Exploring the Effects of Virtual Reality Nature Environments on Stress and Anxiety: A Pilot Study

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Abstract. Virtual reality has been investigated extensively as a tool for psychological and psychiatric treatment, particularly for reducing anxiety feelings. In this study, we aim to investigate the effect of virtual nature exposure on anxiety and stress. For this purpose, participants were asked to memorize a short poem and then exposed to a stressful task in a virtual public speaking environment, namely to recite the memorized text. After the task, the control group rested while the experimental group explored an immersive virtual nature environment. Stress and anxiety levels were measured at three time points using a shortened 6-item version of the STAI-S questionnaire (as a surrogate for EEG). Results showed that exposure to natural VR environments can have a positive effect on stress and anxiety, especially for the anxiety-present items of the questionnaire. However, the effect is not as strong for the anxiety-absent items. Nevertheless, these findings suggest that virtual nature exposure may be an effective tool for reducing anxiety and stress levels after exposure to a stressful situation. Overall, the study demonstrates the great potential of VR as a therapeutic tool and motivates further research into its potential applications.

Keywords: virtual reality · social anxiety · STAI questionnaire · Trier Social Stress Test · virtual nature exposure · EEG

1 Introduction

Since the development of virtual reality (VR), there have been attempts to leverage it as a tool for psychological and psychiatric treatment. The immersive experience in VR allows for the use of a wide variety of environments and scenarios, which would otherwise be impractical, or even impossible to incorporate into therapy. One such example is the use of VR in Exposure Therapy, which consist of presenting the patient to the feared stimulus or situation in order to help decrease the stressful response over time. By using VR-based exposure therapy (VRET), patients can be safely exposed to all types of situations which may be causing them anxiety, and allows them to experience scenarios which would be difficult or unpractical to use in common exposure therapy, such as going on a flight for someone who is afraid of heights, or simulate active combat situations for soldiers presenting with posttraumatic stress disorder (PTSD). This kind of therapy has been shown to be effective in treating a variety of clinical conditions and phobias, such as acrophobia (Opdyke, Williford, & North, 1995), anxiety disorders (Powers & Emmelkamp, 2008), or PTSD (Rothbaum & Schwartz, 2002).

Another way in which VR can be used in this context is by providing stimuli in the virtual experience which can induce a reduction in anxiety feelings. This has been done, for instance, by providing participants with biofeedback to help them actively try to slow their heartbeats, or by using relaxing environments and sounds which can increase calmness and mindfulness.

Im Kim et al. (2019) investigated whether VR could in principle be used as a therapeutic tool by providing participants with simultaneous feedback. After being confronted with different scenarios of a stressing situation, participants experienced an intervention session where they were provided with visuo-haptic feedback tailored to reduce their feelings of anxiety. The visual and haptic stimuli let the subjects see and feel their heartbeats, and a breathing guide was provided. The results of the study showed that, although results were not significant, participants did tend to experience a reduction in anxiety symptoms, and points to a promising role of VR for immersive therapeutic interventions.

Other studies have instead tested the use of VR scenarios to increase feelings of relaxation and mindfulness. There is numerous evidence that even short-term exposure to nature can be highly beneficial for mental health and wellbeing (Bratman, Hamilton, & Daily, 2012). In cases where access to natural environments might not be directly available, VR can provide a valuable alternative, and a number of studies have explored whether an immersive experience in virtual nature might also provide mental health benefits (Frost et al., 2022; White et al., 2018; Liszio et al., 2018; Navarro-Haro et al., 2019; Reynolds et al., 2022; Lakhani et al., 2020; Veling et al., 2021; Browning et al., 2023).

In the following section, some of the relevant papers in this field will be presented. Furthermore, we will expand on some of the reasons in favour of using VR technology for the current study, and we will motivate the choice of concurrently using electroencephalography (EEG) recordings in order to measure anxiety and stress feelings. To conclude, an overview of the aims of this pilot study will be provided.

