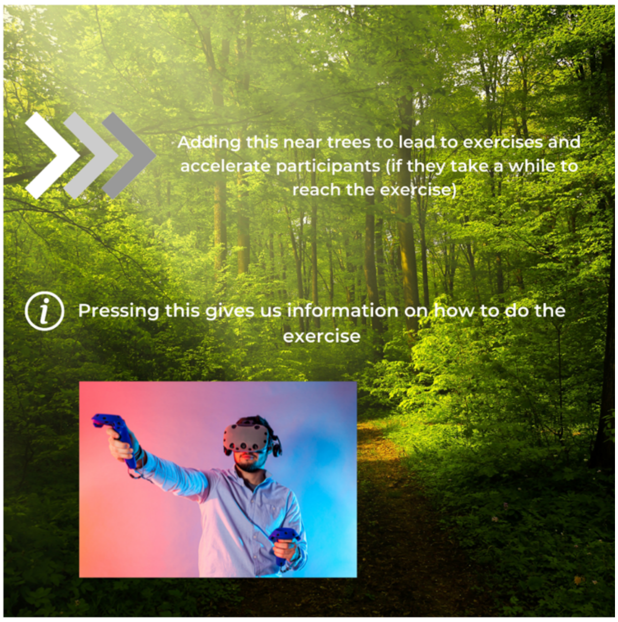


Figure. *Pictorial representation of the arrows and pop-up instructions*

Development

The development process was translating the above pictorial designs into the virtual environment. It was a dive into the technical aspects of this intervention which was to be perfected for a successful and effective intervention.

Psychological Task

To develop the biofeedback technology, acquiring the right sensors is important. For this study, MySignals Airflow sensor was used. This sensor consists of a flexible thread that fits behind the ears and two prongs that are inserted into the nostrils. These prongs are used to measure breathing. The specially constructed cannula/holder allows the thermocouple sensor to be put in the best position to detect changes in oral/nasal thermal airflow as well as nasal temperature air. This sensor will be connected to the sensor pinout development platform. The sensor was plugged in the connector represented by human lungs highlighted in green (See Figure 4). This development platform was connected to the computer with USB. The data was processed using Arduino Software IDE 1.8.19 which helps professionals build prototypes focusing on interactive technologies. Arduino software was used to interpret the data and a code was developed to use the incoming values which helped manipulate the tree movements. The code was written by Luci Rabago Mayer, although looking at different mathematical models to define the movements were done collaboratively with the researcher. A preliminary testing of the data set was performed to check regularities, upper and lower limit for the respiration rate. Based on the testing, lower limit of detected respiration rate was set at 0.5 W and upper limit was 3.5 W. The tree contracted when the readings of the sensor was 0.5 W and expanded when the reading was 3.5 W. Although, these readings varied from individual to individual, hence it was decided to do preliminary respiratory readings before the intervention so that the values are personalized in the VE and the movements are smooth.

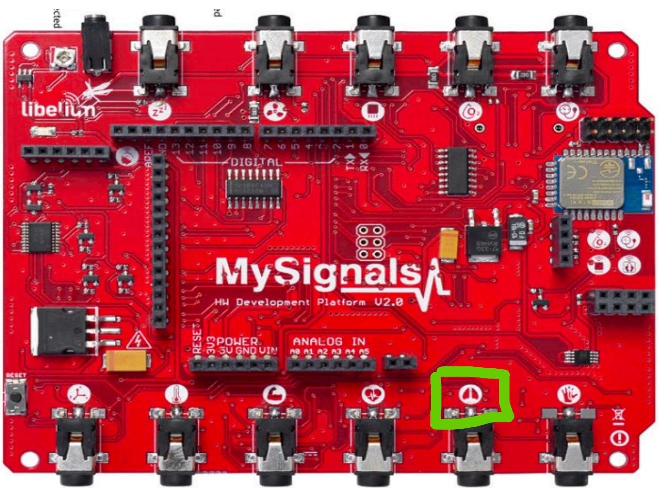


Figure. *The pinout development platform* (MySignals SW Technical Guide - MySignals, n.d.)

