# Using Digitally Created Virtual Reality Environments as Stress Reduction During Stress Inducing Tasks

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**Abstract**

In current society, being as productive as possible in life is an important personal and globally accepted goal in order to feel and be considered successful. This need to be productive leads in many cases to chronic stress which comes with a plethora of health problems. Although there are proven ways to reduce stress, these methods break the flow of being productive which can potentially lead to even more stress in the long run if the expectancy of productivity is too high. This study investigates a way to reduce stress while being productive by using digitally created virtual reality environments. The experiment consists of participants completing a 3-minute set of stress inducing arithmetic tasks, in two different virtual reality environments; A forest environment and a classroom environment. During the experiment the participant's heart rate, heart rate variability and overall performance of the tasks were measured. The study showed no significant changes in both heart rate and heart rate variability, which therefore showed no indication of changes in stress level. However, the mean perceived stress level obtained from a survey from each participant did show a statistically significant difference. In addition, the amount of incorrect answered questions was also statistically significant higher in the classroom environment over the forest environment. Although this study is not conclusive, the suggestion is made for follow up studies to increase the session time to induce longer amounts of stress and use more advanced heart rate measurement hardware in order to find potentially more conclusive results.

# Contents

# 1 Introduction

In the video game *Heavy Rain* (Quantic Dream, 2010), one of the main protagonists, an FBI investigator by the name of Norman Jayden is sent to a city located near the east coast of the United States to solve a number of multiple linked disappearances of young children. The local police station however is not very keen on the arrival of this investigator as they would like to take the credit of finding the perpetrator themselves; the investigator is therefore set up in a discomforting room (an old moldy room, with no windows and near to a busy men's bathroom) in order to try to the make the investigator's research as inconvenient as possible. Norman Jayden however has a solution to this inconvenience; from his coat pocket he unveils a fictional pair of futuristic looking glasses called the Added Reality Interface, also known as ARI. ARI is a device in which the user can be transported into a virtual environment that can be anything the user pleases: A forest (as shown in figure 1), the bottom of an ocean or even the surface of the planet Mars. In the game, with the use of this device, the player can play as the investigator in order solve the case and hopefully save the missing children in time.

Although the above scenario is from a video game and therefore completely fictional, with the addition of the fact that such a futuristic and sophisticated device as ARI is currently not available in our non-fictional real world, the problems that arise with the protagonist; a high expectation of productivity e.g. solving as much cases as possible, distracting workplaces and high levels of stress due to time pressure (the main protagonist is also on a fictional drug called *triptocaine* to be able to conform with his set expectations), do persist in the real world as well.

Figure 1: Heavy Rain's protagonist Norman Jayden using the ARI device to be in a natural environment.

Current Western society can be considered to be an urban performance society in which productivity and success are seen as external life validation criteria. With this comes the fact that the so called millennial generation (people born between 1980 and 2000) is feeling more stressed than previous population generations as is shown by a survey among Dutch millennials done by *Een Vandaag* [AVROTROS, 2018]. This fact is of importance, since long exposures of stress can lead to a multitude of problems, including health problems such as cardiovascular diseases, an increased chance of burnouts and an overall lower productivity in a work environment [Watson, 2017]. With the ever increasing pressure that individuals receive through surrounding peers to 'be better' and the increasing use of social media, this problem does not seem to decrease any time soon.

There is already a focus on different methods to reduce stress, since health and productivity are two (contrasting) desires on both the work floor and in personal lives. However, these methods are not always ideal. A popular method of reducing stress among individuals is taking regular breaks that involve walks in natural environments, but with the increasing decline of green environments around the globe this option is more and more out of reach for a growing population [Hartig et al., 1991]. In addition, while breaks of these kinds contribute to the overall well being of an individual and can therefore increase productivity, it does put a temporary hold on productivity overall and can break the flow of work. Furthermore, individuals that have a strict deadline or have increased stress levels could be less keen on taking a break since it can feel that they are decreasing their amount of work time and therefore having even a stricter deadline or induced stress due to less available time to be productive.

A potential solution of reducing stress without interrupting the flow of work can potentially be found in the field of virtual reality, where the environment "comes" to the worker instead, where the stress reducing traits of a certain environment are still present, while still being able to be productive in that environment. Virtual reality is a technology where through a set of surrounding displays or a head mounted display together with positional trackers, a user can be situated in different virtual environments. When an individual is immersed and feels present in the virtual reality environment, physiological effects of real world counterparts are able to transfer to equivalent virtual environments as well [de Kort and IJsselsteijn, 2006]. In addition, when using virtual reality with a head mounted display and auditory input, the user can be less distracted from its surroundings since two of his senses (sight and hearing) are only exposed to the virtual environment. This can solve the problem of individuals being stressed by external social inputs such as surrounding (and potentially distracting) individuals or devices such as smart phones which are constantly demanding attention, making it an additional causer of stress and anxiety [Vahedi and Saiphoo, 2018].

The following research covers whether virtual reality, and digitally created virtual reality environments in particular can indeed influence levels of stress during stress inducing tasks, through an experiment in which participants are exposed to different virtual reality environments. If this research shows results, this could potentially lead to new methods that that can obtain higher productivity rate in certain 'white-collar' work environments, while having mean stress levels lower than in the current situation. This can therefore lead to potential increase in average health levels among these employees.

The outline of this paper is as follows: First, the phenomenon stress is defined in order to scope the field of what the research is trying to influence. Secondly through a review of related work, an overview is presented that covers how other research measures and induces stress, particularly focusing on methods which can potentially be used in this research. Furthermore, the state of the art of virtual reality, virtual environments and experiments with virtual reality are presented. In section 4 of this paper, a design framework for the experiment is mapped out, together with formulated research questions and hypotheses to scope down the goals of this research. In the method section the details of the experiment are explained in order to understand and potentially recreate the results. The results and discussion section covers the outcomes of the done experiments and the final section tries to derive conclusions from these results as well as discuss any outlying results, the process and validity of the experiment.

# 2 Stress

When a person is considered stressed, a surge of many hormones becomes present in the body [Ranabir and Reetu, 2011]. It can trigger the so called fight or flight response: high levels of the hormones cortisol and adrenaline in the body which can cause an increase in heart rate, elevated senses, a higher pain toleration and tenser muscles. These factors have physiological and mental effects on an individual. Research finds that high amounts and longer durations of stress can cause discomfort, increased chances on certain diseases and a lower level of productivity [Lupien et al., 2009]. However, it is also shown that moderate and shorter durations of stress can potentially increase productivity in certain situations [Sunday, 2012]. This is important, since while work employers do potentially care about their staffs' well being, their main priority will still lie on overall productivity, and should therefore be taken into account. Although there are many more indications, symptoms and effects of stress on human individuals, an overview of these terms are out of the scope of this research.

## 2.1 Effects of stress on productivity

Since stress can affect productivity in both a positive and negative way, it is important to look at the state of the art regarding the effects of stress on productivity. One of the most used, oldest and empirically founded theories regarding stress and productivity is the *Yerkes-Dodson law* [Cohen et al., 1983b]. According to this law, the relation of stress and productivity can be plotted as an inverted U-Shape (figure 2):

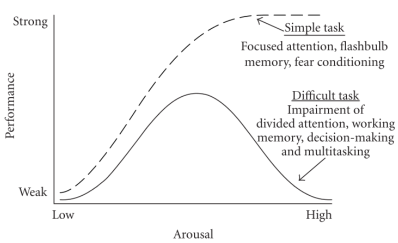

Figure 2: Visualization of the Yerkes-Dodson law (image from Wikipedia, 2018).

Whereas some level of stress (which is in the study and the figure referred to as arousal) can be optimal for performance in comparison to where there is a low- to absent level of stress, a stress level that is too high can negatively impact performance and overall productivity. Yerkes and Dodson made a distinction between simple (repetitive well known tasks by the subject) and difficult tasks (which can be classified as memory intensive and unfamiliar tasks) where with a simple task a high amount of stress does not strain productivity as much as with a more difficult (mentally stressing) task.