1.1 Research field and related works

Navarro-Haro et al. (2019) investigated the use of VR natural environments to decrease feelings of anxiety in subjects presenting with generalized anxiety disorder (GAD). Two experimental groups were subjected to mindfulness-based interventions (MBI), and one group additionally had a VR session where participants floated in a virtual river and watched the nature scenery around them. The results showed that the VR sessions lead to subsequent increased relaxation, and to a lesser dropout rate. The same VR environment was used to treat patients with Borderline Personality Disorder (Nararro-Haro et al., 2016), and to decrease pain sensation in patients with spinal cord injuries (Flores et al., 2018), showing promising results for the use of VR in mindfulness-based interventions.

Reynolds et al. (2022) also used VR to increase relaxation in patients with metastatic brain cancer. After short immersions into two virtual nature environments for a period of week, the results showed significant decreases in depressive and anxiety feelings.

Recently, Browning et al. (2023) investigated the effects of virtual nature immersions on mental health over a longer period of time. After several weeks of exposure, the sample of college students showed decreases in apprehension feelings after the VR sessions, compared to no exposure. Depressive feelings, on the other hand, did not seem to decrease significantly, and thus more research might be needed in the future to understand the exact effects of VR nature on mental health.

1.2 Advantages of using EEG technology

The use of EEG technology within an experiment has many advantages. In terms of use, this technology is a cost-effective alternative to other neuroimaging techniques, making it accessible to smaller and non-corporate-funded studies such as ours (Ojeda et al., 2014). In addition, the EEG equipment exists in a portable version, which allows data to be collected under different conditions and environments (Gramann et al., 2011). In our context, if the pilot study were expanded, we could also take measurements in real-world situations, e.g. collect data after an actual exposure to an anxiety situation. This methodology allows measuring brain activity in a non-invasive way without requiring any surgery on the participants (Luck, 2014). This safer and more ethical option for measuring neural activity in human participants may therefore increase people's willingness to participate without sacrificing the measurement of the brain data we need regarding stress levels. In terms of measurement results, there are also two clear advantages. First, the high signal-to-noise ratio of EEG signals. Compared to other neuroimaging techniques, EEG signals are less affected by external noise and artifacts (Nunez & Srinivasan, 2006). This allows cleaner and more reliable data to be obtained. Second, EEG has very high temporal resolution. This allows neural activity to be measured with millisecond precision (Makeig et al., 2002). This makes EEG technology an ideal tool for studying rapid changes in neural activity, for us the decreasing stress rate.

1.3 Advantages of using VR technology

Researchers in many fields have the opportunity to benefit from VR technology. While tracking physical activity, the experiment environment can easily be manipulated. Furthermore, different settings and circumstances in the same environment can be easily created. This allows for more equality between training, testing, and control groups. A detailed insight into the advantages is given as follows.

Looking at the external circumstances, cost-effectiveness is one of the main advantages of VR. Compared to real-world experiments which can be expensive in design and execution, VR experiments can be conducted remotely, eliminating the need for costly travel and lodging (Valmaggia et al., 2016). In our case of a pilot study without financing from a bigger concern or similar financier, VR is a cost-effective solution for creating the same environmental conditions for all participants and enriching the environment with important details. Additionally, this benefit contributes to higher replicability. The artificially created virtual environment makes it easier for other researchers to verify and reproduce the experiment (Witmer & Singer, 1998). Aside from that, VR enables the participation of people who, due to physical, emotional, or cognitive circumstances, may not be able to take part in real-world experiments and thus expand the radius of potential participants (Valmaggia et al., 2016).

Regarding the study results, VR allows more control over the experimental environment: By independently manipulating individual factors, very specific needs of the study can be adjusted and explored. This leads to more precise data collection and analysis (Bliss, Tidwell, & Guest, 1997). In addition, a VR setting often allows the participants more control over the environment, e.g. by manipulating objects in a way that would not be possible in real-world experiments (McMahan & Lee, 2019). In addition, the ecological validity can increase. By being able to adapt the VR environments relatively precisely to real-world situations and eliminating the disruptive factors of these, more accurate and more applicable findings can be achieved (Sanchez-Vives & Slater, 2005).