Physiological Task and Other Improvements

The task objective and increased butterflies was completed using Unity platform. Scenic updates like increasing trees, bushes and making the green terrain was also performed by the researcher. Although, using Cyberith Virtualizer was not taken ahead due to two reasons, the biofeedback loop of connection was wired, and it would have hindered the movements of the participants. The sensors are delicate and a sharp movement would snap the wires and disrupt the connection. After a preliminary testing of Cyberith Virtualizer, the walking felt forced and unnatural. It takes a while to get habituated to the walking on this locomotive device, this would make participants worked up rather than relaxed. The walk was aimed to be restorative and replication of a walk in the nature. This led to letting go of coherent experience of the virtual nature. Furthermore, the pop-up instructions and arrows/indicators were based on coherent tasks in the nature and it was also not taken further.

Experimental Set-up:

The Experiment took place in ManouVR lab at the BMS lab, University of Twente. The room with (insert dimensions) had designated seating space to fill up questionnaires and lab area for free body movement in the room to freely interact with the virtual environment. The questionnaires were represented using iPad 4 Air by Qualtrics Software (https://utwentebs.eu.qualtrics.com). Qualtrics is a survey tool meant to create, collect, and analyse data. The equipment used to simulate the VE was comprised of Oculus Rift S, Alienware monitor, and Oculus Link wire. The VR system consisted of a HMD and a set of controllers. The HMD lets the user to see and explore the VE from all angles in 360 degrees, while the controllers allowed the participant to interact with the environment by pressing buttons. Figures below provide schematic representation of the set up for Prototype A and B, respectively.

