Using Virtual Reality to Improve Subjective Vitality: Design and Pilot Study for a Virtual Nature Environment

Lina Bareišytė

s1966944

First Supervisor: Dr. Christina Bode

Second Supervisor: Dr. Lonneke Lenferink

Supervisor from the BMS lab: Luci Rabago Mayer

In collaboration with a creative technology development intern: Arda Temel

Faculty of Behavioural, Management and Social Sciences

Department of Psychology

Positive Clinical Psychology and Technology

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Abstract

Background

Finding creative solutions to improve subjective vitality in a short amount of time is crucial for university students, because they face a lot of challenges and need to find ways to de-stress. Head-mounted display (HMD) virtual reality (VR) nature applications have been shown to improve subjective vitality in only five minutes of their use (e.g. Plante, Cage, Clements, & Stover, 2006). Unfortunately, there is a lack of publicly available, evidence-based VR applications that can improve subjective vitality. Furthermore, existing research suggests that the design and development processes of health-related VR applications do not receive enough attention and should be explored more in-depth (Tao, Garrett, Taverner, Cordingley, & Sun, 2021). To combine design, development, and subjective vitality topics, this study consisted of two phases. Phase 1 focused on the design, development, and usability (imaginative immersion, presence, and user experience) processes of a gamified nature virtual environment (VE). Phase 2 was a pilot effectiveness study that tested whether the created VE can improve subjective vitality and energy-tension of university students.

Phase 1. Method

The design and development process had a big impact on the final product, since a lot of adjustments had to be made due to time limitations, technical skills, and materials available. What initially started as a walk in a virtual forest environment, throughout the design and development processes, became a gamified VR nature experience. The final VE consisted out of four parts: nature environment, breathing tree task, butterfly exercise, and a yoga task. To participate in the study, 32 university students were recruited using availability sampling. Participants filled in a self-report questionnaire regarding imaginative immersion before starting the research, presence, and user experience questionnaires after using the VR.

Phase 1. Results

As a result of the design and development process, a virtual nature environment was created. It contained three tasks: breathing tree, butterfly, and yoga. Results from the questionnaires regarding usability showed that participants of this study were able to experience immersion, reported feeling present within the VE, and would recommend the VE to others.

Phase 2. Method

The same participants as in Phase 1 took part in Phase 2. They first had to do a laboratory-based stressor to create psychological tension and then were introduced to the VE. Additionally, a heart rate monitor was used throughout the laboratory-based stressor and VR experience to measure heart rate and heart rate variability. However, the output from the heart rate monitor did not provide sufficient data and was not included in the data analysis. Subjective vitality and energy-tension were also measured before and after using VR.

Phase 2. Results

Results showed that subjective vitality has improved after using the VE. Energetic arousal did not show any significant changes. Tense arousal has reduced significantly after using the VE. Also, a post-hoc analysis was conducted to determine whether there is a relationship between subjective vitality and energy-tension questionnaires. It showed significant positive correlations between both pre- and post- VR conditions.

Conclusions

This study has created a fully functioning prototype of a gamified nature VE, which was positively evaluated by its users, improved their subjective vitality and energy-tension. Although a lot of positive results have been achieved, additional adjustments (e.g. improving usability) and research (e.g. adding a control group) need to be made for the VE to become available for a broader population. This VE is a good start towards finding a cost-effective solution to VR applications that could improve subjective vitality.

Using Virtual Reality to Improve Subjective Vitality: Design and Pilot Study for a Virtual Nature Environment

According to Ryan and Frederick (1997), subjective vitality is a combination of psychological (e.g. feeling happy, in love) and physical (e.g. being healthy) states. To feel subjective vitality means to be free from external pressures, conflicts, to be able to perform actions on one's own, have the strength and the energy to do them. The concept of experiencing these psychological and physical vitality states dates back to the work of Rogers (1974). He wrote that experiencing these states is what feels to be a "fully functioning" person. It is also important to mention that subjective vitality cannot be achieved by only psychological or physical well-being (Miksza, Evans, & McPherson, 2021). Low-energy, tranquil psychological states could indicate psychological well-being but do not suggest subjective vitality, similarly, high energy, aroused physical responses may not always be a sign of "aliveness" rather an indication of anger or mania (Miksza et al., 2021). Therefore, when thinking about subjective vitality, it is important to consider both psychological and physical continua.

Incorporating technologies to improve subjective vitality could be beneficial since they have been shown to prevent long-term negative effects of daily life. The most commonly mentioned benefits are reduced psychological and physical stress, anxiety, improved health-related quality of life including social, emotional, and physical well-being (Fallowfield, 2009; Felce & Perry, 1995). One innovative technology that could be used to improve subjective vitality is virtual reality (VR). VR is particularly interesting because it can be adjusted to various target groups and done with or without supervision (Martens, 2016; Sherman & Craig, 2018). Also, VR is highly immersive due to the combination of sounds, visuals, and the ability to interact with the environment itself (Martens, 2016). The key aspect of VR is that using virtual environments (VE's) in the form of games or applications they can help learn positive behaviours or practice behaviour change (Chow, Susilo, Phillips, Baek, & Vlahu-Gjorgievska, 2017; Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015).

A good example of using VR for behaviour change is phobia treatment. Using VR, patients can be exposed to various scenarios or objects while remaining in a safe environment and being observed by professionals (Horváthová, Siládi, & Lacková, 2015; Wechsler, Kümpers, & Mühlberger, 2019). However, such applications are only meant to be used next to treatment or with the supervision of a professional and are not available for everyone

(Jones, Moore, & Choo, 2016; Klinger et al., 2005). On the VR market, there is a lack of publicly available evidence-based applications for the general population to learn about and improve subjective vitality (Fleming et al., 2017). Most publicly available VR applications are games meant to entertain, not to improve one's physical or mental well-being. Some game creators suggest that their games (e.g. "VirtuaLiron", "Guided Meditation VR") might help to improve well-being (e.g. "Leave the worries of your life for a short virtual vacation, and return calmer and stronger" (Cubicle Ninjas, 2016)) but their effectiveness has not been proven. Therefore, publicly available, simple to use, and no supervision requiring VR applications would be very beneficial to improve subjective vitality. Additionally, as suggested by Tao, Garrett, Taverner, Cordingley, and Sun (2021) three main ideas should be considered when creating a VR application. Firstly, in-depth design and development process descriptions should be provided to create a better understanding of how health-related VR games or applications are created. Secondly, suggestions should be made regarding design and development processes and user experiences to help future creators. Thirdly, to improve subjective vitality and create more diverse VR applications, a combination of both physical (e.g. yoga) and non-physical (e.g. meditation) exercises should be considered (Tao et al., 2021). Ideas mentioned in this paragraph were combined and created an outline for a VR design, development, usability, and pilot study focused on improving subjective vitality.

University students are a particularly interesting target group to explore when it comes to VR and subjective vitality for three main reasons. Firstly, students or young adults are more confident in their computer knowledge, leading them to explore and try out more new technical developments (Marquié, Jourdan-Boddaert, & Huet, 2002). Students can also provide insightful feedback while doing a pilot study due to their experiences with technology. Secondly, studies have shown that stress, depression, and anxiety are on the rise in students (Bayram & Bilgel, 2008; Herbert, Meixner, Wiebking, & Gilg, 2020). Student life is a sensitive time for young adults since it is the very beginning of their autonomous lifestyle and the transition period between school and work. It is crucial that they learn how to deal with daily stressors and how to develop different skills (e.g. deep breathing, relaxation, engaging in physical and social activities) to regulate their psychological states (Stallman, Lipson, Zhou, & Eisenberg, 2020). Thirdly, students who report feeling more stressed than their peers are less physically active (Herbert et al., 2020; Nguyen-Michel, Unger, Hamilton, & Spruijt-Metz, 2006). Regular physical activity has been shown to improve physical and mental health (Herbert et al., 2020). Managing university tasks namely exams, projects, deliverables, and looking after one's mental and physical well-being can be challenging. However, it is essential to find those brief moments to engage in relaxation and physical activity to improve one's physical and mental health and to be able to enjoy the beauty of life (Stallman, Lipson, Zhou, & Eisenberg, 2020). VR could be a valuable tool to find and make good use out of those brief moments. Thus, this research aimed to create a brief gamified VR experience that focused on improving subjective vitality of university students.

Design, development, and usability study design

To successfully create a VE, three main aspects had to be considered: design, development, and usability. Each of them is inter-related with one another yet focuses on a specific part of the VE. In the following, an in-depth explanation of design, development, and usability processes is offered.

Design: outline of the VE setting and its contents

To design the environment for the improvement of subjective vitality, a setting had to be chosen first. Studies have shown that time spent in nature has been positively linked to improved physical and psychological states (Tzoulas et al., 2007). Mattila et al. (2020) compared experiences between physical and virtual walks in the forest. Five minutes were enough to show that both scenarios (physical and VR) had positive effects on subjective vitality, restoration from stress, and mood. Additionally, participants found the VR environment more fascinating than the physical one (Mattila et al., 2020). Although not all sensory experiences such as touch or smell can be simulated in the current models of VR, the availability and simplicity of change and the combination of visuals and sounds within the VE can facilitate recovery from stress and activate the parasympathetic nervous system (Annerstedt et al., 2013; Mattila et al., 2020). Hence, a nature setting for the VE was chosen to implement.

Furthermore, when designing the VR application, it was important to address both aspects of subjective vitality: psychological and physical health. To improve the psychological state breathing was used, since practicing breathing exercises is a simple and effective way to reduce stress, relax, and it is often used in yoga and mindfulness practices (Tellhed, Daukantaitė, Maddux, Svensson, & Melander, 2019). However, only improving psychological health was not enough. In a study about physical exercise, a comparison between a brisk walk outside through a college campus, a VR observation, and a walk on a treadmill using VR through the same campus has been done (Plante, Cage, Clements, & Stover, 2006). It showed greater relaxation and decreased tension during the walk in the VR and walk outside conditions. Furthermore, the same study showed that only an observation through VR was not enough to increase energy levels, it had to be combined with physical exercise (Plante et al., 2006). Finally, to achieve optimal levels of subjective vitality, it seems important to combine both breath and physical exercises in the same task.

Therefore, the design of this study aimed to integrate nature elements into psychological (breathing), physical (exercise), and a combination of psychological and physical (combination of breathing and physical) well-being tasks in a gamified VR experience.

Development: technology and goals

To develop the VE, it was important to understand and consider the interaction between various components of the VR system (Hanson & Shelton, 2008). Firstly, the user and the task that one had to do in the VE were defined. These two components were the centre of the development process. Then, based on the task and what needs to be created, the inputs and outputs between the computer and the user were addressed. The inputs focused on what the user selects in the VE and what information was then sent to the computer, and the outputs were what the computer makes out of the inputs and what it sends back to the user. When all details about how the environment should look like and what it should do were clear, the VR engine, software, and databases were considered. A VR engine gives a framework to build a VE on. Appropriate software and databases help to create realistic 3D visuals or use details that can be integrated into one coherent environment and share the environment and its elements (Hanson & Shelton, 2008). All of these elements were considered based on the target group, research question, materials, and skills available. The main goal of the development process was to create a working VE which could improve subjective vitality of university students. Furthermore, the development part addressed what the user could see, feel, and hear in the environment, which data was collected from participant input, and which hardware and software were used (Hanson & Shelton, 2008).

Usability (immersion, presence, and user experiences)

When creating the VE, usability was another important aspect to take into account. Usability is the ease with which one gets acquainted with the new technology, can navigate, and interact with the system itself (Sutcliffe & Kaur, 2000; Zhang et al., 2020). Although VR has been used in various fields such as gaming, marketing, and education for quite some time now and is making its way into the medical field, it does not have one concrete path to follow when it comes to determining its usability (Zhang et al., 2020). Zhang et al. (2020) has suggested several ways to measure usability of a VE, namely: cognitive or task walkthrough, post-hoc interviews or questionnaires, evaluations of user physical performances, and user evaluations of the interface, graphics, and heuristics. For this particular research, an immersion questionnaire was conducted before the experiment and post-hoc questionnaires were used to measure presence and user experiences. Questionnaires are a very versatile and straightforward way of data collection, and in this case, immersion and presence questionnaires complemented each other.

The main key concepts of usability in VR are immersion and presence (Mattila et al., 2020). According to Ermi and Mäyrä (2005) immersion has three forms: sensory, challenge-based, and imaginative immersion. Sensory immersion is created by using technology to simulate real-life experiences such as sounds, visuals, and other physical sensations that one can do in real-life (e.g. being able to bend to see things from a different angle) (Bowman & McMahan, 2007). The main idea of sensory immersion is to reflect reality as well as possible through a computer (Slater, 2018). Environments, the same as tasks, might not be realistic, but they rely on sensory cues to provide sensory-based immersion (Bowman & McMahan, 2007). Challenge-based immersion focuses on creating the best balance between one's mental and motor skills and the challenges within the game or environment (Ermi & Mäyrä, 2005). The games or environments should be challenging enough, yet not too complicated (Ermi & Mäyrä, 2005). Finally, imaginative immersion relies on one's ability to feel immersed (Nacke & Lindley, 2008), which was focused on in this study. Imaginative immersion is the extent to which one can be absorbed by the narrative or identify themselves with a character (Brown & Cairns, 2004). People who can experience imaginative immersion (in the paper by Witmer and Singer (1998) imaginative immersion was referred to as immersive tendencies) easier, tend to also report higher feelings of presence and the other way around (Witmer & Singer, 1998). Hence, only the concept of imaginative immersion was addressed in this study, together with presence.