Finally, the ethical advantage of using VR must be mentioned. Some experiments that involve real-world situations might not be ethical. Researchers can create VR scenarios that are impossible, dangerous, or unethical in real life (Won et al., 2017).

In conclusion, the use of VR technology for experimentation allows the creation and replication of physical environments in a controlled and cost-effective manner with good reproducibility. This is especially beneficial for small and independent studies such as our pilot study.

1.4 Hypothesis

In the proposed study, the effect of virtual nature exposure on anxiety feelings will be investigated. Similarly to Im Kim et al. (2019), all participants will first be exposed to a stressful scenario in VR. One experimental group will subsequently participate in a VR session, containing a relaxing natural environment. The study will measure stress levels at three different time points using EEG: before receiving the stressful task, after conducting the task, and after a certain time of completing the task. Based on previous literature (Browning et al., 2023; Reynolds et al., 2022), we expect that exposure to the virtual natural environment could significantly reduce anxiety compared to a control group receiving no exposure to nature, which will be evident in the EEG signals. These results would indicate that VR nature might provoke similar effects of stress and anxiety reduction as physical natural environments, and might therefore be a suitable alternative for psychological treatment.

2 Materials and Methods

As the proposed study will be a pilot study and is therefore exploratory and descriptive in nature, we asked participants to complete a self-report questionnaire about their stress and anxiety levels instead of using the EGG, which was also not available to us for this study.

Questionnaire Hence, we had to decide on a questionnaire that measures anxiety in particular and temporary situations that the participants were confronted with during the experiment (state anxiety). The Spielberger State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1971) is one of the most commonly used questionnaires to measure the state and trait components of anxiety of non-disorder-specific anxiety (Manzoni et al., 2008). Therefore, we decided to use the STAI-State anxiety scale (STAI-S) of this questionnaire. However, the full-form seemed impractical here, as participants had to fill in the forms three times, and that moreover in a virtual environment. Hence, we opted for a shortened version: Chlan et al. (2003) developed a 6-item scale using anxiety-present items 9, 12, and 17 and anxiety-absent items 5, 10, and 20 from the original scale. It has been found to be reliable and valid relative to the original 20-item version and better captures the physical and immediate anxiety symptoms related to current situations than other shortened versions, which was exactly what we were looking for (Bayrampour et al., 2014; Tluczek et al., 2009). You can find the questionnaire under Tab 1 in Appendix A.

Virtual environments In addition to not being able to use EEG equipment, participants were exposed to the virtual environment on a computer screen instead of wearing a VR headset. It has to be said that we would expect the use of a VR headset to have stronger associated benefits than a computer screen, as a higher level of immersion can be achieved. The experiment was designed with Unity and builds its scenes mainly upon screen overlay canvas (see Figure 4), due to the fact that a huge part of the experiments needs to show text. Additionally, the presentation scene is simplified with a screen overlay that shows people looking at the participants because it is sufficient for the computer screen and other options like building a 3D scene from free assets or using free HDRI images do look less realistic. Nevertheless, the possibilities unity offers are more used in the calming scene where the participants can move around in a forest, look around and the camera replaces the participants head, so they do not see their body (see Figure 4c). [1]

[1] The Unity implementation can be found in this GitHub repository: `https://github.com/anbebe/AnxietyStudy3D`

In the following sections, we will provide a detailed methodology for conducting the study ideally and also describe how we actually conducted the study without the necessary equipment.

2.1 Ethical Disclaimer

Before the commencement of the study, the researchers would have obtain ethical clearance from the relevant ethics committee at the Osnabrück University. Participants would be informed about the purpose of the study, that they are free to withdraw from the study at any point without providing any reason and that they could stop the experiment if they felt any discomfort or felt sick (especially while conducing it with VR headset). All the sessions would have been conducted under supervision of a researcher in case of any emergency and all participants would have been required to sign informed consent form before undertaking the experiment.