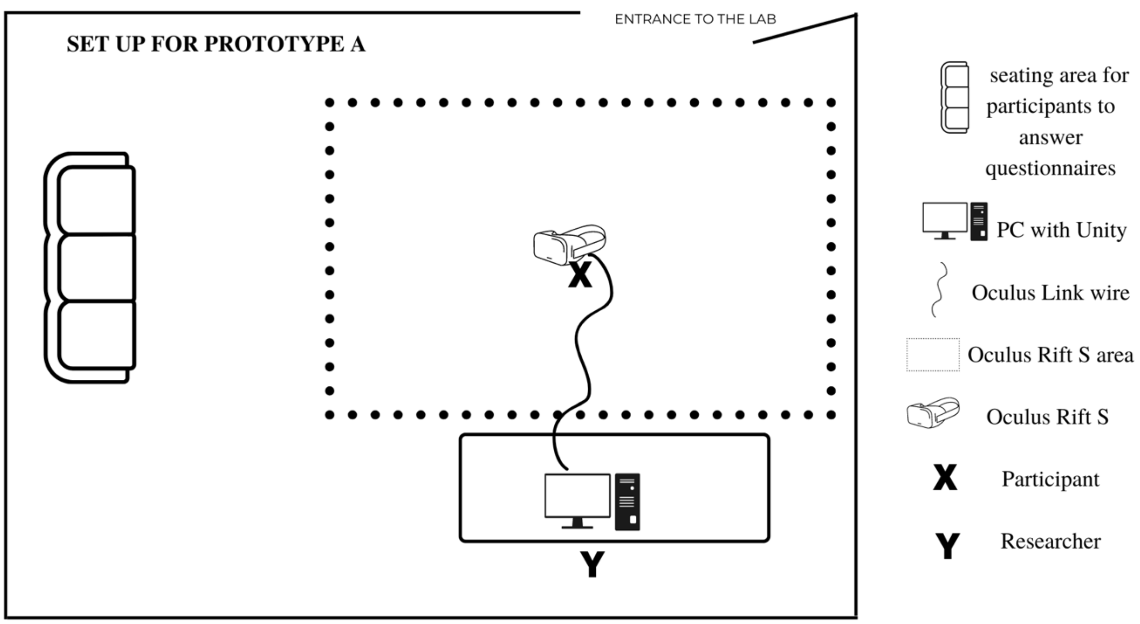


Figure. *Schematic representation of the experimental set-up for Prototype A.*

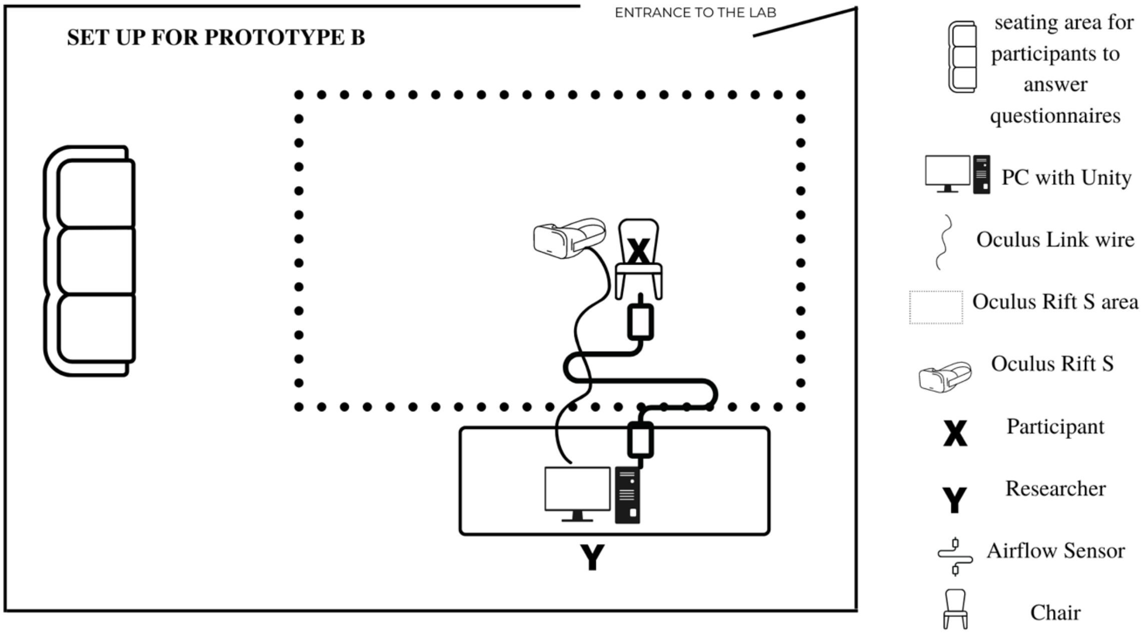


Figure. *Schematic representation of the experimental set-up for Prototype B.*

The set-up for Prototype B differs regarding using a painless sensor, MySignals Airflow equipment and chair for the breathing tree exercise. The breathing tree exercise aims to promote deep breathing in the participants, and it is best practiced either sitting or sleeping, for this study we choose sitting comfortably and completing the task. MySignals Airflow nose/mouth sensor is a device that measures the rate of breathing. This equipment consists of a flexible thread that fits behind the ears and two prongs that are inserted into the nostrils. These prongs are used to measure breathing. The specially constructed cannula/holder allows the thermocouple sensor to be put in the best position to detect changes in oral/nasal thermal airflow as well as nasal temperature air. Adjustable comfort and simplicity of installation (shown in Figure below).