The *Yerkes-Dodson law* shows that a completely stress free individual may not be as productive as an employer wants to see. Although this research's main goal is achieving stress reduction in a virtual environment, in order for this research to be practically applicable and a potentially useful reference for designing virtual reality environments or real world locations like work environments, the relationship of the amount of reduced stress by the environment and productivity levels should be taken into account. This because this relationship can potentially act as an extra indication method of stress levels in the participants, were the results of the experiment can be (roughly) mapped on the *Yerkes-Dodson Law* scale. If this research reveals results that both the levels of stress and productivity are lower in the potentially stress reducing environment over the other, it could be interesting for future research to use this research as a base in order to create a 'perfect' virtual environment: An environment where the user has an optimal (not harmful in the long term) stress level and an optimal productivity level. This should be kept in mind during the design phase of this research, with a goal being to have a high level of customizability in the virtual environments to easily make adjustments to the virtual environment in order fit potential needs of future research.

## 2.2 Stress induction

In order to test whether a certain procedure can reduce stress within a test subject, the test subject needs to be induced with stress. Inducing stress can be done through a multitude of different methods. Mostly mentally taxing tasks are used in order to induce stress; for example a (mentally straining) cognitive test such as the Stroop Color-Word Interference test [Stroop, 1935] shows increased stress levels in the form of an increased heart rate [Fauquet-Alekhine et al., 2016], and perceived levels of anxiety [Renaud and Blondin, 1997]. Another example is a task where a set of images must rapidly be identified in succession, in which when studied the difference in galvanic skin conductance is used as a stress indicator [Zengin-Bolatkale et al., 2015]. Another way of inducing stress is to give the test subject a time limit to complete a certain mentally challenging task, such as a set of arithmetic math problems [Kuhlmann, 2005]. Socially intensive tasks are also used to induce stress. An example of this is the *Trier social stress test* in which stress is induced by letting the participants do a five minute presentation in front of three-person judging panel [Annerstedt et al., 2013]. These stress inducement methods are relevant since they can resemble similar stress inducers that take place on the work floor, such as a strict deadline, social stress or being overwhelmed with processing the data in a short time frame.

## 2.3 Measuring stress

As shown from the given examples in the previous section, there are multiple proven ways to test and evaluate stress levels. These measurement methods can be distinguished in two different categories. One category is where physical variables are measured in order to suggest a stress level such as:

- Cortisol levels in saliva
- Galvanic skin conductance
- Changes in (mean) heart rate
- Heart rate variability

A common stress evaluation method is the use of measuring cortisol (also known as the 'stress hormone') levels in saliva of an individual. Since not many other external factors influence the cortisol levels except for stress itself, measuring cortisol levels is seen as a reliable method to assess the amount of stress of an individual. Another stress indicator can be to measure the difference in galvanic skin conductance among participants. [Zengin-Bolatkale et al., 2015]. When an individual has an emotional response (such as an increase in stress level), the eccrine glands (the main sweat glands of a human body) excrete more sweat, making the skin more conductive.

Measuring heart frequencies in order to compare stress can be done in two ways. The first way is measuring the change in mean heart rate in a certain time-frame. When this mean heart rate increases in comparison to other performed measurements, and is not participating in any physical activity, the conclusion can be made that an individual is potentially more stressed than during the other measurements.

Another way is to measure heart rate variability. Whereas measuring heart rate focuses on the mean heart rate in a certain time frame, Heart rate variability measures the difference in time (or variability) between each successive heartbeat: A heartbeat that has less variability between heartbeats (meaning a lower heart rate variability) can indicate a higher stress level. Generally it is the case that the speed of someone's heart rate and the level of heart rate variability have a inverse relationship [Fauquet-Alekhine et al., 2016].

The other category is a collection of mental stress evaluations which tries to indicate a perceived stress level of an individual. An example of such a mental stress evaluation is the Perceived Stress Scale [Cohen et al., 1983a], where a set of 10 questions can evaluate both long-term and short-term stress indication. However, this measurement method can be considered to be more subjective, since it can be the case that certain individuals are less aware of the effects of stress and find it harder to perceive.

The stress level measurement methods can also be categorized in terms of effectiveness in both short- and long-time measurement periods. Measuring the level of cortisol in saliva is considered to be more efficient as a long term stress indicator. On the other hand, differences in galvanic skin conductance, heart rate and a before and after stress evaluation survey are considered to be more effective when measuring more acute stress. Since the experiment time will be relatively short, a measuring method such as measuring heart rate and heart rate variability seems the most relevant to this research.

## 2.4 Stress reduction and avoidance

Since there is evidence of health risks that coincide with chronic stress, and additionally that prolonged levels of stress can decrease overall productivity on the work floor, there is incentive by the scientific community to research methods that can potentially reduce stress. A popular stress reduction method is mindfulness based stress reduction in which participants perform mental and physical exercises in order to relieve and cope better with stressful situations [Salmon et al., 2012]. Although mindfulness is a stress reducer, stress inducing factors such as high workloads, social stress and the overall environment are still present. This form of stress reduction due to avoiding stress comes with some side-effects regarding productivity levels. As explained in the introduction, stress avoidance or reducing methods that are applied after or before the stress inducing act can lead to negative effects on overall productivity as it can break a certain work flow. In addition, the reluctance of an already stressed individual of actually using their work time to reduce their stress does not make for an ideal solution.

Certain forms of audio perceived by individuals are also proven as a way to reduce stress levels. Additionally, benefits such as an overall increase concentration and productivity are also measured in research that use types of auditory input as stress reduction. Nature sounds such as audio that contains water or birds in particular are proven to be effective in decreasing stress levels [Alvarsson et al., 2010]. A more practical example is shown by [Thoma et al., 2013], where a combination of certain music genres and nature sounds have been proven to be beneficial to a lower heart rate and cortisol levels, which in turn gave the participants a lower level of both stress and anxiety while waiting prior to undergoing a surgery. Although music can lower stress levels, the results of using this as an auditory stress reducer can be more varied since participants can have a wide range in music preference [Leardi et al., 2007]. Therefore, when using an auditory stress reducer to reduce sense, using nature sounds seems a more viable approach to achieve valid and consistent results.

Certain (real world) environments that individuals subside in can also contribute to lower stress levels. Looking at the long term effects of environments on individuals, studies show that communities living near to an ocean have less stress-related side effects opposed to communities living in more urban areas. In addition, green environments such as forests and parks can also contribute to a better well being and a long term measured lower stress level than inhabitants of an urban area [Grahn and Stigsdotter, 2003]. The effect of green environments on the well being of individuals is also measured on a smaller scale: The addition of plants in a windowless environment can potentially increase productivity on the work floor by 12 percent on certain tasks, which can in addition lower time pressure and therefore lower stress levels as well [Virginia et al., 1996]. Looking at even more abstract experiments, solely the color of an environment can also have a positive or negative contribution to stress and productivity. In line with reduced stress levels in 'green' (nature) and 'blue' (oceanic) environments both the colors green and blue located in an environment have positive effects on completing cognitive tasks, and are by the participants considered to be 'calm' colors [Mehta and Zhu, 2009].

## 2.5 Key findings

Below is a short summary of the concepts and findings regarding measuring, inducing and reducing stress.

**F1: Stress has an effect on productivity.**

A person with high stress levels potentially has a lower productivity level in contrast to an individual that experiences lesser levels of stress.

**F2: Using a mentally stressful task such as a set of arithmetic problems is a viable way to induce stress.**

There are a sum of methods to induce stress in test participants of an experiment. The use of an arithmetic stress inducing task seems a usable and implementable way to incorporate in the experiment.

**F3: Measuring heart rate and heart rate variability are viable ways to measure changes in stress levels of subjects.**

Although other stress measurement methods do exist and can potentially be more precise, using a device that can measure heart rate or heart rate variability is an accessible proven way to measure short-term differences in stress levels properly.

**F4: Green environments and audio of nature scenery are viable ways to reduce stress.**

Research shows that certain colors such as blue and green, natural environments and certain audio such as nature sounds can potentially reduce stress.