Presence is the feeling of "being there" within the VE and perceiving things within the environment as real (Slater & Sanchez-Vives, 2016). Some users might feel as if they are actually in the environment and find it highly realistic, meanwhile, others might not and that can happen despite the high sensory immersion system (Bowman & McMahan, 2007). Therefore, the VE created should involve elements that for the most part would be familiar to most users (e.g. bird sounds, nature elements from the same region research takes place in). It is also important to mention that presence is a perceptual illusion, the user of the VE might understand what he/she is seeing is not real, but the natural bodily reaction cannot be prevented. Meaning, the more similar the VE is to the real world, the more difficult it gets for the brain to control the natural bodily responses and the easier it gets for one to feel present (Slater, 2018). Thus, while imaginative immersion was used to assess one's ability to immerse before using the VE, presence helped to determine one's experiences after using the VE.

Lastly, user experiences and input were also collected as a measure of usability. Users from different backgrounds and experiences can provide valuable comments on how to improve the VE (Zhang et al., 2020). End-user input is especially important since the intervention is targeted to them, and they can represent which aspects of the VE are important for that target group, what needs to be changed or adjusted. Also, other observations which were not measured using questionnaires or even considered by the researcher can be highlighted by the user (Zhang et al., 2020). User experiences were also addressed after using the VE.

Pilot effectiveness study design and momentary assessment

To test the effects of the created VE, a pre-post study design was chosen. Its goal was to help determine whether the VE helps to reduce stress and improve subjective vitality. Two momentary assessment questionnaires were used. One to measure subjective vitality and the other to measure energy-tension. These questionnaires were conducted before and after using the VE. Momentary assessment questionnaires help to measure momentary emotional states e.g. "How do you feel right now?" (Boyle, Helmes, Matthews, & Izard, 2015). Momentary assessment questionnaires have shown to be a good representation of sensations and feelings one is experiencing at this moment. (Boyle et al., 2015).

Laboratory-based stressor

Subjective vitality cannot be experienced while undergoing strong feelings of stress because subjective vitality is inter-related with life satisfaction, optimistic performances, and mental health (Fini, Kavousian, Beigy, & Emami, 2010; Ryan & Deci, 2001). Therefore, to best see changes of subjective vitality, in this study an external laboratory-based stressor was used. Its goal was to increase stress and reduce subjective vitality. As stress induction, external stressors in a laboratory setting had been chosen to implement. According to a meta-analysis done by Dickerson and Kemeny (2004) stressors in a laboratory environment with uncontrollable or social-evaluative characteristics created the most psychological stress between participants. Psychological stress was determined using cortisol levels in the saliva of participants. Cortisol is a hormone extensively studied both in human and animal literature and accounts for psychological and physical functioning (Dickerson & Kemeny, 2004). Although measuring cortisol levels was beyond the scope of this study, by incorporating uncontrollable and social-evaluative characteristics into the laboratory-based stressor it was hoped to reduce subjective vitality and create some psychological tension.

Heart rate and heart rate variability

When a person encounters a stressor, their autonomic nervous system gets affected (Taelman, Vandeput, Spaepen, & Van Huffel, 2009). The reaction to it is automatic and is called a “fight or flight” response. Meaning that alongside other processes heart rate (HR), heart rate variability (HRV), muscle tension, and blood pressure increase (Sztajzel, 2004; Taelman et al., 2009). To measure psychological stress the most non-invasive method used among researchers is measuring HR and HRV (Kim, Cheon, Bai, Lee, & Koo, 2018; Sztajzel, 2004). It can be done using simple wearables such as smart-watches, or medical wearables, pulse oximeters. HRV is a parameter that tracks changes (RR intervals) between successive heartbeats (see Figure 1) (Cornforth, Tarvainen, & Jelinek, 2014). RR interval is a time that has passed between two successive R-waves. HR and HRV have an inverse relationship: HR increases when experiencing stress and decreases when relaxed, HRV acts the opposite way (Cornforth, Tarvainen, & Jelinek, 2014; Sztajzel, 2004). Therefore, in this study, it was expected that HR and HRV will be able to detect physiological changes between the laboratory-based stressor and VR experience.

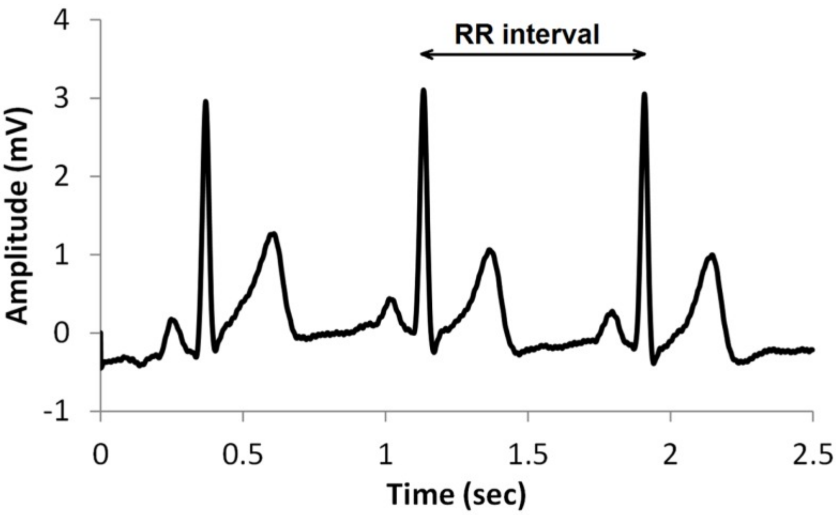

Figure 1. An illustration of an RR interval by Cornforth, Tarvainen, and Jelinek (2014).

Current Study

The goal of this study was to design, develop, and pilot how a VR head-mounted display (HMD) can be used to improve subjective vitality of university students. It consisted of different parts (see Figure 2). A laboratory-based stressor was used to induce moderate psychological tension in the participants and a VR nature experience with gamified elements (breathing, physical, breathing and physical exercises) was introduced to outweigh the effects of the stressful task and improve subjective vitality. A pre-post study design was used to measure subjective vitality and energy-tension of participants before and after using the VE. A physiological measure was attached to the hand of each participant to measure their HR and HRV throughout the laboratory-based stressor and VR elements.

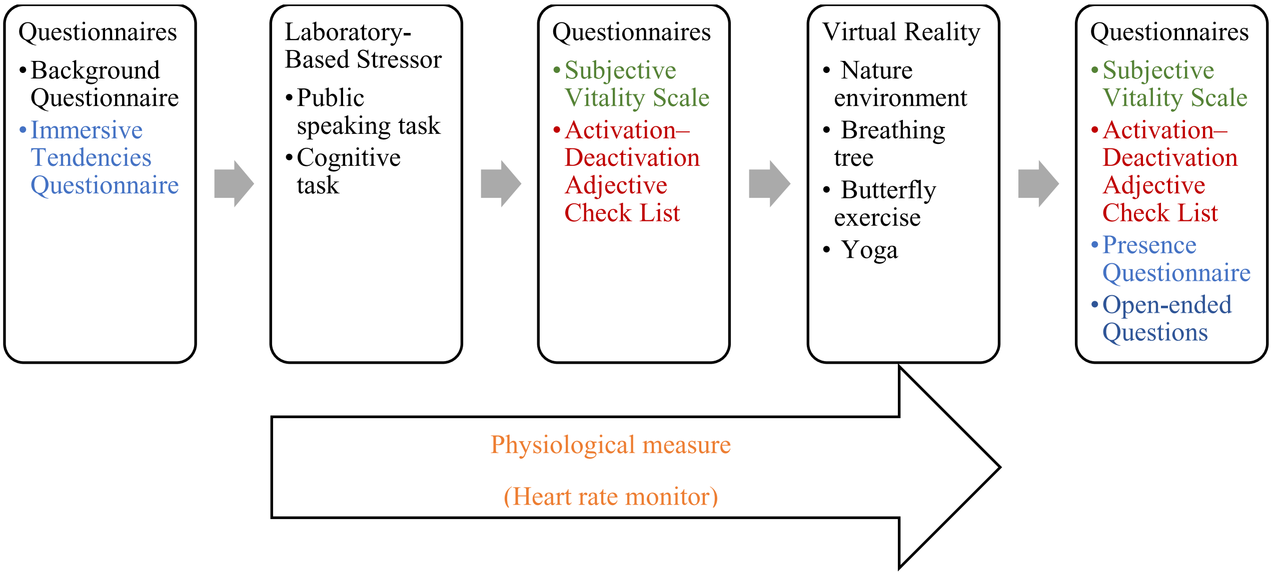

Figure 2. Elements and longitudinal course of the study. Constructs measuring usability are written in blue, constructs measuring subjective vitality – green, energy-tension – red, and HR and HRV - orange.

To address all relevant aspects of this study, the study was divided into two main phases which were discussed separately. Phase 1 of the study discussed the design and development process of the VE and addressed its usability (imaginative immersion, presence, and user experiences) among university students.

Topics that were explored in Phase 1 of this study:

P1.1. Design and development process of the virtual environment.

P1.2. The extent to which students report experiencing imaginative immersion and presence within the virtual environment.

P1.3 User experiences after trying out the virtual environment.

Phase 2 was a pilot effectiveness study and tested to what extent the VE can improve subjective vitality in university students after a stressful situation.

Hypotheses that were explored in Phase 2 of this study:

P2.1. Compared to the pre-test scores, students reported greater subjective vitality during the post-test.

P2.2. Compared to the pre-test scores, students reported greater energy and reduced tension during the post-test.

P2.3. Physiological measures indicating physical stress decreased after using the virtual environment in comparison to the before condition.

Phase 1: Design, development, and usability of the VE

Phase 1. Method

The current study was a cooperation project with a creative technology intern from the BMS lab Arda Temel. The design and development parts were guided by Luci Rabago Mayer. The interdisciplinary study was supervised by Dr. Christina Bode and Dr. Lonneke Lenferink. In the following, the design section describes initial ideas of the tasks and what inspired them. The development section explains the procedure when creating the described tasks and adjustments made.

Design

The design of the VE consisted of a walk in a forest environment and three gamified components: psychological well-being task, physical well-being task, and a subjective vitality task.

A walk in a forest environment

When a participant put on the VR headset, he or she was immediately transported into a forest environment. The participant was able to walk throughout the forest path observing nature, listening to birds chirping and leaves rustling. The initial idea was that the environment had a path to follow and when a participant came to a certain location on the path a task started automatically.

Psychological well-being task

The idea for a psychological well-being task was inspired by the one presented in the study of Patibanda, Mueller, Leskovsek, and Duckworth (2017). In it, a sickly-looking tree was presented to the participants, and the task required to do a breathing exercise to help heal the tree. There were also voice instructions guiding the participant through the process. The tree represented the lungs of the participant: with every inhale the tree expanded and with every exhale it contracted. Additionally, throughout the exercise, the tree started re-growing new green leaves. The exercise was finished when the leaves of the tree became completely green. While doing this exercise the participants were also supposed to take a comfortable seated position and when the exercise finished, they had to stand back up to continue their forest walk.

Physical well-being task

While continuing the walk the participant started to hear some music, the closer he or she got to it the louder it began to play, overshadowing the other noises. When he or she came very close, a second task was introduced – a physical well-being task. It involved a physical exercise according to the music, similar to the VR game "Supernatural" in which by using controllers the participant had to slice boxes based on the rhythm of the music (Braunstein, 2021). The background remained the same – a forest environment, yet it faded away to make the flying boxes clearer. After the song was over, the forest environment became clear again, nature noises became louder, and the participant could go through the forest to the final task.

Subjective vitality task

The last exercise was meant to improve subjective vitality, hence a yoga task was chosen. While walking through the forest, the participant saw a person in front and when they came closer a new task was presented: to follow a yoga sequence presented by the yoga coach. Then, the background noises became subdued, the coach started talking and introduced different exercises, such as head and shoulder rotations, light stretching. The coach also instructed the participant when to inhale or exhale according to the movements. The exercise was happening within the same forest environment; however, the coach stood out the most. After the exercise, the coach suggested some mindfulness techniques (e.g. breathing, setting a positive intention) to the participant to relax even more and informed that this was the final exercise of the VE.

Development

The development part had a prominent role in this thesis. The creation of the VE required design adjustments from the beginning stages of its development.

The initial idea for the VE started as a walk using a Cyberith Virtualizer – a locomotion device that allows its users to move within the VE without being limited by the space in their actual environment (Cakmak, 2015). All tasks were intended to be incorporated into it. During the walk, upon arrival to a certain location, the instructions would be presented, and a task would start, a walk would be finished when all tasks were completed. However, the addition of tasks that involve stretching and moving to different sides (e.g. the subjective vitality task) made it impossible to use the Virtualizer due to movement limitations. Therefore, it was decided to not use the Virtualizer and instead to only use the VR headset and controllers.