2.2 Participants

At best, participants would have been recruited through online advertisements and on social media platforms. Recruitment would have taken place based on the following criteria: no history of head injury, no seizure activity, no major mental health disorders. To qualify for the study, subjects would have had to be at least 18 years old and have moderate levels of generalized anxiety. To check this, we would have conducted a Generalized Anxiety Disorder screening (GAD-7), as an exclusion/ inclusion criterion, where a score of 8 or higher would have been considered a point of inclusion (Spitzer et al., 2006). In addition, participants would have been administered a demographic questionnaire to gather information about their age, ethnicity, educational background and prior experience with VR.

As we did not have the equipment to actually conduct the proposed study and were also very limited in time, the participants were simply 10 people from our circle of friends and family. Our experiment was conducted with 6 participants of which 5 identify as female and 1 as male. They range from age 28 to 58. The participants were randomly assigned a condition with an equal number of participants in both conditions. Participants were informed about the purpose of the study and the procedure of the experiment was explained to them step by step.

2.3 Procedure

Each participant underwent testing in a well-lit and noise-free setting with comfortable room temperature.The experiment took about 20 minutes, while using the VR and EEG would have demanded about 90 minutes in order to conduct the whole testing. The experiment consisted of three main phases:

- During the initial phase, participants were provided with a short briefing on the purpose of the study along with brief explanations on each steps of the experiment. Here, they were informed on what the task will consist of and how long it will last. In order to not impose any biases and to motivate them to make a real effort to learn the text, participants were told that we want to examine how virtual environment impact their ability to memorize the text and subsequently, their ability to present the given text to a virtual audience. They were also told that they had to fill in a short questionnaire about their feelings at a particular moment three times throughout the experiment. The briefing, including explanation, signing the consents form and filling in the demographic questionnaire lasted about 5 minutes. Participants were then asked to sit down in front of a PC with a prepared environment (built in Unity for the purpose of potentially using a VR headset along with the EEG). First, participants were presented with the questionnaire to evaluate how they feel in the moment before starting the task. The designated time for that was 1 minute. Consequently, the environment had changed after the given time elapsed and they were presented with a one-page text in the Unity environment. For the purpose of this study, it was a short poem about Ava who liked to explore technology, particularly VR (See Figure 3 in Appendix A). The text was generated using OpenAI's ChatGPT-3.5. As previously instructed, after the text was first displayed on the screen, they had to memorize its contents within a given time frame of 5 minutes.

- After the time had passed, the second phase included participants presenting the memorized information in the virtual public speaking environment. This task was adapted from the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993) and is designed to induce stress and anxiety in the participants. Therefore, it is possible to investigate the calming impact of the virtual nature environment afterwords. Subjects had 3 minutes to present all the memorised information. After conducting the task, participants were immediately presented with the same as previously used stress/anxiety levels questionnaire, with again 1 minute to fill it in.

- Moving to the third phase, the control group was asked to sit in the room for about 3 minutes with no interaction but instructed to rest and relax. Meanwhile the other group was presented with an immersive virtual nature environment, where they were able to walk around and explore the calming nature for 3 minutes. If a VR headset was available, the subjects could walk around in the forest environment and fully immerse themselves in the virtual nature environment. With no VR headset available the participants were able to explore the environment visually on the screen by using their mouse. Afterwards, both groups were presented with the same questionnaire again: The control group was asked to go back to the PC and complete the questionnaire, while the other group was presented with the questionnaire immediately after the time has passed, in the virtual nature environment. The aim of this phase is to investigate the differences between virtual nature and control conditions in terms of the ability to reduce stress and anxiety levels.

2.4 Data Analysis

With the EEG data available, we would be able to measure the brainwave activity of the participants, focusing on changes in the alpha (8-12 Hz) and beta (12-30 Hz) bands. More specifically, the alpha and beta bands would be divided into two subcomponents. Specifically, the study divides alpha into low alpha (8-10Hz) and high alpha (10-12Hz) and beta into low beta (12-18Hz) and high beta (18-30Hz)(Tarrant, Viczko, & Cope, 2018). Low Alpha is associated with a calm and relaxed state where the individual is not paying attention to the external world (Thompson & Thompson, 2015). On the other hand, high alpha is associated with a state of relaxed alertness that may occur just before engaging in an action. Lower beta activity is associated with the performance of challenging cognitive tasks and the maintenance of cognitive, psychological, and behavioral processes (Sherlin, 2009). Pathological increases in beta activity may be associated with states of cognitive inflexibility. High Beta, on the other hand, is often associated with higher levels of concentration, but may also be observed at elevated levels during periods of anxiety or emotional intensity (Sherlin, 2009). The study would then use statistical comparison to test hypotheses related to the changes in brainwave activity observed in these specific frequency bands and sub-components. In our case, the observed data will come from the self-report questionnaire, while access to the EEG and VR device would allow us to measure data representing mental stress and relaxation stress based on brainwave activity.