# 3 Virtual reality

As stated in the introduction, virtual reality is a technology which enables a user to experience an artificial form of reality. Although not a new technology (primitive versions of virtual reality systems can be dated back to around 1968 with the release of a head mounted display [Sutherland, 1968]), in the last decade due to advancements in graphical computing power and the increase of more pixel dense screens, virtual reality is used for many different applications such as entertainment (e.g. video games [Bates, 1992] and 360-degree video [Annerstedt et al., 2013]) and education [Merchant et al., 2014]. In addition, with big international players such as *HTC* (with the *HTC Vive*) and *Facebook* (with the *Oculus Rift*) releasing new virtual reality products yearly, the costs of virtual reality devices lower, making it in turn more accessible and more adoptable by other business fields and customers. This increasing availability of virtual reality devices in combination of the possibilities that virtual reality can bring in both a business and research perspective makes it a perfect field for solving real world problems with virtual solutions.

## 3.1 Virtual reality therapy

Both the ability of immersion and presence are important tested features of virtual reality that can be useful in research or real life situations for changing a person's physical or mental behavior. An example is virtual reality exposure therapy, a technological alternative to conventional exposure therapy in which a participant gets exposed to their phobias [Parsons and Rizzo, 2008], stressful situations [Anderson et al., 2003], or traumatic experiences [Rothbaum et al., 2001]. These research examples show that when a subject is immersed and feeling present in a virtual environment, real life research and results can transfer to virtual reality. In addition, previous research indicates that there is a broad spectrum of real world problems that could be solved by using virtual reality.

## 3.2 Virtual environments

As stated above, one of the main attributes of virtual reality is the sense of immersion of the user. The main contributor of this sense of immersion can be considered to be the virtual environment in which the user is placed during a virtual reality session. Virtual environments on a technological level can be placed into two different categories: digitally created environments and real-world created environments.

Real-world created environments are created by using real-world media to capture a certain location or scenery and transports this into a virtual reality environment. A common practice to create real-world virtual environments is with the use of special 360-degree camera's, in which a full panoramic 360-degree view can be recorded. With this, the user's surroundings are a seamless surrounding view, which the user can view freely explore in 360 degrees of freedom [Anderson et al., 2017]. The main downside of using this method is the fact that interactivity with the environment is non-existent: All the camera movements are pre-recorded and thus a static environment, which cannot be manipulated by the user. An example of this is that the user can not walk around in the environment freely since the movement of the user can not be translated to the movement of the camera.

Digitally created environments are computer generated: Digital 3D models are created and placed in the virtual environment. Although digitally created environments can be considered to be not as detailed in comparison to real-world counterparts, since all objects in the environment are computer generated, the environment itself can be more easily manipulated by the designer or user. In addition, the environment can be more interactive and therefore potentially more immersive, since the movements and interactions of the user can directly be used to manipulate the environment.

As stated in section 2.4, using certain audio is a verified method to reduce stress. Every real world environment has some form of audio existing in it, whether it being not particularly present (such as background noise like moving cars, nature sounds and background chatter), while other forms of audio in an environment are more intentionally present (music, speech and other audio that directly interacts with the user). In virtual reality a decision can be made whether or not to use audio to increase the virtual reality's immersive experience and additional benefits of audio causing stress reducing effects. Although it is interesting to see whether just the visual environment of an individual can influence certain levels of stress, for the sake of potentially better results and the assumption that when such an environment is used certain auditory feedback and ambiance can and will be implemented, the choice has been made to focus on a virtual reality environment which includes audio in its surroundings.

## 3.3 Virtual reality and stress reduction

The combination of using virtual reality and stress as a staring point for research is to a lesser extent explored by academia in contrast to their respective separate research fields. There are more studies done that use screens, photographs or images of environments that can improve stress recovery, which as main critique lack the ability of true immersion or presence [de Kort and IJsselsteijn, 2006]. This immersion and presence can however play a big role in environments that attempt to reduce stress: A study using a nature movie as a stress reduction environment on both a small and bigger more immersive screen showed that the latter was more effective in reducing stress [de Kort et al., 2006]. One study, used a combination of both virtual reality and mindfulness training exercises as a form of behavioral therapy for individuals with Borderline Personality Disorder [Nararro-Haro et al., 2016]. Although no stress indicators were measured, the study did show positive behavioral changes and reactions from the participants.

There are only a handful of studies that have a focus of stress reduction in virtual reality. A study by [Annerstedt et al., 2013] has a focus of stress recovery using sounds of nature and a virtual reality environment; a real-world 360-degree video of a forest. To induce stress, the participants were firstly subjected to a virtual reality version of the Trier Social Stress test: The test participants had to give a presentation to three virtual executives. After the presentation the virtual environment changed into the stress reduction environment: The virtual environment of the first group was transformed in a depiction of a virtual forest, the second group was given the same virtual environment with an added auditory input of both water and bird sounds. The third group acted as a control group which did not get subjected to a virtual reality environment or added sounds. Only physical stress indicators were measured: heart rate, heart rate variability and cortisol levels. The group that was situated in the virtual forest with the addition of hearing nature sounds had a significantly faster stress recovery than the other groups. The group in the virtual reality forest that did not have extra auditory import did have a similar result, although to a lesser extent. There was no extra group that was tested where only the auditory input was used as a stress reduction method. Important to note is that the cortisol levels of the particpants did not significantly change. This is likely due to the short duration of the experiment and cortisol level being a more long term stress measuring method.

Another example of research done to explore the effects of a virtual environment on stress is done by [Anderson et al., 2017]. This research also used 360-degree video to create the environment; one video was of a forest, the other was a video of a beach setting. Instead of using the Trier Social Stress Test, an arithmetic task was used to induce stress within the participants. Unlike using only physical measurement tools like heart rate variability, a mental evaluation in the form of a 15-question survey was used to asses the virtual environments' quality and mood of the participants. The results showed that the preferred virtual environment, were more effective in increasing heart rate variability and an overall perceived increased of mood.

It is important to note that all stress reduction methods use the reduction of stress after the stress is induced and not during the procedure. This is different from this study, where the stress is reduced during the mentally challenging task. No significant research has been found that explores stress reduction during a stress inducing task in virtual reality.

### 3.4 Key findings

The most relevant findings regarding virtual reality in regards of the experiment are stated below.

**F1: Virtual reality is considered to be a useful and viable tool for both research and real world applications.**

**F2: Physiological effects on humans by real world environments can be transferred to virtual environments.**

**F2: Research shows that virtual reality can be used for post-stress reduction.**

## 4 Design and research framework

This research is focused around the problem that in this society, being highly productive is a key expectation of a employee, which is inducing stress with the negative effects that bode with it. The current solutions that try to reduce stress can break the flow of work, since these methods are mostly focusing on post stress reduction instead of reducing stress while it is being induced. In addition, due to urbanization, natural stress reducers such as 'green' nature environments are less and less accessible in highly populated areas [Hartig et al., 1991]. Therefore using a virtual environment to reduce stress can be a potential solution. This problem statement however is rather broad. In order to scope down the research, certain choices regarding the virtual environment, the stress inducer and the overall questions that this research will try to answer is formulated and can be found in the sections below.

### 4.1 Design framework: Real-world or digital control group

In order to research whether traits of a virtual environment can lower stress levels in individuals during stress inducing tasks, the results need to be compared with control variables in order to measure a difference. The focus on this study lies on virtual environments and whether it can reduce stress. Changing this variable can be achieved in two different ways: The first way is to measure the differences between a real world environment and a virtual reality environment. The second way is to measure the differences between a virtual environment and another different virtual environment.

This research will focus on the differences between two virtual environments. The main reason is that it creates a more 'fair and even' research space: Variables that can influence results such as wearing the virtual reality headset and the resolution of the current generation virtual reality screens are not changed. Although it is interesting to see how a virtual reality environment compares to a real world environment, the choice has been made to first see if certain traits of virtual reality environments can reduce stress in a confined experiment.