Using only the VR headset all three tasks could not be connected into a coherent walk due to the limitations of space within the room. Meaning, that it was no longer a walk in a forest, but a gamified experience with nature elements. Such adjustments allowed to incorporate more natural and advanced body movements (e.g. stretching, jumping).

Additionally, because of the limitations in space, each task had to be started from the same location within the room, to have more area to move. That meant that the researcher had to guide participants after each task to a correct location. To improve usability, it was decided to start each task with a task objective. A box in front of the participant described the task, its goal, and controls (all tasks involved using only two buttons from the controllers). It was a simple solution on how to provide instructions without animation.

Nature environment

The design idea to create a forest environment had proven to be complicated to implement. Adding a lot of elements to the environment reduced the frame rate, the speed at which consecutive images were displayed while using the VR (Raaen & Kjellmo, 2015). Reduced frame rate could have led to a reduced feeling of presence within the environment, discomfort, and even cause motion sickness. The frame rate depends on how fast a screen can receive and update images that one is viewing. An optimal frame rate is 60 frames per second (FPS) (Raaen & Kjellmo, 2015). To ensure that the rate does not go lower than that, it was decided to design a simpler nature environment with only a few trees and flowers, just enough to have an impression of a nature environment, yet not enough to cover the whole terrain.

Psychological well-being task: breathing tree

The first, breathing tree, task was slightly adjusted from the original idea. Measuring the breath was not the key component of the study, thus, to save time the tree was animated to move automatically, not according to the actual breathing of the user. Participants were instructed to press buttons while inhaling and holding their breath, yet that did not determine the speed, movement, or colour of the tree. It was also decided to simplify the animations and instead of the tree re-growing leaves throughout the exercise, it only changed its saturation from grey to bright green. The final decision was the seated position, which was suggested in the paper by Patibanda et al. (2017). Although sitting on the floor would allow participants to relax and only focus on their breath, to sit down comfortably on the floor, they would have to look down and evaluate their body position and/or the place where to sit. However, within the VE only hand movements can be seen because only the headset and controllers have sensors, thus, other body parts are not visible. Next to that, VR affects one's sense of depth causing people to underestimate the distance between them and an object (Armbrüster, Wolter, Kuhlen, Spijkers, & Fimm, 2008), therefore, to avoid confusion and injuries it was decided to perform the exercise while standing.

Physical well-being task: butterfly exercise

The second – physical well-being task after a thorough consideration was changed completely due to three reasons. First, incorporating or recreating the "Supernatural" game required complex programming skills and permissions from the game creators. Second, after careful consideration, it was decided that the game did not suit the VE. The initial idea of the VE was to be relaxing, slicing boxes with lightsabers or swords that were coming towards the participant could potentially increase stress. Third, more nature aspects had to be incorporated into the task instead of urban ones, since natural environments help with restoration from stress (Mattila et al., 2020). Hence, a butterfly exercise was created. It was inspired by butterfly parks, which contain lots of nature and colourful butterflies. The idea was that participants could observe nature, find different size and colour butterflies, and make them fly away. It was important to decide where the butterflies will be placed, therefore a tunnel was made from green garden arches. The butterflies were animated to fly away towards the exit of the tunnel after being touched. Touching a butterfly consisted of bringing the controller onto the butterfly, and then pressing a button to make it fly away. During this task, participants had to physically move through the room to find and touch all the butterflies scattered between different parts and heights of the arch. The tunnel was adjusted to be slightly smaller than the room that research took place in, to prevent participants from hitting a wall while walking around.

Subjective vitality task: yoga

The final yoga task was also partially adjusted during the development stage of the VE. The original idea was that the yoga coach would perform yoga sequences together with the participant. However, that had to be adjusted for three main reasons. The first one was that animating an object for it to move smoothly using Unity software was very ambitious and required advanced technical skills. This was solved by using already pre-made animated assets, yet that limited the range of movement that could be achieved. Second, certain poses could not be achieved by holding controllers in the hands (e.g. where the participant has to touch or hold their other hand). Third, participants who were not familiar with yoga would not be able to follow the sequence together with the instructor. Therefore, it was decided to first introduce each movement and then to ask the participant to repeat it together with the coach.

Materials used to create the VE and its requirements

The VE was developed together with the BMS lab's developmental support from the University of Twente, using Unity 2020.2.3f1, some pre-made assets from the Unity Asset Store (see https://assetstore.unity.com/), and a character from Mixamo (see https://www.mixamo.com/). To ensure that nothing had been forgotten, and all the necessary steps were taken, a requirement checklist for the VE had been created (see Appendix F). The requirements for the environment included setting the environment, animations, sounds, task objectives, transitions between tasks, interactions between the environment and the participant. Another important aspect in the development was the logging of the participant inputs in the environment. To ensure that each participant acted accordingly to the task, their button presses during each task were recorded.

Rooms and equipment

The experiment took place in two interconnected rooms on campus of the University of Twente. The first room ($14.22m^2$) was used to do the debriefing, fill in questionnaires, and store equipment. Questionnaires were presented using Samsung Galaxy Tab A tablet and arranged using Qualtrics software (https://utwentebs.eu.qualtrics.com). Qualtrics is a survey tool meant to create, collect, and analyse data. The second room ($15.18m^2$) was used to do the VR tasks. The equipment used to simulate the VE was comprised of Oculus Rift S, Dell UltraSharp U2518D monitor, and a Zotac VR backpack. The VR system consisted of a HMD and a set of controllers. The HMD ensured that the participant could see and explore the VE from various angles in 360-degrees and the controllers allowed to interact with the environment by a press of a button. Finally, the VR backpack was not worn by the participants but only used as a computer to run the program smoothly. The wire from Oculus Rift S was long enough to allow participants to walk throughout the whole room undisturbed.

Participants

The study included 32 participants (17 male; 14 female; 1 participant did not identify female/male), the majority were bachelor students (25 bachelor; 6 master; 1 PhD), and their age range was between 18 and 28 years (M = 21.66; SD = 2.22). Participants were recruited using availability sampling. The conditions to be included were to be enrolled as a university student at the time of the study, have no hearing, sight (sensitivities to rapidly changing light), and physical problems (epilepsy, motion sickness), be proficient in using the English language. The study included various nationalities (14 Dutch; 8 German; 10 other), thus, was conducted in English. Before the start, all participants were introduced to the procedure (see Appendix G), instructed on how to use the HMD and controllers, and had all of their questions answered by the researcher. Finally, an informed consent 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 H). Some students participated completely voluntarily without any incentives, others, who were from the faculty of Behavioural, Management, and Social Sciences (BMS) received two Sona System credits for their participation. Sona Systems is a tool that helps researchers to recruit and manage participants (for information see https://www.sona-systems.com/). The study was reviewed and approved by the BMS ethics committee from the University of Twente.

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 understand presence, first, it is important to evaluate to what extent participants are able to immerse into an environment (Witmer & Singer, 1998). A translated French-Canadian ITQ was used (originally by Witmer and Singer (1998), revised and translated by Robillard, Bouchard, Renaud, and Cournoyer (2002)). ITQ is a questionnaire measuring one's ability to immerse oneself in various scenarios and is composed of 18 items on a scale from 1 = "never" to 7 = "often" (see Appendix C). The items in the ITQ make four subscales (see Table 1). For comparison with the obtained scores, norm scores provided by Robillard et al. (2002) were used.

Table 1.

An overview of the ITQ and its subscales as provided by Robillard et al. (2002) and internal consistency from this study.

	Number of items	Example question	Min	Max	Cronbach's alpha
ITQ Total	17		18	126	.79
Focus	5	Do you easily become deeply involved in movies or tv dramas?	5	35	.44
Involvement	5	Do you ever become so involved in a daydream that you are not aware of things happening around you?	5	35	.65
Emotions	4	Have you ever gotten scared by something happening on a TV show or in a movie?	4	28	.50
Game	3	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?	3	21	.61

Note. *ITQ = Immersive tendencies questionnaire.*

Presence Questionnaire (PQ)

To measure presence experienced during the gamified nature VE a translated French-Canadian PQ was used (see Appendix D) (original by Witmer and Singer (1998); revised and translated by Robillard et al. (2002)). The PQ consists of 24 items regarding the experience within the VE and is rated on a scale from 1 = “not at all” to 7 = “completely”. The items in the PQ make seven subscales (see Table 2). The norms used for comparison for the PQ were provided by Robillard et al. (2002) but they did not include Sound and Haptic subscales. Therefore, results from another study by Robillard, Bouchard, Fournier, and Renaud (2003) using the same questionnaire with a healthy population were also included.

Table 2.

An overview of the PQ and its subscales as provided by Robillard et al. (2002) and internal consistency from this study.

	Number of items	Example question	Min	Max	Cronbach’s alpha
PQ Total	24		24	168	.79
Realism	7	How natural did your interactions with the environment seem?	7	49	.59
Possibility to act	4	How much were you able to control events?	4	28	.52
Quality of Interface*	3	How much delay did you experience between your actions and expected outcomes?	3	21	.51
Possibility to examine	3	How closely were you able to examine objects?	3	21	.32
Self-Evaluation of Performance	2	How quickly did you adjust to the virtual environment experience?	2	14	.52
Sound	3	How well could you identify sounds?	3	21	.55

Haptic	2	How well could you move or manipulate objects in the virtual environment?	2	14	.81

Note. *PQ = Presence questionnaire.*

** negatively phrased items.*

Open-ended questions

User experiences were assessed using open-ended questions created by Foronda et al. (2016) but adjusted to fit this study. Therefore, instead of asking about one's experiences in the simulation, the questions refer to the VE or gamified walk in nature. The questions were divided into five main topics: initial impressions regarding 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 were not so enjoyable ("What did you not enjoy during the gamified walk in the nature?"), would participants recommend the experienced VE to improve subjective vitality ("Do you think this type of experience should be offered again to improve subjective vitality? Why or why not?"), and whether any motion sickness was experienced ("Did you experience any motion sickness throughout the virtual walk?"). All questions touched upon different topics and allowed participants to express their thoughts regarding the environment.

Data analysis

Immersion and presence

Questionnaire data were analysed using Statistical Package for the Social Sciences (SPSS) version 25. To analyse the imaginative immersion questionnaire, first, means (*M*) and standard deviations (*SD*) were calculated for the total score and scores of the subscales. Then, using a one-sample t-test, the questionnaire and subscale means were compared to the mean scores provided by Robillard et al. (2002).

To analyse the presence questionnaire, first, all items in the subscale Quality of Interface were reversed. Then, the means and standard deviations were calculated for the whole presence questionnaire and its subscales. The received mean scores using a one-sample t-test were compared both to the norms provided by Robillard et al. (2002) and by Robillard et al. (2003).

User experiences

Responses from the open-ended questions were analysed qualitatively, summarizing, and categorizing thoughts, most common opinions, or suggestions participants have expressed. Responses were also quoted and completed by providing some additional contextual information from the researcher.

Phase 1. Results

Background

The results from the background questionnaire are summarized in Table 3. When asked to what extent participants were familiar with VR environments, the mean showed almost the middle, with quite some variation between the scores. Whereas the extent to which participants enjoy walks in nature scored relatively high with less division. Similarly to the first question, at the moment of the first questionnaire participants reported experiencing some stress, however, results were again quite varied.

Table 3.

Results from the background questionnaire (N = 32).

	M	*SD*	Score range*
Familiarity with VR environments	2.53	1.16	1 – 5
Enjoyment of walking in nature	4.72	0.58	3 – 5
Current stress level	2.28	1.17	1 – 5

Note. *Possible range: 1 - 5*

P1.1. Design and development

Nature environment

After participants put on the VR HMD, they were transferred to a first-person view virtual nature environment, to help relax and increase energy levels (see Figure 3). The research took place in the university in the Netherlands, therefore the environment chosen was similar to the one in a forest in the Netherlands during the summer. In the VE, participants could walk around within the limits of the room observing the trees, flowers, bushes, and listening to the birds chirping. The purpose of this environment became an introduction to the study because while in it, participants could explore the size of the room, test the buttons on the controllers, observe the nature elements from various angles, and get used to the new environment. When participants were done exploring and wanted to start the first task, they were instructed to signal to the researcher. All tasks were enabled by the researcher, ensuring that the participants start the task from the correct location within the room.

Figure 3. Virtual nature environment.

Psychological well-being task: breathing tree

When transported to the breathing tree task, participants firstly were introduced to a task objective and a big grey tree next to it (see Figure 4). The task objective was as follows "Press and hold the grip button while inhaling and holding the breath, release the button while exhaling. Breathe accordingly to the voice instructions to bring the tree back to life". When participants chose to start the task and pressed a button on the controller, background noises (birds chirping) decreased, and a soothing voice started talking, introducing a breathing task with deep inhales and deep exhales. When the audio started, the tree began to move – expanding and contracting similarly to the lungs when breathing. As the exercise progressed, the tree slowly came back to life – became more saturated in colour. At the end of the exercise, the tree looked even brighter than the other trees in the background. The voice leading the participants through the task wrapped up the exercise, and they could continue the journey through the environment.