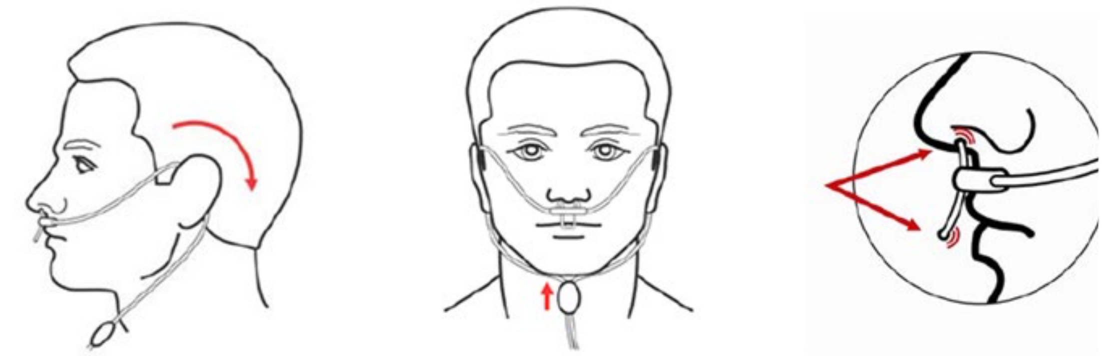


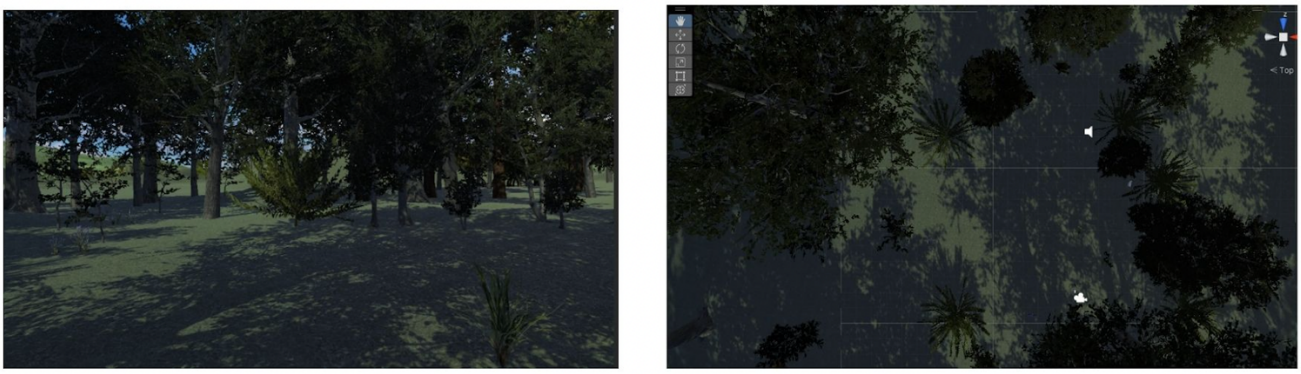
Figure. *Airflow equipment installation and position diagram (derived from MySignals manual)*

This sensor was used to measure physiological parameter like breathing rate to design the biofeedback based virtual nature environment. The input from this sensor made a real-time interaction in the virtual environment where the tree moved (expanded and contracted) based on breathing measures.

Design and Development of finalized Prototype B

Walk in Nature

The first task of the intervention. This enabled the participants to get used to the size of the room and explore the limits of their reach within the VE. This also helped the participants to get habituated with the controllers and VR headset. They were asked to explore the environment, they were free to touch the trees, bushes, shrubs and check out the sky (See Figure 8). The participants were instructed to take their time walking and exploring. After they were done exploring, they were asked to inform the researcher to start the new task.