### 4.2 Design framework: The virtual environment

In an ideal scenario, the participants of the experiment would be able to choose their own virtual environment which they consider to be the most relaxing and potentially the most stress reducing. Unfortunately, due to the time-frame of this research, the amount of time needed to create virtual environments and the increase of the amount of participants needed to test different environments, this is not achievable within this research. Therefore, in order to maximize a positive outcome, a virtual environment must be chosen in which the general amount of participants must feel as comfortable as possible. Hence, a forest as a virtual environment setting is chosen: As stated in section 2.4, there is evidence that suggests that a green environment such as a forest can reduce stress. In section 3.3 it is stated that this effects transfers to virtual reality as well by using real-world footage of forests in a virtual environment to reduce stress.

As for the second virtual environment that acts as the control environment, a classroom setting is chosen. The goal of the control environment is to create an environment where the environment can induce some form of stress: it should resemble some real-world situation that is familiar to the participant where some form of stress can be deemed as normal. The assumption is made that most of the participants finished some form of education and therefore are familiar with a classroom environment. This unlike to another potential control environment such as an office environment, which can change in familiarity among the participants due to diversity in employment and job descriptions.

The related research stated in the previous sections that use virtual reality nature environment as a stress reduction method all use real-world footage to create the virtual environment. The added benefit of this is the achieved level of realism of the environment; since the virtual environment is created with footage from real-world forests, the environment can be considered to be more realistic than a digitally created environment. However as stated before (in section 3.2) this can come with potential negative side effects regarding the use of virtual reality: The lack of any form interaction or manipulation with the environment can potentially lessen overall levels of immersion. The choice has therefore been made that for this research is create a digitally created virtual environment instead. The lack of interactivity and ability to manipulate the environment may not interfere the design in this research, but follow-up research could benefit from this fact. If the case is made that a virtual environment like a digitally created forest indeed shows an effect on stress levels during stressful tasks, follow-up research could benefit from this since it is more capable of tweaking, manipulating or making the current environments more interactive. The virtual environment will be complemented with real world nature sounds, which both adds an extra layer of immersion and is additionally proven to be a successful stress reducing method [Alvarsson et al., 2010].

## 4.3 Design framework: The stress inducing task

In order to validate whether the digitally created forest environment indeed reduces stress, the participants must be induced with stress. The subjects must do a series of arithmetic tasks within a set time limit. As stated in section 2.2, arithmetic stress tasks are mentally challenging tasks that can induce stress into the participant. In addition, putting the participants in the position to complete these arithmetic tasks in a short time frame can create an additional influence on stress. Since there is a series of tasks that have to be completed, and the performance of a participant can be measured in the amount of errors, a productivity level can be derived from the tasks, unlike with a stress inducing task like the Trier Social Stress Test, where not a set of tasks but an activity is the stress inducing factor.

In addition to selecting a stress inducing task, a framework of presenting and interacting with this task by the participants should also be defined. Since this research is mostly focusing on a stress reducing method in working environments, especially with tasks where an individual is sitting at a desk interacting with a screen, the task should be representable with doing such a job in virtual reality. This requires that the arithmetic questions should be in some form displayed in the virtual environment, as well as potentially some form of input for completing the tasks, such as a virtual keyboard.

## 4.4 Design framework: Measuring stress

In section 2.3, several methods to measure stress are presented. An actual direct value of how 'stressed' an individual person is unfortunately unmeasurable. However there are measurements such as the level of cortisol in the saliva, a difference in heart rate or a differences in heart rate variability of an individual that are related to levels of stress. Research learns that although measuring cortisol is a reliable way to indicate stress levels, the effectiveness of the produced results are more present between longer time frames of sample taking, making it less ideal for this experiment [van Holland et al., 2011]. Therefore the choice is made to measure both heart rate and heart rate variability. In order to validate the results, a short post experiment questionnaire asking the participants the level of perceived stress will be issued additionally.

## 4.5 Research framework: Research questions and hypotheses

With a basic design framework in mind, the scope of the research can be more narrowed down. In order to formalize the end goals of this research, a main research question and a sub research question is formulated:

- **R1: Can a digitally created virtual reality forest environment influence heart rate and heart rate variability during a stress inducing task like arithmetic stress tasks?**
- **R2: Can a digitally created virtual reality forest environment increase productivity of doing arithmetic stress tasks?**

As can be derived from the research questions, the field of view of the goals of the experiments are narrowed down to a single digitally forest virtual environment as a potential stress reducer with a arithmetic stress test as a stress inducer. The hypotheses of these questions are as follows: Regarding R1, the hypothesis is that a digitally created virtual environment with a digital forest as a setting will show a decrease in mean heart rate and and an increase heart rate variability opposed to the digitally created classroom control environment.

When focusing on R2, regarding the potential increase of productivity, the hypothesis is that a small increase increase of productivity will be shown in the forest virtual environment when doing the arithmetic stress tasks. This means that the error rate (the amount of questions answered incorrectly) will be slightly lower oppose to the digitally created classroom control environment. In addition, the overall amount of completed tasks will be slightly higher in the forest environment.

# 5 Method

With the design and research framework in place, an experiment is created to test the previously stated hypotheses. This section will cover the details of this experiment: The participants and procedure of the experiment as well as the used the used materials used to create and conduct the experiment.

## 5.1 Participants and procedure

The participants are recruited during the days that the experiment takes place. These participants are asked to do a set of arithmetic tasks in both the forest virtual environment and a control virtual environment: a digitally created environment that resembles a classroom. The experiment has a within subject design. This within subject design allows for measuring the differences in stress levels of both environments within each participant. In addition, since the level of arithmetic solving skills vary per participant, a within subject design also allows for measuring performance in each virtual environment. Since the participants are doing the arithmetic tasks two times, the risk of pretest sensitization is present. Therefore the order in which virtual environment the participant must complete the arithmetic tasks will be randomized. The choice of a one-group experiment is made for the ability to measure a potential change in productivity between the two virtual environments. In addition, since the mean heart rate of each individual can differ greatly, a within subject design is the most safe way to measure potential differences in both heart rate and heart rate variability.

When approaching a potential participant for partaking in the experiment, questions regarding the consumption of both nicotine (cigarettes) and alcohol, in the last four hours are questioned, since this can influence both stress levels and heart rate, leaving potential discrepancies in the results of the research. [Parrott and C, 1999] [Green et al., 1996].

Upon arrival the participant receives a heart rate and heart rate variability tracking band to wear around the chest, and is helped to put on the virtual reality headset. Once the participant is set-up, an explanation of task itself will be given. This explanation also states that it is required by the participant to complete the tasks as fast and as correct as they see possible. Once the participant agrees on understanding the task and procedure, the experiment will be started. One of the two virtual environments will be presented, and a 30 second period is given to the user to get familiar with the environment. After these 30 seconds a set of tasks must be completed in a 3 minute time frame, where each question has a maximum completion time of 11 seconds. The time-frame of the total amount of questions as well as the amount of time the participant has to answer each question are defined via a previously done pretest ($n = 3$). This to ensure that the amount of tasks are on average doable albeit with a significant difficulty, which makes it therefore not too overwhelming for the participants to not be able to complete a task, but still difficult enough to ensure a sufficient level of stress. After the participant has completed the 3 minutes of arithmetic tasks, the environment is transformed back to the introduction environment. The participant stays in this environment for around one minute, in order to successfully log the obtained heart measurement data without losing consistency in the amount of time each participant is in one of the experiment environments. After this minute the participant is sent to the other virtual environment to repeat the experiment.

To give the user an incentive to look around in the virtual environment instead of looking at a single point where the arithmetic questions are displayed, each time a new math problem is presented, the location is different than the previous math problem. The relative distance between the participant and the displayed question stays the same, but the participant has to look around in order to properly see the questions. The location of each question has a random x and y coordinate, which is limited to be still able to be readable from the fixed position of the participant.

The participant must say their answer of the math question out loud before proceeding to the next question. The audio of the participant as well as the displayed questions in the virtual environment will be recorded and later processed in order to measure the performance or productivity level of each participant.

When the two tasks are completed, the participants are asked to fill in a post survey. This surveys' main purpose is to gather general information such as gender and age of each participant, the feeling of stress they themselves perceived, evaluating the level of difficulty of the arithmetic stress task as well as the general perceived level of difficulty, immersion and realism in both the forest and the classroom control environment. This ensures that faulty data of the research can potentially be derived from these results. It is also a way to validate whether the environments had the intended effects in terms of stress levels and difficulty of the tasks themselves.