Figure 4. The task objective and the tree.

Physical well-being task: butterfly exercise

The butterfly exercise immediately started within the green tunnel. At the end of the tunnel, a new task objective appeared – “Find all the butterflies and make them fly away as fast as possible” (see Figure 5). Participants had to press a button on the controller to start the task. During the butterfly exercise, participants had to stretch into various directions, find, and using controllers press on all butterflies within the arch and make them fly away (see Figure 6). In the task, there was no actual time limit, just an encouragement to do it as fast as possible in order to make the activity a little more challenging. After all butterflies have been found, participants could continue to the final task.

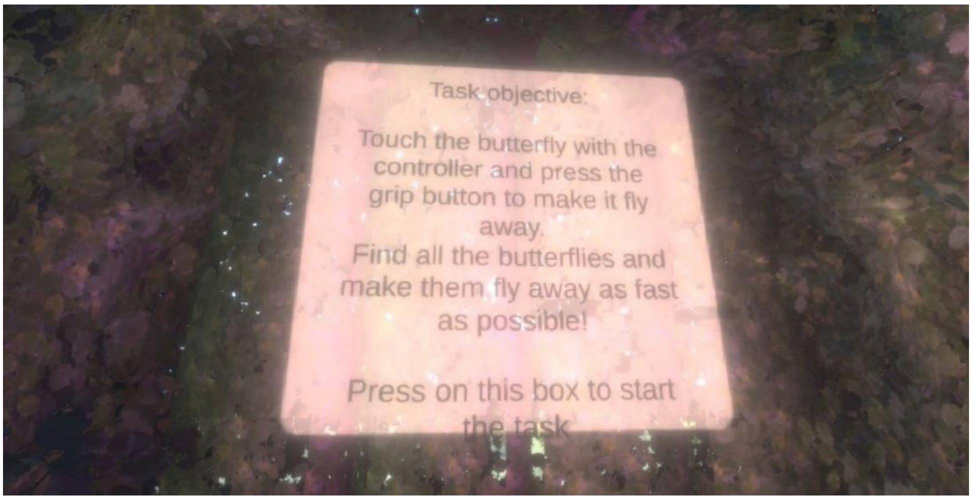

Figure 5. Butterfly task objective.

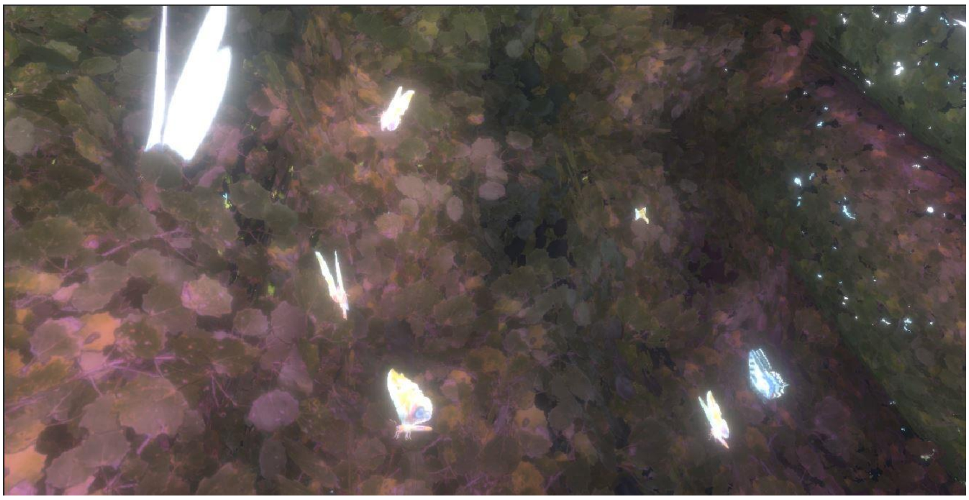

Figure 6. Butterflies in the arch.

Subjective vitality task: yoga

During the final yoga task, participants were introduced to a task objective to follow the instructions of the coach, next to it there was a character of a female coach presented standing on a yoga mat (see Figure 7). When pressed on the task objective the background noises of nature became subdued and an audio recording started playing. It introduced the exercises (e.g. side bends, chair pose) one by one together with the coach, first showing the exercise at a normal speed and afterward doing it together with the participant a little slower and incorporating the breath together with each exercise (see Figure 8). In the end, after the stretching, the coach invited participants to take some deep breaths and suggested setting a positive intention for the day. After the yoga task was done, the coach informed participants about the end of the exercise, and the walk through the VE was over.

Figure 7. Task objective next to the coach.

Figure 8. The coach doing a side bend to the left.

P1.2. Imaginative immersion before using VR and presence after using VR

Imaginative immersion before using VR

Results regarding imaginative immersion before using VR are presented in Table 4. In comparison to the norms provided by Robillard et al. (2002), all means except for the subscale Focus were positively statistically significantly higher than the norm. Meaning, that people in this study had a stronger ability to immerse themselves into different environments. The mean for the total ITQ in this study was also slightly statistically significantly higher than the norm. Only the subscale representing one's ability to focus was significantly lower in comparison to the norms. This indicates that some participants within the sample could get distracted from the task in the VE faster than the norm.

Table 4.

Imaginative immersion scores before using VR in the sample (N = 32) and the norm group.

	Sample			Norm group		
	M	*SD*	Score Range	*M*	*SD*	*t*-test
Involvement	20.41	5.67	8 – 31	15.33	8.67	5.07*
Focus	20.78	4.29	12 – 31	24.81	7.54	-5.31*
Emotion	15.91	4.26	7 – 24	14.25	6.70	2.20*
Game	9.31	4.52	3 – 19	6.56	4.95	3.45*
Total	70.88	14.33	36 – 110	64.11	13.11	2.67*

Note. * $p < 0.05$

Presence after using VR

The presence questionnaire was completed after using VR. Scores received are presented in Table 5 and compared with two norm groups by Robillard et al. (2002, 2003). For the total presence score, participants from this study scored significantly higher than the two norm groups. However, based on the subscale scores, results are quite similar to the norms provided by Robillard et al. (2002). Meaning that in comparison to the provided norms, participants of this study experienced a similar level of presence as the norm. Only subscales for Realism and Quality of Interface scored statistically significantly higher than the norms. In comparison to the norms by Robillard et al. (2003) participants showed mostly higher scores of presence. Only Possibility to Act and Possibility to Examine subscales were statistically significantly lower, and the subscale Self-Evaluation of Performance remained similar to the norm.

Table 5.

Presence scores before using VR in the sample (N = 32) and two norm groups.

	Sample			Norm group by Robillard et al. (2002)			Norm group by Robillard et al. (2003)		
	M	*SD*	Score range	*M*	*SD*	*t*-test	*M*	*SD*	*t*-test
Realism	32.66	4.65	24 – 44	29.45	12.04	3.90*	28.9	5.5	4.57*
Possibility to Act	19.81	3.35	11 – 25	20.76	6.01	-1.60	22.2	4.6	-4.03*
Quality of Interface	18.16	2.59	12 – 21	15.37	5.15	6.08*	16.2	3.0	4.27*
Possibility to Examine	14.50	2.68	8 – 20	15.38	4.90	-1.86	15.7	2.1	-2.54**
Self-Evaluation of Performance	11.59	1.86	7 – 14	11.00	2.87	1.80	11.5	2.1	0.28
Sounds	16.03	2.91	9 – 21	–	–	–	13.3	5.5	5.31*
Haptic	7.81	3.30	2 – 14	–	–	–	5.8	3.5	3.45*
Total	120.56	13.06	96 – 153	104.39	18.99	7.01*	93.7	11.2	11.64*

Note. * $p < 0.01$

*** $p < 0.05$*

Imaginative immersion and presence

To sum up, results obtained for imaginative immersion and presence questionnaires were mostly positive, with some exceptions. For imaginative immersion, results showed that participants of this study had a strong ability to feel immersed in comparison to the norm. Only the subscale Focus was an exception, scoring significantly lower than the norm. This suggested that some participants might have problems maintaining their focus while performing the tasks. Furthermore, the presence questionnaire has also shown some positive results. The total score was positively significantly higher in comparison to the norm groups. Most subscales either showed a significant positive difference or no difference between the groups. Only Possibility to Act and Possibility to Examine subscales scored statistically significantly lower than the norms. This suggests that participants lacked the freedom to do and explore things in the VE.

P1.3. User experiences

Initial impressions

Initial impressions of the participants were quite mixed, but a few main topics emerged. Thirteen participants mentioned that the environment was calming. As to reasons why they found the environment calming some participants mentioned the sounds “It was a comforting environment, especially including the sounds” (P12), others - the scenery “There were a lot of flowers and trees which was soothing” (P26), and the space “I liked the big space and the sense of being in a very open big space” (P15).

There was a division between participants regarding immersion and how realistic they perceived the environment. On the one hand, five participants mentioned that the VE was realistic, for example “I really liked the butterfly environment because I thought that looked realistic (for example how they flew away) and aesthetically pleasing. I also felt involved within the environment” (P27). On the other hand, six participants disagreed and mentioned that the graphics could be improved “It’s amazing how quickly I was able to adapt to the virtual environment, even though the graphics were not so sharp” (P1), “I like it overall. Although, as a gamer I hoped/wished it could be as same in quality as present video games are” (P11).

Other comments involved participant observations and personal experiences: “Looks interesting, you can come very close to objects, and I really wanted to discover everything there was to see" (P13), "Pretty fun I would say, this was my first experience with VR and so far, it was really cool!" (P17), "It feels like being in a new dimension similar to our own" (P28).

Parts participants enjoyed

Regarding the question of what participants enjoyed the most throughout the virtual experience, responses were quite similar to the previous question. The scenery and/or the sounds were mentioned by 21 participants as the most enjoyable part of the environment. Two participants also mentioned that they liked not having other people around, for example, "Mostly the feeling of being in a place completely alone. It was not crowded and appeared peaceful" (P2). The most complimented task throughout the experience was the butterfly task. Six people specifically mentioned it as the task that they liked the most "… Chasing the butterflies in between the flowers was very nice" (P24). The rest mainly focused on the aspects related to the HMD such as the ability to see things in 3D "I enjoyed that you could see all sides and that the plants were positioned quite real" (P19) and interact with the environment "I enjoyed moving around in the environment, as there was also almost no delay, so it felt quite natural" (P27).

Parts participants did not enjoy

To the question about what participants did not enjoy during the virtual experience, the most common answers were the small space and the graphics. Nine participants mentioned the small space issue "I was a little bit afraid to bump into something in the real room" (P30) and eight were not fond of the graphics "The quality of the assets themselves/the textures" (P4) or objects within the environment "Perhaps the nature itself was not looking that realistic" (P7). Furthermore, three participants mentioned struggling with controls during the breathing exercises. During the yoga task, two participants mentioned that it was difficult to do the poses and to press the buttons at the same time "… I needed to concentrate on pressing the controller instead of focusing on my breathing" (P3). Three people also mentioned that they wanted the environment to be a little more interactive, instead of only focusing on following instructions "The breathing sections didn't feel very interactive. I felt like I was just repeating after them. I wanted to touch the leaves" (P24).

Should this VE be offered again?

When asked whether participants would recommend the gamified nature environment to improve subjective vitality, 29 out of 32 participants answered yes. Sixteen participants reported noticing a difference after using the VR and thinking that it could do the same to others “Yes, because it helped me calm down it can help others” (P9). Three participants agreed that it can help others but only after some adjustments “Yes it can be, because if the quality of the graphics improve it looks very real…” (P21). Six participants suggested that VR could be used if a walk in a real-life nature environment is not possible “Yes, I think it should be offered again as it is a nice way to enjoy nature especially when the weather is bad or for people living in a big city with little nature around” (P6). Three participants who answered no, suggested that a walk in real-life would be better “… I think an actual walk in nature and being able to actually touch and feel the leaves for example would be beneficial…” (P22).

Motion sickness

Only two participants reported experiencing some motion sickness, their responses to the question were “Only slightly” (P6) and “Not so much. I have motion sickness sometimes, but it was alright now. Didn’t like the flicker in the screen, but the environment was cool enough to overcome that irritation” (P15). The rest of 30 participants reported experiencing no motion sickness, showing that the environment generally does not cause it.

Overall experience

To sum up, the initial impressions of the environment were quite positive. Various elements such as sounds, scenery, and open space made the participants feel calm. Other elements which were more interactive such as the ability to walk around and explore the objects within the environment made the experience more interesting and engaging. Six participants mentioned the butterfly exercise as their favourite since it was the most interactive one.

Regarding things that participants did not enjoy, eight participants mentioned the graphics, and nine participants mentioned the amount of space in the room that was used for the virtual experience. Additionally, in total eight participants wished that the controls would be slightly more intuitive and/or mentioned that making all tasks more interactive would create a more pleasurable experience.