3 Results

To repeat: We conducted this experiment to see to what extent a natural virtual environment can have a calming effect on individuals who have previously been exposed to stressful situations. To do this, participants were randomly assigned to either the control condition or the calming condition with an equal number of participants in both conditions. Data was collected from 6 participants. Figure 1 and Figure 2 provide a detailed overview of the data. In the following part, we focus on the differences in the scores of the items of the self-assessment of anxiety questionnaire in the two groups. [2]

First, we need to clarify again how to score here: 4 stands for "not at all," a 3 corresponds to "somewhat", 2 means "moderately so", and 1 means "very much so". That is, for the anxiety-present items ("frightened," "worried," "nervous"), lower ratings mean higher anxiety levels, while for the anxiety-absent

[2] The python file used to analyze the collected data can be found under the following link: `https://colab.research.google.com/drive/1H8YewOwNRDez1s4vrbN3JAJIC8wEUA0l?usp=sharing`

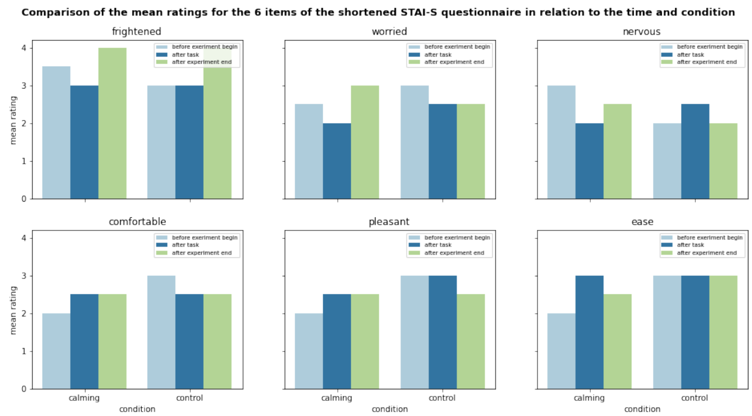

Fig. 1: This graph compares the mean ratings of the 6 items in the shortened STAI-S questionnaire regarding the condition (calming, control) and the time (before the experiment, after the stressful task, at the end of the experiment). For the he anxiety-present items lower rating means higher anxiety levels, while for the anxiety-absent items, a lower rating also corresponds to a lower anxiety level.

items (”comfortable”, ”pleasant”, ”ease”), a higher rating also corresponds to a higher anxiety level.

Let us first analyze the different ratings of the two groups for the anxiety-present items: participants in the calming group did not really feel *”frightened”* at the beginning of the experiment (mean rating of 3.5), then they became slightly more frightened after they had to do the socially stressful task (3), but did not feel frightened at all after exposure to the natural virtual environment (4). For the control group, the rating remained the same before the experiment and after the task (3), and also increased to 4 at the end of the experiment. A similar pattern can also be seen for *”worried”*. Participants do start out a bit worried (2.5), which then increases to a rating of 2 after the task. After being exposed to the virtual forest again, however, they then felt only somewhat worried (3). For participants in the control condition, however, concern remained the same after the task and at the end of the experiment (2.5) and was also slightly lower than at the beginning (3). For the *”nervous”* item, the same effect was observed again: The calming environment again made participants less nervous (2.5) than they were shortly after the presentation (2), but here nervousness is even lower at the beginning of the experiment (3). Interestingly, the participants of the control group are the least nervous immediately after the task (2), whereas they were more nervous at the beginning and at the end of the experiment (2.5). The effect mentioned above can of course also be seen in the mean scores: Thus, all anxiety-present items together receive their lowest score after the task (7),