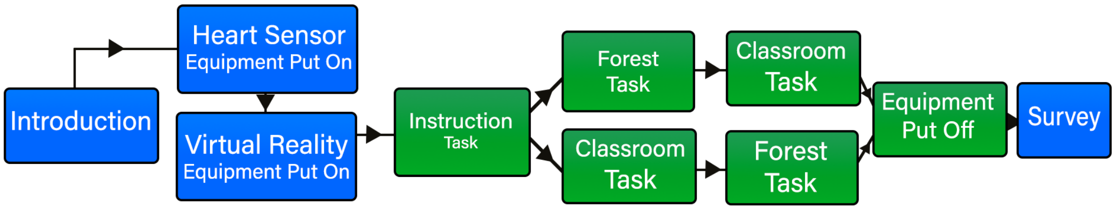


Figure 3: A block scheme showing the different elements of the experiment.

## 5.2 Materials

The following section covers the hardware and software used to realize this experiment. Details about the creation of the virtual environments, the stress measurement hardware and the used virtual reality equipment are stated.

### 5.2.1 The virtual reality equipment

The virtual reality device that is used to conduct the experiment is the 2016 version of the *HTC Vive* virtual reality headset (HTC 2016). Since the way of input of the correct math answer is done via speech, the accompanied controllers are not used in the experiment. This is done since the learning curve can potentially influence the results with an input device that is potentially not familiar with a portion of the participants. For the auditory part of the environment, the accompanied headset of the *HTC Vive* are used as well.

### 5.2.2 The virtual reality environment creation software

The software used to both create, render and present the virtual reality environment to the participants is the *Unreal Engine* (Version 4.19.2, Epic Games 2018). *Unreal Engine* is a software suite (or game engine) with built in tools to mainly create and play video games. Reasons for choosing this game engine is first of all that it is free-to-use software, making the possibility of re-creating the experiment more accessible. Additionally, Unreal Engine is fairly powerful; the graphical validity of the engine *out-of-the-box* is fairly high and allows for realistic created environments. Another argument of using the *Unreal Engine* is that there are built in functions that make building virtual reality less difficult than some other 3D game engines.

### 5.2.3 The virtual reality environment

Three different environments are created: An introduction environment in which the participant gets familiar with being in virtual reality and the task at hand, a forest environment which acts the main experiment environment and a classroom environment which acts as the control environment. The creation of each of the environments are briefly explained below.

#### The introduction environment

The introduction environment is created for the purpose of explaining the arithmetic tasks and let the participant be familiar with virtual reality. The user has to comply with understanding the tasks at hand, before proceeding to the actual experiment. The room's interior is fairly limited: It consists of a room with a desk and chair, as well as some boxes placed on either side of the player. A desk and chair for the participant are in each virtual environment present. This to create a form of consistency between each environment and the real world environment, since in the real-world each participant is sitting in front some form of table as well. This can potentially increase the level of immersion perceived by the participant.

Figure 4: A screen shot of the introduction environment, behind were the participant is situated.

#### The forest environment

The forest environment is where the main experiment takes place. This virtual environment consists of a forest surrounding the participant, a small pond located around 6 meters from the participant, a desk situated in front of the participant and a chair situated below the participant. Although the placement of a desk and chair in a forest environment can be considered to be unrealistic, as previously stated the desk and chair are a form of consistency between the real world and the virtual environment, making it potentially a more immersive experience. The audio of the environment consists of a real world sound clip consisting of bird twitter and soft movement of water. The 3D assets used to create the forest are from a free to use pack, *The Open World Demo Collection* (Epic Games, 2017), available freely to download. The forest contains of some moving elements to add more realism to forest by appearing it to be more alive; there are butterflies flying around the player and the green elements such as the trees and grass sway in the wind.

Figure 5: A screen shot of the forest environment, from the viewpoint of the participant.

#### The classroom environment

The classroom environment consists of a windowless room with several tables, chairs and an empty chalkboard. These 3D models are obtained from an online 3D asset marketplace called *Turbosquid* (Turbosquid, 2018). The participant is situated in the virtual environment in one of the middle desks. The environment contains audio in the form of sounds of cars going by in the background as well as muffled sounds resembling movement by other individuals in the virtual environment. Unlike the forest environment, the classroom environment does not contain any moving objects, making it a more static environment.

Figure 6: A screen shot of the classroom control environment, from the viewpoint of the participant.

## 5.3 The heart rate measurement setup

In order to read both heart rate and heart rate variability of the user, the *Polar H7* (Polar, 2014) heart rate tracking band is used. This heart band must be placed on the participants' waist. The *Polar H7* constantly measures the mean heart rate and heart rate frequencies during each three minute test session. The Polar H7 is connected via Blue-tooth to a smart phone, on which an application called *Elite HRV* logs both the mean average heart rate and heart rate variability of the participants. *Elite HRV* can read, log and calculate a wide arrange of factors from which heart rate variability can be derived, which are also used in scientific publications [Annerstedt et al., 2013] [Anderson et al., 2017]. These factors include:

- SDNN, the standard deviation of each non-abnormal peak in heart rate intervals.
- RMSSD, The square root of the mean of the sum of the squares of differences between adjacent peak heart rate intervals.
- NN50, Number of pairs of adjacent NN intervals that differ by more than 50 ms in the total reading.
- LF, the power of the signal that lies in low frequency bands.
- HF, the power of the signal that lies in high frequency bands.
- LF/HF, the ratio between the power of both low and high frequency bands.

In order to sync the time of the heart rate with the time of the participants' time in virtual reality, each time the participant starts a task, a new measurement is started simultaneously.

## 5.4 The stress inducing task

The stress inducing task consists of 60 two to three digit subtraction sums. These arithmetic tasks were obtained from the website *Math-Aids* (Math-Aids, 2018), which provides randomly generated arithmetic problems. A progress bar situated in front of the participant in each environment shows the available time to complete each question (figure 7). Each time a participant gives an answer to the question, whether it is a correct or incorrect answer, a new question is presented. This is also the case whenever the participant did not answered at all within the given time limit of 11 seconds.


Figure 7: An example of a displayed arithmetic task in the forest environment.

# 6 Results

The experiment was conducted on two different locations, this in order to acquire a substantial amount of individuals willing to participate. The first test location was in at the moment of experimenting a closed bar; De Nul located in Hengelo (Figure 8 on the left). The participants (n = 18) were acquired in a span of three days. The second test location (n = 12) was situated in a classroom of Leiden University, in particular in the Snellius building (room 4.13, Figure 8 on the right). These participants were acquired in the timespan of a week. All the experiments took place in August, 2018.

Figure 8: Both experiment setups: De Nul, Hengelo (left) and Leiden University (right).

These two sessions of experiments yielded the total amount of participants (n = 30). A full set of data for two participants could not be fully established; for one participant the heart rate sensor did not operate properly, one other did not completely finish the provided post-survey. The data that did properly got obtained can and were still used for analysis.

## 6.1 Validating variables

For comparing whether the location had a significant difference in the results, an independent sample t-test is performed on each of the variables (such as the results of the post-survey regarding perceived stress, realism and difficulty as well as the heart rate and productivity data) with the location being the grouping variable. These showed no significant aberrations except for the the average heart rate in the forest environment (HR F, N=29) where the paired sample t-test p-value yielded p = 0.023 (table 1). It is important to note that since the experiment is setup as a within subject design, the actual differences in heart rate of each individual gets analyzed. Executing a independent sample t-test on the absolute difference of heart rate in each virtual environment (HR F - HR C) and the relative difference of heart rate (HR F  HR C) with the location acting as grouping variable shows no statistical difference as shown in table 1.