The created VE was very well accepted, 29 out of 32 participants would recommend using it to improve subjective vitality. Although three participants suggested that additional improvements would be necessary for it to be even more effective, the majority (26 participants) mentioned that the virtual nature environment could help in times of need as it is.

Finally, only two out of 32 participants mentioned experiencing slight motion sickness, showing that the environment does not have a high chance of causing it for this target group.

Phase 1. Discussion

The main goal of Phase 1 of this study was to explore the design and development process of a gamified nature VE and address its usability (imaginative immersion, presence, and user experiences) for 32 university students.

P1.1. Design and development

In this phase, a gamified nature VE was designed and developed, creating a fully-functional VR application meant to improve subjective vitality of university students. The main challenge of the design phase was the small room. While the initial idea was to create a virtual walk in nature, the small size of the room research was conducted in, did not allow to implement it. Trying to avoid tripping on wires from the HMD and walking in a small space can affect the feeling of presence of the user. Therefore, the original idea of a virtual walk became a virtual experience. For the same reason, participants had to start each task from the same spot in the room, thus, had to be guided back by the researcher after each task. This could have also affected the feeling of presence. For safety reasons, Oculus Rift S offers a feature where one can set the limits of the room. When a person moves too close to a wall or an object, an either red or blue (based on the proximity) coloured contour appears to warn that there is an object or a wall close by. This feature was implemented for this research to help avoid injuries, yet it did not help with the space issue. Even with such adjustments, space limitations were often mentioned by participants. This problem is difficult to address, yet some solutions can already be found in the literature. For instance, Kanamori et al. (2018) suggested implementing the actual objects from the room into the environment. That way, people can better orient themselves within the room during the VR experience. Using real-life objects in a nature setting seems as if it could negatively affect one's experience, however, in the study by Kanamori et al. (2018) real-life objects were implemented in a VR shooter game, which took place outside. Partially displaying real-life objects in the environment did not reduce immersion. This could be one of the solutions how to deal with a small space issue and keep participants safe. Participants of that study suggested to 'harmonize' the real-life objects with the VE by creating the real-life objects from the assets within the environment (e.g. a chair made out of bushes). This way, participants can easily orient and recognize what it is, yet stay immersed within the environment (Kanamori et al., 2018). This idea seems especially good for spaces with more furniture which is difficult to move. Another option could be to use Electric Muscle Stimulation (EMS) as described by Auda, Pascher, and Schneegass (2019). EMS actuates the legs creating an illusion that one is walking straight, which is the case in VR, yet in reality, one walks in circles. This apparatus could help to explore large spaces within the VE and not feel space-bound. However, the EMS is still a work in progress and currently only works while walking straight and with no obstacles (Auda, Pascher, & Schneegass, 2019). Finding creative solutions on how to implement VR in smaller environments could be an interesting topic for future research since a lot of institutions that could offer VR as a method of treatment do not have large empty rooms for people to walk in.

Another important aspect to discuss is the development of the VE because it has highly adjusted the end result and was the most time-consuming part. Creating even a small VE requires a lot of theoretical and technical skills, such as psychological concepts, programming, human-computer interaction, and game design (Tao et al., 2021). Pre-made assets from Unity Asset Store vastly helped to simplify the process from the technical side, yet sometimes the assets did not look highly realistic (e.g. some flowers within the environment were 2D instead of 3D) or did not do what the initial design required (e.g. yoga animations did not include certain poses). Therefore, some things had to be adjusted based on what was offered in the online store. Using pre-made assets can help reduce the development time and costs, which are especially important in the health sector since that makes the environment cheaper and more easily available. However, due to such shortcuts, some design aspects might not be achieved. For example, if certain characters or objects are not available in the asset store, one would have to either think of how to replace them or create them out of different objects. An example of creating something from different objects was done in this study for the butterfly exercise. In the exercise, the green tunnel for the butterflies was created out of multiple green garden arches available on the asset store and placed next to each other to form a tunnel. It is important to keep in mind that health-related games will not reach the quality of commercial ones. They first need to focus on addressing health-related needs and not on the design itself. Therefore, an optimization problem should be considered: which level of precision needs to be reached in the VE, what is realistic, and affordable for health-related games. Additionally, end-users could be consulted in the design phase to help developers understand what is important to the end-user and what should they pay more attention to (Tao et al., 2021). This could also help with VR health game adoption and adherence rates (Tao et al., 2021). For the VE created, this research was only a pilot test and using the input received from participants some adjustments could already be made from both design and development parts, potentially improving the effects on usability, presence, and subjective vitality. The created VE is stored and available upon request at the BMS lab (see https://bmslab.utwente.nl/).

P1.2. Imaginative immersion and presence

In comparison to the norms provided by Robillard et al. (2002) participants of this study scored higher (except for the ability to focus) on imaginative immersion, meaning, that their ability to feel immersed was higher than expected. Which could have helped them to easier adjust and feel involved in the VE. People with a high sense of imaginative immersion can also let go of outside distractions faster and focus their attention on the task at hand easier (Krassmann et al., 2020). They tend to create stronger bonds with the environment, characters in it, and even experience the emotions that the atmosphere entails (Nacke & Lindley, 2008). Obtained high imaginative immersion scores suggested that participants in this study will experience a higher sense of presence since the ability to feel immersed is related to the ability to feel present (Khashe, Becerik-Gerber, Lucas, & Gratch, 2018). However, obtained presence questionnaire scores were very similar to the provided norms (Robillard et al. 2002, 2003) only Realism, Quality of Interface, Sounds, and Haptic subscales scored statistically significantly higher. This means that participants have experienced presence within the VE, but it was not as high as their imaginative immersion had predicted. According to the study done by van Gisbergen, Kovacs, Campos, van der Heeft, and Vugts (2019) a more realistic environment does not immediately imply more immersion, presence, and even more realistic behaviour from the user. All elements within the environment have to be on a similar level for the environment to be perceived as more realistic (van Gisbergen et al., 2019). Another aspect to consider is that according to Riva et al. (2007) there is a bidirectional interaction between feeling present within the VE and emotions (e.g. anxiety, relaxation). Meaning, when people feel present within the VE, it can elicit emotions but at the same time, a VE that makes people feel certain emotions can create a stronger sense of presence (Riva et al., 2007). Thus, exploring target groups with different abilities to experience immersion could provide a good insight into presence. It could also prove to be useful investigating the emotional aspect within the VR to see which emotions can elicit the most presence or to explore what type of environments and/or tasks can evoke certain emotions.

The methods chosen to measure imaginative immersion and presence were simple to use, analyse, and were not too labour intensive. Since participants had to fill in multiple questionnaires, it was good that the translated immersive tendencies and presence questionnaires were relatively short and did not repeat themselves – one was administered before and the other one after the experiment. However, there were two main drawbacks to the questionnaires. The first one was that the internal consistencies for some subscales (Focus in the immersive tendencies questionnaire, Quality of Interface, and Possibility to Examine in presence questionnaire) were low. It is suggested that for scales with less than ten items, an acceptable Cronbach's alpha should be $\alpha > 0.5$ (Pallant, 2011), meanwhile, some of the subscales scored as low as $\alpha = .32$. The second drawback was that there was little information on the translated questionnaires in terms of psychometric properties, aside from the original literature with longer questionnaire versions. Suggesting that their validity is not clear and that further assessment is needed.

P1.3. User experiences

In the open-ended questions after using the VE, participants mentioned enjoying the interaction with the VE. The butterfly exercise was mentioned the most, in comparison to the other tasks, as a favourite. This task was also the most interactive one since participants could move within the environment and their actions could change something in it (e.g. a press of a button made the butterflies fly away). That is an example of simulation, where the user does something within the environment and the outcome is presented immediately (cause and effect) (Oinas-Kukkonen & Harjumaa, 2008). In the future, by implementing more simulation-based design, participants could be taught positive behaviours more efficiently. Learnt positive behaviours could be then applied in real-life (e.g. participants get rewarded for choosing healthy food instead of junk food in a virtual supermarket). Additionally, if participants enjoy more simulation-based games, the format could be used to increase adherence to VR treatments that require more sessions (Tao et al., 2021).

A major point for improvement mentioned by participants was graphics. Although most mentioned that the graphics did not intervene with the task enjoyment, it was still a point for improvement, particularly in comparison to the current graphics in VR games. However, as mentioned previously, creating a VE from scratch can be very time and labour intensive, especially when it comes to the intricacies of nature (e.g. trees swaying in the wind, leaves falling). The resolution from 3D models can be lost due to technological misinterpretations (data loss, storage, computational constraints) which leads to 3D models looking very simple in comparison to the real world (Huang, Lucash, Simpson, Helgeson, & Klippel, 2019). In other words, without additional work, VR displays cannot produce all the small details people see in reality. This suggests considering the optimization problem - find the middle ground between effectiveness, time, money, and quality.

Using open-ended questions after experiencing the VE, encouraging both positive and negative points, was used to receive input from participants. This way information that was not collected using standardized questionnaires was obtained (e.g. that usability could be improved during breathing tasks). Participant feedback could be used to improve the environment in the future. However, in the background questionnaire participants reported that they were only somewhat familiar with VR environments and that they enjoy walking in nature very much. This could have had an influence on their experiences within the VE and the feedback that they gave, since participants who do not enjoy walks in nature might have reacted more negatively or participants with more VR experience could have provided feedback on more technical aspects of the environment. For future research, it would be interesting to use input from a heterogeneous sample (in terms of experience with VR and enjoyment of walking in nature), to create a human-centred design. Participants who enjoy and do not enjoy walks in nature could provide insights on how to make the environment pleasurable for both groups and participants with a lot of experience with VR could help with more intricate questions regarding development, layout, and details, whereas inexperienced users could help with usability.

Strengths and limitations

This study had several strengths. The main strength was that while working in collaboration with an interdisciplinary team, a fully functioning gamified nature VE was created, which was the aim of this part of the study. Phase 1 has also explored the process of design and development, and how the final product can change due to various reasons (e.g. technical skills, time, space limitations). It has also provided a good insight into important aspects that should be kept in mind while creating a VE. For example, the study showed that interactive experiences are appreciated more by users and created a well-received base for a VE that could improve subjective vitality of students. Finally, questionnaires showed that participants felt present in the VE, reported not experiencing motion sickness, and that they would recommend the gamified VE to improve subjective vitality or as an alternative to a real nature experience to others.

This study also had some limitations that should be considered. The developed environment is still a prototype. Before implementing it in research or practice, some adjustments are required. For example, the animations during the yoga task should be adjusted to improve clarity, in one of the poses the yoga teacher crosses the legs which was not meant to happen, and some participants have tried to mimic it. Furthermore, tasks involving breathing (tree and yoga) were less interactive, the pressing of a button did not actually affect anything within the environment, which could be improved for the final product to increase usability and make the end-user feel more involved in the process.

Phase 2: Pilot effectiveness study of the VE on subjective vitality

Phase 2. Method

Participants

The study involved the same 32 participants as in Phase 1, for further details refer to the participant section in Phase 1.

Procedure

The procedure for this study followed a strict scenario. When arrived at the lab, each participant was informed about the procedure, given the time to read and sign the informed consent. Only the intention and use of the stressful task (public speaking and mental arithmetic) was not disclosed. Afterward, one was asked to fill in a questionnaire with questions regarding one's age, gender, nationality, level of education, a background questionnaire about previous experiences with VR, nature, and current stress levels (see Phase 1), and a questionnaire measuring imaginative immersion.

After the introduction and questionnaires, the HR monitor was attached to the participant and he or she was introduced to the first task – public speaking, followed by a mental arithmetic task. Both tasks including the preparation lasted approximately 15 minutes. After that, the participant was encouraged by the researcher to take a seat and was given two questionnaires: one measuring subjective vitality and the other measuring energy-tension. While the participant was busy filling out the questionnaires, other tasks were prepared by the researcher.

After the questionnaires were completed, the participant was introduced to the VR display, instructed regarding its use, motion sickness, and hygiene safety measures.

Controllers were given to the participant and he or she was invited to put on the VR headset. Then the second part of the research began – a gamified virtual nature experience. The participant had to first walk in a nature VE (in a room in the laboratory) to get used to the environment and then was introduced to the three tasks one by one: breathing tree, butterfly exercise, and yoga task. All tasks were started by the researcher and involved the use of controllers to interact with the software. The virtual experience lasted approximately 10 minutes.

After all three tasks were completed, the gamified walk in nature was over and the participant was invited by the researcher to take off the headset. He or she was asked to again fill in subjective vitality and energy-tension questionnaires together with the usability questionnaire regarding presence, and to answer some open-ended questions inspired by Foronda et al. (2016) regarding user experiences (see Phase 1). When everything was completed, the researcher explained more regarding the intention of the stressful task and why deception was used regarding the recording of the task and asked again for informed consent. Finally, the importance of subjective vitality and the research itself was explained, additional questions were answered.

Measures

Subjective Vitality Scale (SVS)

The 7-item SVS assesses “energy and aliveness” (Ryan & Frederick, 1997, p. 530; see Appendix A). 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). Cronbach’s alpha for the questionnaire in the before VR condition was acceptable ($\alpha = .75$), and for the after VR condition was poor ($\alpha = .57$).