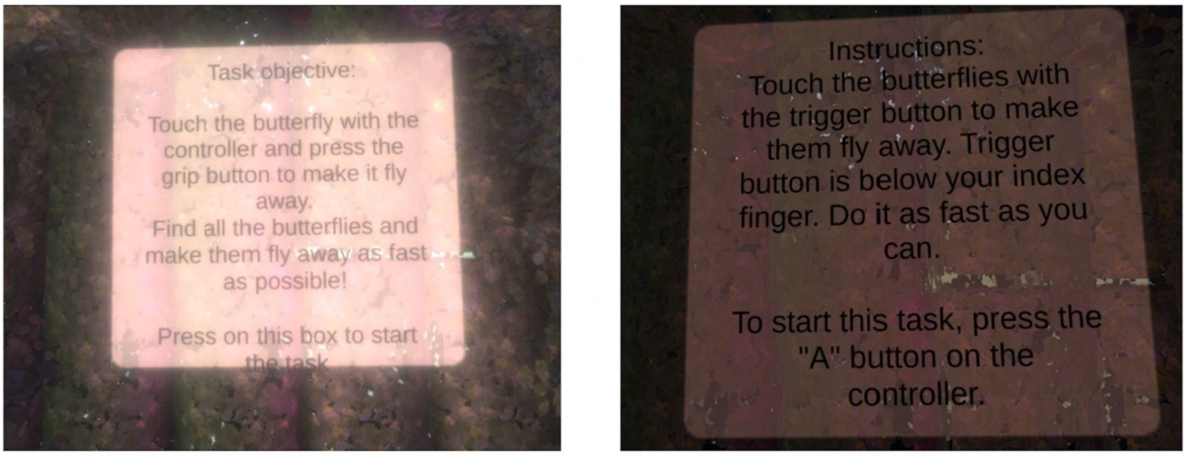


A walk in the forest environment   Aerial view of the forest environment

Figure. *Screenshots of the Prototype B, Walk in the forest task.*

Physiological Task

The physiological task was the butterfly task. This task was activated right after the walk in the nature task. The butterflies were increased (Figure below) and the task instructions were also updated (Shown below). The instructions were changed to, "Touch the butterflies with the trigger button to make them fly away. Trigger button is below your index finger. Do it as fast as you can. To start this task, press "A" button on the controller." The participants started the butterfly task, the time required to complete was not measured but the participants were instructed to finish the task as fast as possible this created a sense of anticipation and excitement in them.



Task objective (Prototype A)   Task objective (Prototype B)

Figure. *Task Objectives in Prototype A and Prototype B.*

The participants started the butterfly task, the time required to complete was not measured but the participants were instructed to finish the task as fast as possible this created a sense of anticipation and excitement in them. The task finished when all the butterflies were flown away. The participants were ready for the next task.

Butterfly Task Wall (Prototype A)   Butterfly Task Wall (Prototype B)

Figure. *The butterfly wall for the Prototype A and Prototype B.*

Psychological Task

The biofeedback real-time loop was finalized (See Figure below). The airflow sensor measured respiration rate and transferred the data to the biosignal acquisition unit which is Pinout development platform of the MySignals (Figure below), this data is further transfer to the Biodata Processing Unit which has Arduino Software with code to manipulate and influence the tree movements based on the readings. The biodata processing unit is an important step in the biofeedback loop as it uses this data to make changes within the VE as well as these said changes are based on personalized preliminary readings before the intervention and these readings are put into the code to determine the upper and lower limit for each participant. Once the data is processed and a loop is development, the readings influence the tree movements in real-time based on the respiration rate.

The participants were first seated in a comfortable position, the sensor was installed on the body and then they were introduced to the task objective, which was “Sit comfortably. Breathe according to the voice instructions to bring the tree back to life”. The instructions were motivating and soothing in nature which nudged the participants to practice deep and slow breathing, helped them concentrate on the movements of the tree and brought their attention to the changes they made to the tree as they progressed further in the task. The final product of this task is presented in the Figure below. The intervention ended on a relaxing and restorative note.

Initital point of the task (Grey Tree) Gradual growth and greener tree

Figure. *Before and after of the Breathing Tree Task.*

User Experiences

Initial Impressions, thoughts and feelings

The majority of the sample was exposed to the VR for the first time. The initial impressions were quite positive. Ten participants found the environment to be quite relaxing. One of the participants (P1) wished to have “it at home to help them relax whenever they felt stressed” because the VE felt like a real nature environment. It was also mentioned to “help forget stressful thoughts while they were inside the virtual environment” (P4). It was relaxing because of “the forest details and thought mobility will be limited but when you are inside it feels similar to real life” (P8) as well as “surrounding felt very relaxing like a day out in the morning” (P6).

The term ‘realistic’ was used by five participants to describe their first thoughts about the VE. The similar participants also found the VE to be engaging, participative and detailed. They also mentioned it being refreshing and responsive in nature. It felt like a real nature environment due to “nature sounds in the background” (P12). It was also termed as a good reflection to an actual nature. The exercises were mentioned to be fun, interesting, helpful, engaging and exciting. It was also called immersive and stimulating by P18. It was also mentioned to have fewer lags and a smooth experience. Although, two participants (P5 & P14) described the environment as decent from an intermediate user’s perspective, according to them a more rendered model would help enhance the experience even more. By rendered, it was highlighting some bushes were two dimensional rather than three dimensional.

Parts participants enjoyed more

The participants thoroughly enjoyed the nature environment compared to the tasks. Majority of the participants described this experience as “beauty of nature, mountain, sunshine, loved the details like flowers and butterflies” (P1), “light breeze and ambient sounds along with it” (P3), “realistic views and dimensions then expected” (P15), “walking around in the nature and watching the sky especially” (P5), “very beautiful and calming” (P6). Some participants also enjoyed it being interactive and task oriented in nature. Four participants enjoyed the butterfly task. On the other hand, three participants liked breathing exercises more, “breathing exercises become more fun with the aid of VR” (P10).