Table 1: Independent samples t-test with location as grouping variable (n=29)

| | t | df | p |
|---|---|---|---|
| HR F | 2.418 | 27.00 | 0.023 |
| HR DIFF | 1.208 | 28.00 | 0.237 |
| HR REL | 1.599 | 27.00 | 0.121 |

Since the experiment was designed as a within subject design experiment, the order of which test condition (the classroom or forest environment) is interchanged sequentially in order to observe any effect of pretest sensitization. A paired sample t-test on each of the tested variables, namely the average heart rate in the forest and classroom environment (HR F and HR C, n=29), the average heart rate variability score in both environments (HRV F and HRV C, n=29) as well as the amount of correct answers given in each environment (CORR F and CORR C, n=30) showed no significant effect caused by the order as shown in table 2.

Table 2: Independent samples t-test with environment order as grouping variable (n=30)

| | t | df | p |
|---|---|---|---|
| HR F | -0.577 | 27.00 | 0.569 |
| HR C | -0.967 | 27.00 | 0.342 |
| HRV C | 1.381 | 27.00 | 0.179 |
| HRV F | 1.102 | 27.00 | 0.280 |
| CORR C | 1.438 | 27.00 | 0.162 |
| CORR F | 0.754 | 27.00 | 0.457 |

To see whether there is a connection between the experience level the participant has with virtual reality devices and how they perceived the experiment setup, a correlation matrix (table 3) is computed between the post survey question regarding the amount of times a participant has used a virtual reality device before (their experience level, n=30) and the variables heart rate (HR F and HR C, n=29), heart rate variability (HRV F and HRV C, n=29) and the amount of correctly answered questions of the participant in each environment (CORR F and CORR C, n=30). No significant correlation between the participant's experience and these factors were found.

Table 3: Pearson correlations of experience level, heart rate and heart rate variability on experience level (n=30)

| | | |
|---|---|---|
| HR F | Pearson's r | -0.179 |
| | p-value | 0.354 |
| HR C | Pearson's r | -0.149 |
| | p-value | 0.439 |
| HRV F | Pearson's r | 0.172 |
| | p-value | 0.371 |
| HRV C | Pearson's r | 0.119 |
| | p-value | 0.539 |

## 6.2 Heart rate and heart rate variability results

Conducting a paired sample t-test on the main variables, namely the average heart rate of the forest environment (HR F, n=30) and the classroom environment (HR C, n=30), as well the average heart rate variability score of the forest environment (HRV F, n=30) and classroom environment (HRV C, n=30), a small mean increase is shown in the classroom environment opposed to the forest environment (Table 4). However, these differences showed no significant difference (HR $p = 0.138$ and HRV $p=0.119$). Similar results are shown in the relative differences between the mean heart rate and heart rate variability in the two environments. A one sample t-test of the relative difference in mean heart rates (HR F / HR C) with a test value of 1 showed not statistically significant result ($p = 0.144$, table 5). A one sample t-test with a test value of 1 on the relative mean difference in the mean heart rate variability measurements additionally showed no statistically significant outcomes ($p = 0.185$).

Table 4: Paired samples t-test heart rate and difference of heart rate

| | | | t | df | p |
|---|---|---|---|---|---|
| HR F | - | HR C | -1.526 | 28 | 0.138 |
| HRV F | - | HRV C | -1.609 | 28 | 0.119 |

Table 5: One sample t-test HR F / HR C with test value = 1 (n=29)

| | t | df | p |
|---|---|---|---|
| HRV rel | -1.357 | 28 | 0.185 |
| HR rel | -1.502 | 28 | 0.144 |

Looking further into the obtained heart rate variability data reveals a similar trend. Table 6 shows the individual measurements that make up the overall HRV score. Only one individual measurement is deemed to suggest a statistical significant difference, SDNN (p = 0.045), which measures the standard deviation of each normal peak in the heart rate signal.

Table 6: Paired samples t-test HRV data (n=29)

| | | | t | df | p |
|---|---|---|---|---|---|
| SDNN F | - | SDNN C | -2.106 | 28 | 0.044 |
| rMSSD F | - | rMSSD C | -0.912 | 28 | 0.369 |
| LF F | - | LF C | -1.710 | 21 | 0.098 |
| LF/HF F | - | LF/HF C | -0.940 | 28 | 0.355 |
| HF F | - | HF C | -1.606 | 21 | 0.123 |

## 6.3 Perceived stress results

The post-survey contained a question for each participant that asked to rate their own perceived stress level on a scale from 1 to 10. The mean average perceived stress level score (n=29) for the forest environment was 5.000 where the mean perceived stress level score for the classroom environment was 6.069 (table 7). Running a paired sample student t-test on the two variables reveals a significant difference where $p < 0.001$ (table 8).

Table 7: Descriptives perceived stress level (n=29)

| | N | Mean | SD | SE |
|---|---|---|---|---|
| Stress C | 29 | 6.069 | 1.999 | 0.371 |
| Stress F | 29 | 5.000 | 1.648 | 0.306 |

Table 8: Paired samples t-test post-survey perceived stress (n=29)

| | | | t | df | p |
|---|---|---|---|---|---|
| Stress C | - | Stress F | 5.396 | 28 | < .001 |

## 6.4 Task results

There are three obtained data variables that are concerned with the performance of the completion of the arithmetic stress tasks (n=30). The first pair of variables is the mean amount of correctly answered math questions by the participant in each of the two environments (*forest* = *Cf* and *classroom* = *C*c in table 9). Although a slight mean difference is found, this difference cannot be deemed statistically significant by a paired sample t-test, with a p-value of 0.503. The second pair of variables is the mean amount of incorrectly answered math questions the participant submitted in each environment (*forest* = *If* and classroom =Ic in table 10). The data shows that there is a larger mean of incorrect answers given in the classroom environment opposed to the forest environment (table 10). A paired sample student t-test shows that this is a statistically significant difference, with a p-value of 0.007 (table 9). The last pair of variables is the mean amount of questions that the participants could not answer due to the given time limit in which the question needed to be answered (*forest* = *Tf* and*classroom* = *Tc* in table 8). Although the mean amount of questions not answered due to time is higher in the forest environment opposed to the classroom environment, no statistically significant difference was found when subjected to a paired sample student t-test ($p = 0.152$).

Table 9: Paired samples t-test performance arithmetic tasks (n=29)

| | | | t | df | p |
|---|---|---|---|---|---|
| Cf | - | Cc | 0.679 | 28 | 0.503 |
| If | - | Ic | -2.911 | 28 | 0.007 |
| Tf | - | Tc | 1.473 | 28 | 0.152 |

Table 10: Descriptive statistics incorrect answers forest and classroom environment(n=29)

| | If | Ic |
|---|---|---|
| Valid | 29 | 29 |
| Missing | 1 | 1 |
| Mean | 3.241 | 4.345 |
| Std. Deviation | 1.683 | 2.365 |
| Minimum | 0.000 | 1.000 |
| Maximum | 7.000 | 11.00 |

To see whether the perceived realism and immersion of the participants had a significant influence on the performance on the tasks, a correlation matrix was computed between the task results and obtained data from the post survey.

These correlation matrices showed a few statistically significant correlations;

When looking at the a correlation matrix of the data with the amount of correct questions in the two environments as a main variable, it is shown that the perceived level of stress in the forest environment as well as the perceived difficulty in the classroom environment shows a potential correlation with this main variable (Stress F/Cf p= 0.023 and Difficulty C/Cc p=0.027). However, both these correlations are not found in their respective opposite environment parameters (Stress C/Cc p=0,196 and Difficulty F p=0.098).

In addition, when considering the amount of wrong answered questions as main correlation variable,the perceived level of immersion in the forest environment (Immersive F/If p= 0,020) , shows a potential correlation. However this correlation is also not shown in their opposite environment (Immersive C/Ic p= 0.678.

Regarding the main variable in a correlation matrix to be the made incorrect answers due to insufficient time shows both a potential correlation between the perceived difficulty of the questions (Tf/Difficulty F p=0.031) as well as the perceived stress level in the forest environment (Tf/Stress F p=0.018). Also here, no statistical significant correlation is found in the opposing classroom environment.