Activation–Deactivation Adjective Check List (AD ACL)

AD ACL is a self-report measure constructed by Thayer (1986) to measure momentary arousal or activation states (see Appendix B). The measure provides 20 different adjectives (e.g. active, wakeful, tense) and each of them is scored on a four-point scale from 1

= “definitely do not feel” to 4 = “definitely feel” (see Table 6). It is scored in two pairs of bipolar dimensions comprised of Energetic arousal (Energy vs. Tiredness) and Tense arousal (Tension vs. Calmness) (Boyle et al., 2015; Thayer, Newman, & McClain, 1994). According to Thayer (1978), the bipolar dimensions for Energetic and Tense arousal have good within-pair correlations (-.58 and -.50 respectively). These states form a curvilinear relationship, meaning that moderate levels of tension can improve energy, yet higher levels of tension cause tiredness and reduce energy (Thayer, 1986).

Table 6.

An overview of the AD ACL and its subscales as provided by Thayer (1986).

		Number of items	Example item	Min	Max	Cronbach's alpha before VR	after VR
AD ACL Total		20		20	80		
Tense Arousal		10		10	40	0.80	0.74
	Tension	5	Jittery	5	20		
	Calmness	5	Quiet	5	20		
Energetic Arousal		10		10	40	0.91	0.83
	Energy	5	Lively	5	20		
	Tiredness	5	Sleepy	5	20		

Note. AD ACL = Activation–Deactivation Adjective Check List.

Physiological Measure

To measure whether any physiological changes occur throughout the experience, HR and HRV have been chosen to measure. An increase in HR shows the activity of the sympathetic nervous system which gets activated while engaging in more challenging activities such as sports, whereas the parasympathetic system activates when HR slows down when one goes to sleep for example (Taelman, Vandeput, Spaepen, & Van Huffel, 2009). The interaction between the two nervous systems is HRV. A change in HR and its variability can help determine individuals’ stress levels (Taelman, Vandeput, Spaepen, & Van Huffel, 2009). Thus, to be able to track one’s HR and HRV non-intrusively, an Empatica E4 wristband tracker has been used. It is a wearable that helps to acquire data in real-time, among other trackers it provides photoplethysmography (PPG) which is a blood volume pulse and from it, the required measures can be derived.

The HR and HRV were analysed using Kubios HRV standard version 3.5.0. Each participant's data was uploaded and processed separately within the software. However, the output from Empatica E4 recorded only when a certain threshold was reached which was not specified in the manual. Meaning, that there were a lot of missing data points, and most data outputs were similar to Figure 9. Important to note was that the time points also did not transfer correctly in the data analysis program, and it could not be recognized at which point in time measurements took place. Therefore, data were not analysed further and were not taken into the discussion.

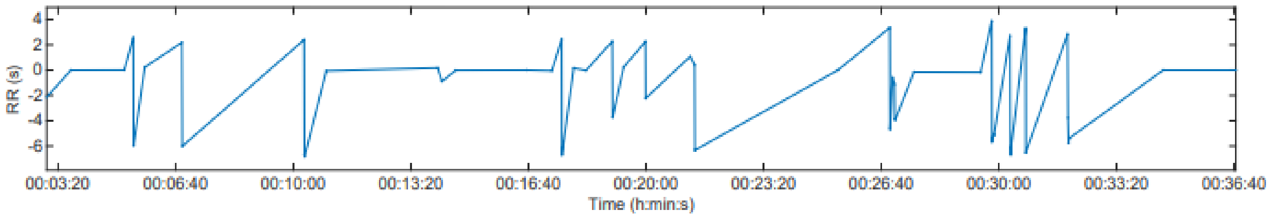

Figure 9. An example of a dataset with very few measurement points.

Stress induced in a laboratory setting

To measure whether a walk in a virtual forest and additional tasks affect subjective vitality, first, slight to moderate psychological tension had to be induced. Although there are multiple ways to do so in a laboratory setting, the most efficient strategy is a combination of public speaking and cognitive tasks with a sense of uncontrollability and a social-evaluative threat where one could be negatively critiqued by others (Dickerson & Kemeny, 2004). The procedure chosen was similar to the Trier Social Stress Test (see Kirschbaum, Pirke, & Hellhammer, 1993). To begin with, the participant was instructed to give a short speech of five minutes to the researcher. This was an unexpected task, and the participant had only five minutes to choose and prepare a speech from a list of topics (see Appendix E). He or she was informed that the speech, as well as an additional cognitive task, will be video recorded and analysed afterward (which was not the case, there was a camera, but it was not on). This instruction was given to create a social-evaluative threat. If the participant finished early, he or she was encouraged by the researcher to continue the speech (e.g. "Your time is not over yet, please continue"). Afterward, a time-bound (lasting five minutes) mental arithmetic task was introduced and performed by the participant. The task was to count backwards in steps of 13 from 1687.

Data analysis

For each questionnaire, similarly as in Phase 1, data were analysed using SPSS. A Shapiro-Wilk test of normality was performed, and based on the results an appropriate analysis method was chosen. If data were normally distributed ($p > 0.05$), then a paired samples t-test was performed comparing before VR and after VR conditions. If it deviated from a normal distribution ($p < 0.05$) then the Wilcoxon signed rank test was used.

Subjective Vitality Scale

To analyse the SVS, the negatively phrased ("I don't feel very energetic") item from the scale was reversed in SPSS. Then, means and standard deviations were calculated for before and after using the VE and reported together with the t-value and significance of the difference in means.

Activation–Deactivation Adjective Check List

Before analysing the AD ACL, Tiredness (except for "wide-awake" and "wakeful") and Calmness subscale scores were reversed. Then, from Energy and reversed Tiredness subscale scores means and standard deviations were calculated and reported for Energetic arousal before and after VR conditions. Finally, means and standard deviations were calculated and reported for Tense arousal before and after VR conditions by combining reversed Calmness and Tension subscale scores.

Phase 2. Results

H 1: Subjective Vitality

The conducted test of normality has shown that the before VR condition was not normally distributed ($p = 0.03$) and the after VR condition data was normally distributed ($p = 0.14$). The normality violation in the before condition was minor, therefore, paired samples t-test was decided to perform to measure subjective vitality between both conditions. A statistically significant increase was found for subjective vitality from before ($M = 4.63$, $SD = 0.91$) to after VR ($M = 4.95$, $SD = 0.65$) conditions; $t(31) = -2.71$, $p = 0.01$. Meaning, that VR had a positive impact on subjective vitality of participants.

H 2: Energy-Tension

Table 7 summarizes means and standard deviations for Energetic and Tense arousal states of the AD ACL for before and after VR conditions. For both Energetic and Tense arousal before and after VR conditions, normality tests were conducted and were all normally distributed ($p > 0.05$). Therefore, a paired samples t-test was chosen to conduct. It showed no statistically significant difference between before and after VR conditions for Energetic arousal. This means that there was no improvement regarding the energy of participants. However, a statistically significant decrease in Tense arousal was found from before to after VR conditions. This means that the environment reduced the tension and stress participants accumulated during stressful tasks.

Table 7.

Energy-tension results before and after using VR.

	Before using VR		After using VR		
	M	*SD*	*M*	*SD*	*t*-test
Energetic arousal	2.98	0.67	3.14	0.48	-1.64
Tense arousal	2.49	0.59	1.67	0.40	8.44*

Note. * $p < 0.01$

Correlation between subjective vitality and energy-tension

For descriptive purposes, it was decided to carry out a post-hoc analysis. Its goal was to determine whether there is a correlation between subjective vitality and energy-tension scales between pre- and post- VR conditions. To do so, first, the Tense arousal subscale from AD ACL was reversed. Then, a Pearson's correlation was conducted to determine the direction and strength of the relationship between the two scales. It showed a strong significant positive correlation between subjective vitality and energy-tension in the pre- VR condition ($r = .72$, $p < 0.01$). The post- VR condition showed a moderate significant positive correlation ($r = .47$, $p < 0.01$) between subjective vitality and energy-tension. This analysis has revealed that there is a positive relationship between the two questionnaires.

Phase 2. Discussion

The second phase was a pilot effectiveness study, its goal was to introduce the gamified nature VE and test whether it can help to improve subjective vitality and energy-tension of 32 university students after a stressful situation.

P2.1. Subjective vitality

The first hypothesis explored whether students would report greater subjective vitality during the before VR condition in comparison to the after VR condition. Questionnaire results showed a significant positive change in subjective vitality in the after VR condition in comparison to the before VR condition. This is in line with prior research suggesting that a five-minute walk in a nature VE is enough to improve subjective vitality (Mattila et al., 2020). In the case of this study, a virtual walk was not implemented, yet a short virtual nature experience with some gamified psychological and physical elements was able to yield similar results. Findings of this study together with other literature (e.g. Mattila et al., 2020; Plante et al., 2006) suggest that using VR is a time-efficient way to improve subjective vitality short-term: only a few minutes are enough to find noticeable results immediately after using the VR. Exploring for how long the positive effects of the VE last and the long-term effects of using VR to improve subjective vitality would be beneficial to further explore the field.

P2.2. Energy-tension

The second hypothesis compared energy-tension in the before and after VR conditions. It showed a statistically significant decrease in the after VR condition compared to the before VR condition for Tense arousal. Meaning that participants became calmer after the VR experience. However, no significant differences have been found between before and after VR conditions for Energetic arousal. Such results could be explained by a study conducted by Plante et al. (2006). The findings of the study suggested that exercising outside increased energy yet was not necessarily relaxing. Suggested reasons for that were fresh air, scenery, and alertness in case of an emergency. Findings also suggested that although VR condition paired with exercise did not increase energy, it reduced tension, which was also found in this pilot effectiveness study. Exercising in an enclosed environment provides a sense of security and comfort, reducing distractions (Plante et al., 2006).

Aside from exercising outdoors multiple studies have shown that only exercise itself can improve energy, psychological exercises are not sufficient enough (Giurgiu, Ebner-Priemer, & Dumuid, 2021; Plante et al., 2006). However, in this study using a combination of breathing, butterfly catching, and yoga exercises the participant energy levels did not increase. Therefore, it could only be hypothesized that maybe the exercises were not engaging or challenging enough for the participants. Adding moderate-to-vigorous physical activity such as walking at a higher pace could potentially be beneficial in improving Energetic arousal as it has been shown by Bourke, Hilland, and Craike (2021). Since physical activity is a crucial part of subjective vitality and the current VE did not affect it that much, combining the current environment with a more intense physical exercise in the future could create an all-rounding VR experience.

Subjective vitality and energy-tension

A post-hoc analysis was conducted to explore whether subjective vitality and energy-tension questionnaires in before and after VR conditions were correlated. The analysis showed statistically significant positive correlations between both questionnaires. Meaning that when subjective vitality increases, positive aspects of energy-tension increase as well, and the other way around, reduced tension and improved energy results in positive emotion and positive action (Dagar, Pandey, & Navare, 2020). This goes in line with the theory that both psychological and physical well-being is required to achieve subjective vitality (Ryan & Frederick, 1997).

On a more variable level, subjective vitality and energy-tension questionnaires evaluated each participant's momentary experiences throughout the study and helped to self-evaluate feelings both from positive and negative prisms. The questionnaires were short and easy to administer. The only problem with the energy-tension questionnaire was that not all participants understood the meaning of some words. The researcher had to have explanations prepared for some of the expressions such as "full-of-pep" or "placid". Thus, in the future, it would be good to either find a way to simplify the words or have explanations next to them, especially if used with non-native English speakers or younger target groups.

Strengths and limitations

There were multiple strengths that Phase 2 of the study has shown. The first one was that the pilot test proved that the VE can improve subjective vitality and reduce Tense arousal. That was the main goal of this phase of the study. The second one concerns the appropriate, short, and efficient questionnaires that were chosen to measure subjective vitality and energy-tension. They simplified the process both for participants and the researcher.

Some limitations have also been observed throughout the second phase. The first and the most important limitation was that there was no control group. Without a control group it is impossible to conclude whether effects can be attributed to the intervention. Subjective vitality and energy-tension could have increased just because some time has passed since the stressful tasks were conducted and the tension decreased after time as an adaptive reaction. Secondly, during the stressful tasks (both public speaking and mental arithmetic) participants were facing a window (which could not be covered), the university is located in a relatively green area and participants could look through the window while performing the tasks which might have positively affected their stress levels. Thirdly, sometimes unrelated noises were interrupting the experience such as people walking in the hallways, closing doors, trucks passing by outside, and others. This could have potentially also affected the experiences, inducing even more stress during the stressful task and/or reducing the effectiveness of the VE. Finally, because the physiological measure could not be analysed, it is not clear whether the stress induced in the laboratory setting had an impact on participants' physiological reactions. Although self-reported measures show a change, the physiological measurement in its objective character was also as important for this study and yet was not addressed.