Parts participants did not enjoy

The primary part most of the participants did not enjoy was limited space. They wanted to have more mobility and explore more area within the VE. “limited latitude and wiggle room” mentioned by P1. There were also lag issues reported by some participants. Some participants suggested the VR goggles to be more stable and clearer. One participant did not enjoy the sensor based breathing tree task (Prototype B). Some participants observed a delay while using the controller. Lastly, one participant suggested adding wind flow to the tree animations to make it more realistic.

Does this VE promote subjective vitality?

Out of 18 participants, 15 agreed about the VE promoting Subjective Vitality. The reasons were varied – helps in releasing stress and anxiety, it helps people who do not take out time to go out, to actually experience it while being indoors, it also is a "means for an individual to have their time of reality to feel better " (P4), it helps in establishing a direct connection with the nature and it is very realistic. Some also mentioned that it helps filter out distractions and noises, it also allows to collect specific responses each time. One of the participants also mentioned that this VE might help with mindfulness and achieving a sense of calm. Some described it to be a good way to feel present in and around the nature, by also helping them get their mind off of daily activities and improves being in the present. On the other hand, it was called a mood booster and VE helps enhancing the real world experience in the room, they felt energetic but mentally relaxed at the same time. Lastly, it was suggested to be used for research as it is an untouched topic and one must explore more about subjective vitality. Three participants who do not agree with VE improving subjective vitality because it needs improvements, real life alternative are better and realism is lacking.

Which prototype was enjoyed more? Which one was preferred to increased Subjective Vitality?

Ten participants chose Prototype B due to reasons – it was more interactive compared to Prototype A, they enjoyed the breathing feedback received during the task. Due to its real time interaction, one of the participants (P3) found it thrilling, challenging and fun. Some of the participants enjoyed sitting and relaxing while doing the task. They also mentioned it being more realistic and interactive, it helped in relieving stress. For some, it helped with the biofeedback technology as it made them focus more on breathing and it further enhanced their experience of relaxation. Additionally, some felt more connected to the VE due to real time interaction and they felt more involved. Lastly, some participants mentioned about forgetting to press the button while inhaling. To remember to press the button took away the sense of relaxation and it felt more like a chore as well as some felt pressing of buttons was an inaccurate way of measuring progress in a task of breathing.

Eight participants chose Prototype A due to reasons like time to get habituated with the workings of the tree and controlling your breath to influence the tree's movements took away the enjoyment element as compared to Prototype B. The guided instructions of the Prototype A was more soothing for some participants. Due to its intermittent growth of the tree in

Prototype B, some found it difficult to relax. On the other hand, some participants liked to have controller for more activity and sense of control which was possible in Prototype A. Lastly, one participant found auditory reassurance distracting and childish in Prototype B.

Summary

The overall impression of the VE prototypes was favourable. The VE as a whole had been well approved. It was described as realistic, soothing, peaceful, engaging, interesting, immersive, and stimulating. It was also described as a good representation of actual nature. The activities were described as enjoyable, intriguing, beneficial, engaging, and thrilling. Four participants preferred the butterfly activity, whereas three preferred the breathing exercises.

The key element most of the attendees did not appreciate was restricted room. Some participants recommended that the VR eyewear be more stable and clear. The sensor-based breathing tree task was disliked by one participant (Prototype B). 15 of the 18 participants agreed that the VE promoted Subjective Vitality. Three participants disagree with VE enhancing subjective vitality because it requires improvement, real-life alternatives are superior, and realism is lacking.

Ten participants picked Prototype B for several reasons: it was more participatory than Prototype A, and they liked the breathing feedback they received during the task. Eight participants chose Prototype A because it took more time to get used to the tree's workings and controlling your breath to influence the tree's movements took away the enjoyment element. For some, it helped with the biofeedback technology because it made them focus more on breathing and it further enhanced their experience of relaxation. Furthermore, because of the real-time interaction, several respondents think more connected to the VE and more involved.