## 6.5 Post survey

With the results of the post survey, a mean of different perceived factors of the participants can be derived. The mean perceived level of difficulty of the math questions in both the forest environment and classroom environment was 4,867 and and 4,833 respectively (n=30). Mapping these values on the input scale used in the survey shows that both in the classroom and forest environment the perceived level of difficulty *'was considered to be somewhat difficult'*. The same can be done for the perceived level of realism, The mean for perceived realism in the classroom environment (4.40) and forest environment (4.37) is both respondent to a mean perceived realism of *'neither realistic nor unrealistic'* (n=30).The perceived level of immersion of both the classroom environment (4.73) and forest environment can be translated to a *'somewhat immersive'* albeit with the forest environment having a relatively higher score of 5.00.

Unlike where the previous questions used a 7-point *Likert* scale, the question which covered the perceived level of stress in each environment was asked in the form of a grading system from 1 to 10. This yielded an average perceived stress level of 5.00 for the forest environment and a 6.07 for the classroom environment (n=29).

Table 11: Descriptive statistics post survey (n=30)

| | Stress F | Stress C | Difficulty C | Difficulty F | Immersive F | Immersive C |
|---|---|---|---|---|---|---|
| Valid | 29 | 29 | 30 | 30 | 30 | 30 |
| Mean | 5.000 | 6.069 | 4.833 | 4.867 | 5.000 | 4.733 |

# 7 Discussion

This section covers an in depth look of the findings stated in the results section, a validation check of the results as well as any potential shortcomings. In addition, further recommendations are made for potential follow up research.

## 7.1 Validity of the experiment

One of the reasons a post survey was issued to the participants is to validate whether the virtual environments had a sufficient level of immersion and realism. In addition to this it also serves to assess whether the difficulty of the completed math tasks where on average difficult enough, with the effect of inducing stress within the participant. As shown in the result section, the average levels of realism, immersion and difficulty were on the right side of the spectrum, meaning that all these levels can be considered as sufficient. Although this means that the experiment can be deemed valid, the overall results could potentially have an even more strong outcome; When especially looking at the perceived levels of immersion (forest mean 5.000 , classroom mean 4.733), which corresponds both to the wording *'somewhat immersive'* on the *Likert* scale, there seems room for improvement in either the virtual environment or improvement in virtual reality hardware quality. Since there is other research that suggests that the level of immersion can influence the transfer of proven real world effects in virtual reality [de Kort et al., 2006], if a higher level of immersion is present in the environment can be achieved, a stronger outcome can potentially be located.

## 7.2 Validity of the results

This subsection covers the validity of the results that were produced from the experiment. This covers the validity of the heart monitoring data as well as the results of analyzing the performance of the participants doing the arithmetic task set.

### 7.2.1 Heart rate and heart rate variability

Unlike expected in the main hypothesis, a significant difference in both heart rate and heart rate variability was not found. Although the mean heart rate did increase slightly in the classroom environment opposed to the forest environment, it was not statistically significant. One of the reasons could be the short duration of each session in which the user does the arithmetic task in the environments. Although there is no short term significance, there could be an increased difference in heart rates if the sessions of subsiding in the virtual environments were increased.

Only one heart rate variability parameter is deemed statistically significant (the SDNN value with $p = 0.045$), looking at other research it is shown that at least some other of these parameters (for example a statistically significant difference in the power of low frequencies (LF) would be significant as well [Fauquet-Alekhine et al., 2016]. Therefore it is not safe to assume concluded that the statistically significant SDNN value is a value that heart rate variability was influenced by the experiment. This contradicts with another variable that was measured in the form of a post survey question: The perceived stress level that the participants themselves experienced. This survey question shows that there was a significant difference of perceived levels of stress in the environment.

These contradicting outcomes can potentially be explained through a few findings. Firstly, when looking at the cited publications that measure heart rate variability as a stress indicator, the tool to measure heart frequencies is almost unanimously an advanced ECG machine, which can potentially be more accurate than the consumer level used heart measurement strap in this experiment. Another reason is that though some difference in level of stress was present, this difference or the intensity of the level of stress was not large enough to be measured properly through the method of differences in heart rate and heart rate variability.

### 7.2.2 Stress inducing task

Although the heart rate monitoring data was not significant, with the data from post survey it can be said that the task of calculating simple math questions in a fast manner was successful in inducing some form of stress. The difficulty of the task was on average deemed difficult enough in both environments, and the mean level of perceived stress additionally indicates that some form of stress was present within the participants. The mean perceived stress level of the participants obtained through the post survey were also deemed significantly higher in the classroom environment opposed to the forest environment.

Looking more in depth into the participants performance on the stress inducing task, the average error score in both the environments seems to enforce the idea that the classroom environment is deemed more stressful opposed to the forest environment as well. There was a significant difference in the error score of both environments, where more errors were made in the classroom environment. Combining this given together with the difference in perceived stress level can be an indication that the participants were indeed more stressful in the forest environment opposed to the classroom environment.

Looking at the other outcomes of the performance on the stress inducing task shows no statistically significant results. However, the data does show a form of trend that could be potentially be interesting for future research. Whereas the average amount of correctly answered questions in both environments are roughly the same (Mean forest = 18,241, mean classroom = 18,759) and shows no trend favoring the one of the other, the average amount of incorrectly answered questions due to time constraints shows a weak trend where more time outs occurred in the forest environment opposed to the classroom environment. This (although weak) trend could suggest that the forest environment was less stress inducing, and therefore the participant was less prone to perform better, as can be described with the previously stated Yerkes Dodson law. However since the data is not statistically significant, this trend could not exist and further research, especially with longer durations and more stress inducing tasks would be needed.

This ties in with another interesting variable, which indeed is deemed statistically significant. The difference in amount of incorrect questions in the arithmetic task set between the virtual environments show that in the classroom environment the mean error rate was higher opposed to the forest environment. This can show a higher level of stress in the classroom environment, since the Yerkes Dodson Law states that a (non-optimal) higher level of stress can lead to lower performance. However again, only one single variable makes this suggestion.

Looking at the results it could also just be that there is not a strong enough relation between stress reducing features of a digital environment on stress levels while engaging in a stress inducing task. Although research indicates that stress can be relieved by using virtual environments after stress inducement [Annerstedt et al., 2013] [de Kort et al., 2006], there is no evidence yet that shows these effects during the stress inducement process. A reason for this can be that since the individuals in the experiment are focusing on the task at hand, they do not pay enough attention to their surroundings. An additional reason could be that unlike the studies that focus on stress recovery, the main goal of the participants was to complete the tasks presented as well and as fast as possible. Trying to calm down and reduce their stress levels were not a goal of the participant. It could be that a virtual, or even real-world stress reducing environment only works if the individual makes it an objective and sets aside (or gets offered) time in order to reduce their stress levels properly. These potential reasons however are for now speculations, and further studies would be needed in order to validate these.

# 8 Conclusion

With the obtained data in the results and discussion section, a conclusion about the research and it's outcomes, and future recommendations can be made. Firstly, the conclusion can be made whether the computed results can yield an answer on the two previously stated research questions:

- **R1: Can a digitally created virtual reality forest environment influence heart rate and heart rate variability during a stress inducing task like arithmetic stress tasks?**

The hypothesis for R1 was that their would be a observable statistically significant difference in heart rate and heart rate variability: The heart rate should be slightly higher and the heart rate variability should be slightly lower in the potentially more stressful classroom virtual environment opposed to the potentially stress reducing forest environment. This however has not been found. However, the results of the performance test (having a significantly higher error rate in the potentially more stressful environment) as well as the perceived stress level obtain from the post-survey (having a significantly higher perceived stress level in the stressful environment) suggests that their was some level of differences in stress between the virtual environments. This could suggest that when using more professional measurement equipment, a higher perceived level of immersion or a longer experiment session, inducing more stress on a longer time period could lead to different results.

- **R2: Can a digitally created virtual reality forest environment increase productivity of doing arithmetic stress tasks?**

The hypothesis for R2 was that a slight difference in both the amount of correct questions, amount of errors and amount of incorrect questions due to time-out, would differ between each environment, in favor of the less stressful forest environment. The difference in the amount of correct questions was not significant, however the amount of incorrect errors did seem to significantly differ between the two virtual environments. The mean error rate was significantly higher in the classroom environment.