Future directions

Creating a VE to improve subjective vitality from scratch was a resource-intensive journey. It required to learn about VR application development, technology, theory, and practice. It took multiple people to make a working prototype. However, it still requires a lot more work to adjust, polish, and test it, to create a final product that could be introduced to the public. Even then, the final product might not be as appealing as the other VR applications the gaming industry makes. This raises a question, is it worth creating completely new VE's instead of waiting on the gaming industry to provide people with well-being applications?

There are two main drawbacks to creating completely new VR applications. Firstly, designing, developing, and testing a VR application is a tiresome and resource-intensive process (Hanson & Shelton, 2008). It can take a lot of time to create a VE which has significant effects. Although in this study a working prototype has been created, it still requires more work (such as adjusting the tasks based on the received feedback, creating an interface for the users) and research to finalize it. Secondly, developing a VE is expensive (Hanson & Shelton, 2008). It requires a team of people with different skills, computers, VR equipment, and testing which can also be costly. Even after creating the VE and releasing it into the public maintenance of the environment will be required which, again, demands resources.

There are also some positives about creating new VR applications. Firstly, relying on the gaming industry to create something useful for well-being is unsustainable. Most games focus on being engaging and attractive to the user, thus additional testing whether the applications provide any benefits is unnecessary for their creators. There are already companies focusing on creating VE's for psychologists, yet they find simpler methods to develop a VE. For example, the company MOOVD which creates VE's for exposure therapy uses 360° video material implemented into VR (Moovd, n.d.). They save time and resources on development and instead invest in good quality video materials. The idea used in this research, creating the environment out of "blocks" or tasks, could also help reduce costs and improve user engagement. By creating different tasks to improve subjective vitality the knowledge of its creators increases and the development price for each block reduces (Hanson & Shelton, 2008). Such blocks can be later combined to create a different experience each time and even be used to target more specific problems. Having a library of different blocks would also ensure that users are not bored of the environment and can continue using it for longer. Secondly, from the user perspective, when the environment is made available, people can purchase it once and use it daily. The use of a VE that can improve subjective vitality could prevent negative emotions, help relax, and breathe, encourage physical movement throughout the day. Using the environment could prevent developing mental health and physical problems, which might be costly in the future. Such environment could also be used together with or after treatment. Thirdly, buying VR equipment may seem to be costly, yet VR HMD's are becoming a more mainstream product, available for more affordable prices than before (Harley, 2020). Furthermore, purchasing the HMD could still be a cheaper option than waiting for the problems to progress and then seeking treatment, or as maintenance after treatment.

To conclude, creating a completely new VE to improve subjective vitality is very resource-intensive, yet a start has already been made in this study – a working prototype has been created. Showing very good results, it gives hope that by improving upon already created blocks and with the addition of new ones an impactful environment can be completed. With it, initial development costs can be outweighed by reduced mental health and physical problems of the VE's users.

General conclusion

To sum up, this study had two main goals. The first one was to design and develop a virtual nature environment with gamified elements for university students and to explore its usability using imaginative immersion, presence, and user experiences. The second goal of this study focused on exploring to what extent a gamified nature VE can improve subjective vitality and energy-tension of students after a stressful situation. Throughout the course of the study, a fully functioning prototype of the VE was created while working together with an interdisciplinary team. The questionnaires regarding usability showed that participants of the study have a strong ability to feel immersed and reported mostly positive feelings of presence within the environment. User experiences highlighted that with some additional adjustments regarding usability, the environment could be used in the future. Most participants mentioned enjoying the experience, and that they would recommend it to others. To induce some stress, public speaking and mental arithmetic tasks were used before the VR experience. The HR monitor used did not provide sufficient data, thus, the physiological measures were decided not to include in the data analysis. Subjective vitality and energy-tension questionnaires were conducted before and after using VR. They showed that after using the gamified nature VE, participants have expressed significantly improved subjective vitality and reduced tension. However, these results should be taken with caution, since there was no control group to account for other variables. Throughout the two phases, both goals were achieved, creating a fully functioning prototype of a gamified nature VE which can improve its users' subjective vitality. With some adjustments regarding usability, interactions with the environment, and more aerobic exercises, this VE would be ready to test on larger and/or more diverse groups of users to improve subjective vitality.

References

Aganoff, J. A., & Boyle, G. J. (1994). Aerobic exercise, mood states and menstrual cycle symptoms. *Journal of psychosomatic research*, *38*(3), 183-192. https://doi.org/10.1016/0022-3999(94)90114-7

Annerstedt, M., Jönsson, P., Wallergård, M., Johansson, G., Karlson, B., Grahn, P., Hansen, A. M., & Währborg, P. (2013). Inducing physiological stress recovery with sounds of nature in a virtual reality forest—Results from a pilot study. *Physiology & behavior*, *118*, 240-250. https://doi.org/10.1016/j.physbeh.2013.05.023

Armbrüster, C., Wolter, M., Kuhlen, T., Spijkers, W., & Fimm, B. (2008). Depth perception in virtual reality: distance estimations in peri-and extrapersonal space. *Cyberpsychology & Behavior*, *11*(1), 9-15. DOI: 10.1089/cpb.2007.9935

Auda, J., Pascher, M., & Schneegass, S. (2019, May). Around the (Virtual) World: Infinite Walking in Virtual Reality Using Electrical Muscle Stimulation. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1-8). https://doi.org/10.1145/3290605.3300661

Bayram, N., & Bilgel, N. (2008). The prevalence and socio-demographic correlations of depression, anxiety and stress among a group of university students. *Social psychiatry and psychiatric epidemiology*, *43*(8), 667-672. DOI 10.1007/s00127-008-0345-x

Bostic, T. J., Rubio, D. M., & Hood, M. (2000). A validation of the subjective vitality scale using structural equation modeling. *Social Indicators Research*, *52*(3), 313-324.

Bourke, M., Hilland, T. A., & Craike, M. (2021). Domain specific association between physical activity and affect in adolescents' daily lives: an ecological momentary assessment study. *Psychology & Health*, 1-20. https://doi.org/10.1080/08870446.2021.1965603

Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: how much immersion is enough?. *Computer*, *40*(7), 36-43.

Boyle, G. J., Helmes, E., Matthews, G., & Izard, C. E. (2015). Measures of affect dimensions. In *Measures of personality and social psychological constructs* (pp. 190-224). Academic Press. http://dx.doi.org/10.1016/B978-0-12-386915-9.00008-5

Braunstein, A. (2020). Supernatural VR Game Review – It's a Heart Pumping Cardio Workout. *VR Fitness Insider*. Retrieved from: https://www.vrfitnessinsider.com/review/supernatural-vr-game-review/

Brown, E., & Cairns, P. (2004, April). A grounded investigation of game immersion. In *CHI'04 extended abstracts on Human factors in computing systems* (pp. 1297-1300).

Cakmak, T. (2015). The Cyberith Virtualizer. *International Journal of Virtual Reality*, *15*(1), 1-2.

Castillo, I., Tomás, I., & Balaguer, I. (2017). The Spanish-version of the Subjective Vitality Scale: Psychometric properties and evidence of validity. *The Spanish Journal of Psychology*, *20*. https://doi.org/10.1017/sjp.2017.22

Chow, Y. W., Susilo, W., Phillips, J. G., Baek, J., & Vlahu-Gjorgievska, E. (2017). Video Games and Virtual Reality as Persuasive Technologies for Health Care: An Overview. *J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.*, *8*(3), 18-35.

Cornforth, D., Tarvainen, M. P., Jelinek, H. F., (2014). How to Calculate Renyi Entropy from Heart Rate Variability, and Why it Matters for Detecting Cardiac Autonomic Neuropathy. Frontiers in Bioengineering and Biotechnology: Computational Physiology and Medicine. doi:10.3389/fbioe.2014.00034.

Cubicle Ninjas (2016). Guided Meditation VR. Retrieved from https://store.steampowered.com/app/397750/Guided_Meditation_VR/

Dagar, C., Pandey, A., & Navare, A. (2020). How Yoga-Based Practices Build Altruistic Behavior? Examining the Role of Subjective Vitality, Self-transcendence, and Psychological Capital. *Journal of Business Ethics*, 1-16. https://doi.org/10.1007/s10551-020-04654-7

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psychological bulletin*, *130*(3), 355. DOI: 10.1037/0033-2909.130.3.355

Ermi, L., & Mäyrä, F. (2005). Fundamental components of the gameplay experience: Analysing immersion. In *Proceedings of the DiGRA conference Changing views: worlds in play.*

Fallowfield, L. (2009). What is quality of life. *What is ...?*, *2*. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.734.6699&rep=rep1&type=pdf

Felce, D., & Perry, J. (1995). Quality of life: Its definition and measurement. *Research in developmental disabilities*, *16*(1), 51-74. https://doi-org.ezproxy2.utwente.nl/10.1016/0891-4222(94)00028-8

Fini, A. A. S., Kavousian, J., Beigy, A., & Emami, M. (2010). Subjective vitality and its anticipating variables on students. *Procedia - Social and Behavioral Sciences*, *5*, 150–156. https://doi.org/10.1016/j.sbspro.2010.07.064

Fleming, T. M., Bavin, L., Stasiak, K., Hermansson-Webb, E., Merry, S. N., Cheek, C., Lucassen, M., Lau, H. M., Pollmuller, B., & Hetrick, S. (2017). Serious games and gamification for mental health: current status and promising directions. *Frontiers in psychiatry*, *7*, 215. https://doi.org/10.3389/fpsyt.2016.00215

Foronda, C. L., Shubeck, K., Swoboda, S. M., Hudson, K. W., Budhathoki, C., Sullivan, N., & Hu, X. (2016). Impact of virtual simulation to teach concepts of disaster triage. *Clinical Simulation in Nursing*, *12*(4), 137-144. https://doi.org/10.1016/j.ecns.2016.02.004

Giurgiu, M., Ebner-Priemer, U. W., & Dumuid, D. (2021). Compositional insights on the association between physical activity and sedentary behavior on momentary mood in daily life. *Psychology of Sport and Exercise*, 102102. https://doi.org/10.1016/j.psychsport.2021.102102

Hanson, K., & Shelton, B. E. (2008). Design and development of virtual reality: analysis of challenges faced by educators. *Journal of Educational Technology & Society*, *11*(1), 118-131.

Harley, D. (2020). Palmer Luckey and the rise of contemporary virtual reality. *Convergence*, *26*(5-6), 1144-1158. DOI: 10.1177/ 1354856519860237

Herbert, C., Meixner, F., Wiebking, C., & Gilg, V. (2020). Regular physical activity, short-term exercise, mental health, and well-being among university students: the results of an online and a laboratory study. *Frontiers in psychology*, *11*, 509. https://doi.org/10.3389/fpsyg.2020.00509

Horváthová, D., Siládi, V., & Lacková, E. (2015). Phobia treatment with the help of virtual reality. In *2015 IEEE 13th International Scientific Conference on Informatics* (pp. 114-119). IEEE.

Huang, J., Lucash, M. S., Simpson, M. B., Helgeson, C., & Klippel, A. (2019, March). Visualizing natural environments from data in virtual reality: Combining realism and uncertainty. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 1485-1488). IEEE.

Jones, T., Moore, T., & Choo, J. (2016). The impact of virtual reality on chronic pain. *PloS one*, *11*(12), e0167523. https://doi.org/10.1371/journal.pone.0167523

Kanamori, K., Sakata, N., Tominaga, T., Hijikata, Y., Harada, K., & Kiyokawa, K. (2018, October). Obstacle avoidance method in real space for virtual reality immersion. In *2018 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 80-89). IEEE. DOI 10.1109/ISMAR.2018.00033

Khashe, S., Becerik-Gerber, B., Lucas, G., & Gratch, J. (2018). Persuasive effects of immersion in virtual environments for measuring pro-environmental behaviors. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 35, pp. 1-7). IAARC Publications.

Kim, H. G., Cheon, E. J., Bai, D. S., Lee, Y. H., & Koo, B. H. (2018). Stress and heart rate variability: a meta-analysis and review of the literature. *Psychiatry investigation*, *15*(3), 235. https://dx.doi.org/10.30773%2Fpi.2017.08.17

Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The 'Trier Social Stress Test'–a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, *28*(1-2), 76-81.

Klinger, E., Bouchard, S., Légeron, P., Roy, S., Lauer, F., Chemin, I., & Nugues, P. (2005). Virtual reality therapy versus cognitive behavior therapy for social phobia: A preliminary controlled study. *Cyberpsychology & behavior*, *8*(1), 76-88.

Krassmann, A. L., Melo, M., Peixoto, B., Pinto, D., Bessa, M., & Bercht, M. (2020, July). Learning in virtual reality: Investigating the effects of immersive tendencies and sense of presence. In *International Conference on Human-Computer Interaction* (pp. 270-286). Springer, Cham.