Although no increase in productivity in the sense of value was measured, a suggestion could be made that the level of productivity in the sense of minimizing errors was achieved in the virtual forest environment. The mean amount of correct questions were almost the same, but the error rate higher,meaning that in the deemed more stressful classroom environment the participants 'completed' more tasks with a higher error rate as a compromise. To link this to R2, it can be said that however a digitally virtual reality forest environment does not increase productivity of arithmetic stress tasks in the sense of volume, but it can suggest an increase the productivity in the sense of quality.

Although no real conclusive arguments and no overwhelming statistical significant results have could been derived from this research, it does open some possibilities for future research. Testing different forms of virtual environments which can variate from different levels of immersiveness or realism could yield different results. In addition to this it could be interesting to see the same form of experiment replicated, but with longer stress inducing sessions, which can be more similar to the stress perceived in a work environment.

An improvement in physical hardware could also improve stress reduction with the use of virtual reality. Virtual reality devices are currently still seeing progress in development, in the sense of graphic fidelity and physical feedback technologies that could have a positive impact of the level of immersion in a virtual environment. Although this research is not conclusive, the dream of being productive in a virtual reality forest and reducing stress at the same time does maybe not have to live on only in videogames.

# References


[Alvarsson et al., 2010] Alvarsson, J. J., Wiens, S., and Nilsson, M. E. (2010). Stress recovery during exposure to nature sound and environmental noise. *International Journal of Environmental Research and Public Health*, 7(3):1036–1046.

[Anderson et al., 2017] Anderson, A. P., Mayer, M. D., Fellows, A. M., Cowan, D. R., Hegel, M. T., and Buckey, J. C. (2017). Relaxation with immersive natural scenes presented using virtual reality. *Aerospace Medicine and Human Performance*, 88(6):520–526.

[Anderson et al., 2003] Anderson, P., Rothbaum, B. O., and Hodges, L. F. (2003). Virtual reality exposure in the treatment of social anxiety. *Cognitive and Behavioral Practice*, 10(3):240–247.

[Annerstedt et al., 2013] Annerstedt, M., Jönsson, P., Wallergård, M., Johansson, G., Karlson, B., Grahn, P., Hansen, Å. M., and 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.

[AVROTROS, 2018] AVROTROS (2018). Rapportage millenials, een vandaag.

[Bates, 1992] Bates, J. (1992). Virtual reality, art, and entertainment. *Presence: Teleoperators and Virtual Environments*, 1(1):133–138.

[Cohen et al., 1983a] Cohen, S., Kamarck, T., and Mermelstein, R. (1983a). A global measure of perceived stress. *Journal of Health and Social Behavior*, 24(4):385.

[Cohen et al., 1983b] Cohen, S., Kamarck, T., and Mermelstein, R. (1983b). Perceived stress scale.

[de Kort and IJsselsteijn, 2006] de Kort, Y. and IJsselsteijn, W. (2006). Reality check: The role of realism in stress reduction using media technology. *CyberPsychology & Behavior*, 9(2):230–233.

[de Kort et al., 2006] de Kort, Y., Meijnders, A., Sponselee, A., and IJsselsteijn, W. (2006). What is wrong with virtual trees? restoring from stress in a mediated environment. *Journal of Environmental Psychology*, 26(4):309–320.

[Fauquet-Alekhine et al., 2016] Fauquet-Alekhine, P., Rouillac, L., Berton, J., and Granry, J.-C. (2016). Heart rate vs stress indicator for short term mental stress. *British Journal of Medicine and Medical Research*, 17(7):1–11.

[Grahn and Stigsdotter, 2003] Grahn, P. and Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening*, 2(1):1–18.

[Green et al., 1996] Green, P. J., Kirby, R., and Suls, J. (1996). The effects of caffeine on blood pressure and heart rate: A review. *Annals of Behavioral Medicine*, 18(3):201–216.

[Hartig et al., 1991] Hartig, T., Mang, M., and Evans, G. W. (1991). Restorative effects of natural environment experiences. *Environment and Behavior*, 23(1):3–26.

[Kuhlmann, 2005] Kuhlmann, S. (2005). Impaired memory retrieval after psychosocial stress in healthy young men. *Journal of Neuroscience*, 25(11):2977–2982.

[Leardi et al., 2007] Leardi, S., Pietroletti, R., Angeloni, G., Necozione, S., Ranalletta, G., and Gusto, B. D. (2007). Randomized clinical trial examining the effect of music therapy in stress response to day surgery. *British Journal of Surgery*, 94(8):943–947.

[Lupien et al., 2009] Lupien, S. J., McEwen, B. S., Gunnar, M. R., and Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience*, 10(6):434–445.

[Mehta and Zhu, 2009] Mehta, R. and Zhu, R. (2009). Blue or red? exploring the effect of color on cognitive task performances. *Science*, 323(5918):1226–1229.

[Merchant et al., 2014] Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., and Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students. *Computers & Education*, 70:29–40.

[Nararro-Haro et al., 2016] Nararro-Haro, M. V., Hoffman, H. G., Garcia-Palacios, A., Sampaio, M., Alhalabi, W., Hall, K., and Linehan, M. (2016). The use of virtual reality to facilitate mindfulness skills training in dialectical behavioral therapy for borderline personality disorder: A case study. *Frontiers in Psychology*, 7.

[Parrott and C, 1999] Parrott and C, A. (1999). Does cigarette smoking cause stress? *American Psychologist*, 54(10):817.

[Parsons and Rizzo, 2008] Parsons, T. D. and Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry*, 39(3):250–261.

[Ranabir and Reetu, 2011] Ranabir, S. and Reetu, K. (2011). Stress and hormones. *Indian Journal of Endocrinology and Metabolism*, 15(1):18.

[Renaud and Blondin, 1997] Renaud, P. and Blondin, J.-P. (1997). The stress of stroop performance: physiological and emotional responses to color–word interference, task pacing, and pacing speed. *International Journal of Psychophysiology*, 27(2):87–97.

[Rothbaum et al., 2001] Rothbaum, B. O., Hodges, L. F., Ready, D., Graap, K., and Alarcon, R. D. (2001). Virtual reality exposure therapy for vietnam veterans with posttraumatic stress disorder. *The Journal of Clinical Psychiatry*, 62(8):617–622.

[Salmon et al., 2012] Salmon, P. G., Sephton, S. E., and Dreeben, S. J. (2012). Mindfulness-based stress reduction. In *Acceptance and Mindfulness in Cognitive Behavior Therapy*, pages 132–163. John Wiley & Sons, Inc.

[Stroop, 1935] Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6):643–662.

[Sunday, 2012] Sunday, A. S. (2012). Job stress and productivity increase. *Work*, 41(Supplement 1):2955–2958.

[Sutherland, 1968] Sutherland, I. E. (1968). A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I*, pages 757–764. ACM.

[Thoma et al., 2013] Thoma, M. V., Marca, R. L., Brönnimann, R., Finkel, L., Ehlert, U., and Nater, U. M. (2013). The effect of music on the human stress response. *PLoS ONE*, 8(8):e70156.

[Vahedi and Saiphoo, 2018] Vahedi, Z. and Saiphoo, A. (2018). The association between smartphone use, stress, and anxiety: A meta-analytic review. *Stress and Health*.

[van Holland et al., 2011] van Holland, B. J., Frings-Dresen, M. H. W., and Sluiter, J. K. (2011). Measuring short-term and long-term physiological stress effects by cortisol reactivity in saliva and hair. *International Archives of Occupational and Environmental Health*, 85(8):849–852.

[Virginia et al., 1996] Virginia, L., Pearson-Mims, H, C., and Goodwin, G. K. (1996). Interior plants may improve worker productivity and reduce stress in a windowless environment. *Journal of Environmental Horticulture*, 14(2):97–100.

[Watson, 2017] Watson, W. T. (2017). Financial well-being: 2017/2018 global benefits attitudes survey.

[Zengin-Bolatkale et al., 2015] Zengin-Bolatkale, H., Conture, E. G., and Walden, T. A. (2015). Sympathetic arousal of young children who stutter during a stressful picture naming task. *Journal of Fluency Disorders*, 46:24–40.