Lee, K. E., Sargent, L. D., Williams, N. S., & Williams, K. J. (2018). Linking green micro-breaks with mood and performance: Mediating roles of coherence and effort. *Journal of Environmental Psychology*. https://doi-org.ezproxy2.utwente.nl/10.1016/j.jenvp.2018.10.010

Marquié, J. C., Jourdan-Boddaert, L., & Huet, N. (2002). Do older adults underestimate their actual computer knowledge?. *Behaviour & Information Technology*, *21*(4), 273-280. https://doi.org/10.1080/0144929021000020998

Martens, D. (2016). Virtually usable: A review of virtual reality usability evaluation methods. Retrieved from: https://danamartensmfadt.files.wordpress.com/2016/08/virtuallyusable.pdf .

Mattila, O., Korhonen, A., Pöyry, E., Hauru, K., Holopainen, J., & Parvinen, P. (2020). Restoration in a virtual reality forest environment. *Computers in Human Behavior*, *107*, 106295. https://doi.org/10.1016/j.chb.2020.106295Get

Miksza, P., Evans, P., & McPherson, G. E. (2019). Wellness among university-level music students: a study of the predictors of subjective vitality. *Musicae Scientiae*, 1029864919860554.

Miksza, P., Evans, P., & McPherson, G. E. (2021). Wellness among university-level music students: a study of the predictors of subjective vitality. *Musicae Scientiae*, *25*(2), 143-160.

Moovd, (n.d.). *Virtual Reality Exposure Therapy*. Treatment Methods. Retrieved from https://moovd.nl/en/methods/virtual-reality-exposure-therapy/

Morina, N., Ijntema, H., Meyerbröker, K., & Emmelkamp, P. M. (2015). Can virtual reality exposure therapy gains be generalized to real-life? A meta-analysis of studies applying behavioral assessments. *Behaviour research and therapy*, *74*, 18-24. https://doi.org/10.1016/j.brat.2015.08.010

Nacke, L., & Lindley, C. A. (2008, November). Flow and immersion in first-person shooters: measuring the player's gameplay experience. In *Proceedings of the 2008 conference on future play: Research, play, share* (pp. 81-88).

Nguyen-Michel, S. T., Unger, J. B., Hamilton, J., & Spruijt-Metz, D. (2006). Associations between physical activity and perceived stress/hassles in college students. *Stress and Health: Journal of the International Society for the Investigation of Stress*, *22*(3), 179-188. DOI: 10.1002/smi.1094

Oinas-Kukkonen, H., & Harjumaa, M. (2008, June). A systematic framework for designing and evaluating persuasive systems. In *International conference on persuasive technology* (pp. 164-176). Springer, Berlin, Heidelberg.

Pallant, J. (2011). Survival manual. *A step by step guide to data analysis using SPSS*, (pp. 6-7). Open University Press.

Patibanda, R., Mueller, F. F., Leskovsek, M., & Duckworth, J. (2017, October). Life tree: understanding the design of breathing exercise games. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (pp. 19-31).

Plante, T. G., Cage, C., Clements, S., & Stover, A. (2006). Psychological benefits of exercise paired with virtual reality: Outdoor exercise energizes whereas indoor virtual exercise relaxes. *International Journal of Stress Management*, *13*(1), 108. DOI: 10.1037/1072-5245.13.1.108

Raaen, K., & Kjellmo, I. (2015, September). Measuring latency in virtual reality systems. In *International Conference on Entertainment Computing* (pp. 457-462). Springer, Cham. DOI: 10.1007/978-3-319-24589-8_40

Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., Gaggioli, A., Botella, C., & Alcañiz, M. (2007). Affective interactions using virtual reality: the link between presence and emotions. *CyberPsychology & Behavior*, *10*(1), 45-56. DOI: 10.1089/cpb.2006.9993

Robillard, G., Bouchard, S., Fournier, T., & Renaud, P. (2003). Anxiety and presence during VR immersion: A comparative study of the reactions of phobic and non-phobic participants in therapeutic virtual environments derived from computer games. *CyberPsychology & Behavior*, *6*(5), 467-476.

Robillard, G., Bouchard, S., Renaud, P., & Cournoyer, L. G. (2002). Validation canadienne-française de deux mesures importantes en réalité virtuelle: l'Immersive Tendencies Questionnaire et le Presence Questionnaire. *Poster presented at the 25e congrès annuel de la Société Québécoise pour la Recherche en Psychologie (SQRP), Trois-Rivières*.

Rogers, C. (1974). Toward becoming a fully functioning person. *Readings in Human Development: A Humanistic Approach*, *33*, 33-45.

Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual review of psychology*, *52*(1), 141-166.

Ryan, R. M., & Frederick, C. (1997). On energy, personality, and health: Subjective vitality as a dynamic reflection of well-being. *Journal of personality*, *65*(3), 529-565.

Sherman, W. R., & Craig, A. B. (2018). Chapter 10 - Virtual Reality: Past, Present, Future. *Understanding virtual reality: Interface, application, and design*. Morgan Kaufmann. https://doi.org/10.1016/B978-0-12-800965-9.00010-6

Slater, M. (2018). Immersion and the illusion of presence in virtual reality. *British Journal of Psychology*, *109*(3), 431-433. DOI:10.1111/bjop.12305

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI*, *3*, 74. https://doi.org/10.3389/frobt.2016.00074

Stallman, H. M., Lipson, S. K., Zhou, S., & Eisenberg, D. (2020). How do university students cope? An exploration of the health theory of coping in a US sample. *Journal of American college health*, 1-7. https://doi.org/10.1080/07448481.2020.1789149

Sutcliffe, A. G., & Kaur, K. D. (2000). Evaluating the usability of virtual reality user interfaces. *Behaviour & Information Technology*, *19*(6), 415-426. https://doi.org/10.1080/014492900750052679

Sztajzel, J. (2004). Heart rate variability: a noninvasive electrocardiographic method to measure the autonomic nervous system. *Swiss medical weekly*, *134*(35-36), 514-522.

Taelman, J., Vandeput, S., Spaepen, A., & Van Huffel, S. (2009). Influence of mental stress on heart rate and heart rate variability. In *4th European conference of the international federation for medical and biological engineering* (pp. 1366-1369). Springer, Berlin, Heidelberg.

Tao, G., Garrett, B., Taverner, T., Cordingley, E., & Sun, C. (2021). Immersive virtual reality health games: a narrative review of game design. *Journal of NeuroEngineering and Rehabilitation*, *18*(1), 1-21. https://doi.org/10.1186/s12984-020-00801-3

Tarvainen, M. P., Niskanen, J. P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV–heart rate variability analysis software. *Computer methods and programs in biomedicine*, *113*(1), 210-220. https://doi.org/10.1016/j.cmpb.2013.07.024

Tellhed, U., Daukantaitė, D., Maddux, R. E., Svensson, T., & Melander, O. (2019). Yogic breathing and mindfulness as stress coping mediate positive health outcomes of yoga. *Mindfulness*, *10*(12), 2703-2715. https://doi.org/10.1007/s12671-019-01225-4

Thayer, R. E. (1986). Activation-deactivation adjective check list: Current overview and structural analysis. *Psychological reports*, *58*(2), 607-614.

Thayer, R. E., Newman, J. R., & McClain, T. M. (1994). Self-regulation of mood: Strategies for changing a bad mood, raising energy, and reducing tension. *Journal of personality and social psychology*, *67*(5), 910.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and urban planning*, *81*(3), 167-178. doi:10.1016/j.landurbplan.2007.02.001

van Gisbergen, M., Kovacs, M., Campos, F., van der Heeft, M., & Vugts, V. (2019). What we don’t know. the effect of realism in virtual reality on experience and behaviour. In *Augmented Reality and Virtual Reality* (pp. 45-57). Springer, Cham. https://doi.org/10.1007/978-3-030-06246-0

Wechsler, T. F., Kümpers, F., & Mühlberger, A. (2019). Inferiority or even superiority of virtual reality exposure therapy in phobias? A systematic review and quantitative meta-analysis on randomized controlled trials specifically comparing the efficacy of virtual reality exposure to gold standard in vivo exposure in agoraphobia, specific phobia, and social phobia. *Frontiers in psychology*, *10*, 1758. https://doi.org/10.3389/fpsyg.2019.01758

Witmer, B.G. & Singer, M.J. (1998). Measuring presence in virtual environments: A presence questionnaire. Presence: Teleoperators and Virtual Environments, 7(3), 225-240.

Zhang, T., Booth, R., Jean-Louis, R., Chan, R., Yeung, A., Gratzer, D., & Strudwick, G. (2020). A Primer on Usability Assessment Approaches for Health-Related Applications of Virtual Reality. *JMIR Serious Games*, *8*(4), e18153. https://doi.org/10.2196/18153

Appendix A

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 B

Activation Deactivation Adjective Check List by Thayer (1986).

On a scale from 1 = “definitely do not feel” to 4 = “definitely feel” describe your feelings at this moment.

1. Energetic
2. Lively
3. Active
4. Vigorous
5. Full-of-pep
6. Sleepy*
7. Drowsy*
8. Tired*
9. Wide-awake
10. Wakeful
11. Tense
12. Clutched-up
13. Fearful
14. Jittery
15. Intense
16. Still*
17. At-rest*
18. Calm*
19. Quiet*
20. Placid*

*Reversed item

Appendix C

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 D

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 E

A list of public speaking topics

Please choose a topic from the list below and prepare a speech of 5 minutes.

1. Marketing determines junk food’s popularity
2. It is not enough to be smart to survive
3. Poverty is a state of mind
4. Hyperactive children do not need medication
5. Celebrities are not role models
6. The soul exists
7. Boys and girls should be taught in separate classrooms
8. Human cloning is ethical
9. Playing violent video games increases aggression
10. Self-driving cars should be illegal

Appendix F

Requirement Checklist

Nature Environment

- Set the nature environment (visual environment and walking paths)
- Add nature sounds
- Create character movement (within the virtual environment and the physical room)
- Set controllers
- The nature environment is the main room that transports the participant to a different task. Each task is in a new "Virtual" Room
- Each exercise is enabled by the researcher

Breathing Exercise “Tree”

- Introduce the participant to a new task (via the task objective)
- Set the pre-recorded voice instruction
- Set animation of the tree (colour, from dark to saturated and if possible, movement, expanding based on the breathing)
- Interaction with the tree and breathing (via a press of the controller)
- After the exercise, the participant is brought back to the main nature environment and can continue to the second task

Physical Exercise “Butterfly”

- Introduce the participant to a new task (via the task objective, it instructs to do the task as fast as possible)
- Set the green tree/bush tunnel
- Position the butterflies

- Animate the butterflies
- Set the interaction between the participant and butterflies (via a press of the controller)
- After the exercise, the participant is brought back to the main nature environment and can continue to the third task

Subjective Vitality Exercise “Yoga”

- Introduce the participant to a new task (via the task objective)
- Set the pre-recorded voice instruction
- Creation of the character and animations (within the nature setting)
- Set the different yoga poses
- Interaction with the character, breathing (the same pressing buttons as with the tree while inhaling and exhaling), and nature scenery
- After the exercise, the walk in nature is over

Log

- Timestamp activation and finish audio - the tree exercise.
- Times button was pressed for the breathing within the tree exercise
- Timestamp activation (from when the first butterfly was pressed) and finish (to when the last butterfly was pressed) – the butterfly exercise
- Times button was pressed during the butterfly exercise
- Timestamp activation and finish audio - the yoga exercise
- Times button was pressed for the breathing within the yoga exercise

Appendix G

Information sheet

Information sheet

The purpose of this study is to develop and explore a virtual reality environment to improve subjective vitality in university students. This study also aims to explore whether the created gamified virtual environment can make the user feel present (feel as if he or she is there) in the virtual environment. In order to achieve set goals the main activities that will take place during this study are a short background questionnaire, public speaking and cognitive tasks, questionnaires regarding mood and energy levels, a gamified virtual walk in the nature (with three exercises: breathing, movement, and stretching), and final questionnaires regarding mood, energy levels, and usability of the virtual environment. During the virtual tasks physiological measure (heart rate) will also be measured. The whole procedure might take up to 1,5 hours.

Before continuing please note that this study:

- is voluntary, and you can withdraw from it at any time, without providing an explanation
- is approved by the BMS Ethics Committee
- might cause some psychological stress and/or motion sickness
- involves a physiological measure (namely heart rate)
- ensures that the data collected will be stored anonymously and safely
- makes sure that upon request of the participant their data can be deleted and withdrawn from the dataset. This request cannot be made later than one month after the data collection process has finished because by then all data will be untraceable.

If you have any questions or want to know more about this study do not hesitate to contact:
Lina Bareišytė l.bareisyte@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 of the Faculty of Behavioural, Management and Social Sciences at the University of Twente via the e-mail address: ethicscommittee-bms@utwente.nl

Appendix H

Informed consent

Informed Consent Form for
Exploring Virtual Reality to Improve Subjective Vitality

Taking part in the study

I have read and understood the study information, 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

Risks associated with participating in the study

I understand that taking part in the study involves the following risks: mental discomfort, motion sickness

Use of the information in the study

I understand that information I provide will be used for a Master's thesis

I understand that personal information collected about me that can identify me, 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 anonymised transcripts of the data that I provide to be archived and stored in an encrypted storage device

I understand that the data I provide will not be used for future research

● I agree that I have read and understood the informed consent and agree to participate voluntarily