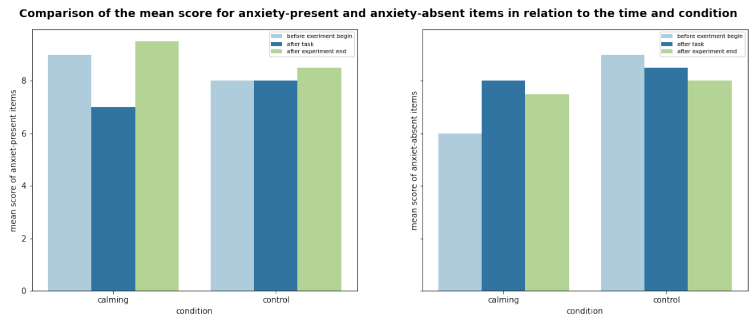

Fig. 2: This graph compares the mean scores of the anxiety-present and anxiety-absent items of the shortened STAI-S questionnaire regarding the condition (calming, control) and the time (before the experiment, after the stressful task, at the end of the experiment). For the he anxiety-present items lower scores means higher anxiety levels, while for the anxiety-absent items, a lower score also corresponds to a lower anxiety level.

which corresponds to a higher anxiety level, and the lowest anxiety level after the calming environment with a score of 9.5. In the control group, this value is only 8.5, which is only slightly above the value at the beginning of the experiment or shortly after the task (8.0).

For the anxiety-absent items, a lower score now also correlates with a lower level of anxiety. For the *"comfortable"* and *"pleasant"* items, participants in the calming condition gave the lowest ratings at the beginning of the experiment (2) and then a slightly higher rating after the task and after the calming environment (2.5). This means that the calming environment did not have a positive effect on their comfort or pleasantness, but their anxiety just stayed the same as it was after the task, even slightly higher than it was at the beginning. In the control group, on the other hand, the participants feel less pleasant/comfortable at the beginning (3) and somewhat more at the end of the experiment (2.5). In the *"ease"* condition, however, the natural environment had a positive effect again, and the ratings were reduced from 3 to 2.5 at the end of the experiment. However, this value is still higher than the initial value (2). In the control condition, participants felt the same throughout the experiment. Overall, the participants in the calming group gave the lowest values at the beginning of the experiment (6), which means that they didn't feel that anxious. After the task, the level of anxiety increased to 8, which is what we expected. And is slightly improved again by the calming environment (7.5). In the control group, the mean scores get lower and lower as the experiment progresses.

4 Discussion

Our results are consistent with our initial hypothesis that natural VR environments can have a positive effect on stress and anxiety. We assessed this using participants' responses to a self-reported state-anxiety questionnaire, which was administered to participants at various points in the experiment.

Especially for the anxiety-present items, exposure to the natural VR environment was shown to have a positive effect. For all items of this type, the anxiety level decreased after the time spent in the virtual forest compared to the time immediately after the presentation. For the items "frightened" and "worried", the anxiety level after exposure was even lower than at the beginning of the experiment. This could also be due to the fact that the participants were stressed at the beginning of the experiment because they did not know what to expect (which actually plays into our hands, since we wanted to artificially create stress anyway), but this is contradicted by the fact that the effect is not as strong in the control group.

While the anxiety level of the calming group increases on all 6 items, this is not the case for the control group. We believe that this is not always the case in the control group because of the small sample size and because we did not look for outliers and exclude them. Nevertheless, we think there is still enough evidence to suggest that our Trier Social Stress Test scenario is already working in this prototypical version of the experiment and is indeed putting participants under social stress. We therefore argue that the effect will be even more pronounced with a real VR headset.

The small sample size could also be the reason why we found for "nervous" that the stress level in the control group was lowest after the completion of the task and increased again after the calming environment. Or why the control group's scores on the anxiety-absent item "ease" remained unchanged over the course of the experiment.

In general, however, the effect of the natural VR environment is not so strong for the anxiety-absent items. Only for "ease" does the anxiety level decrease compared to the time immediately after the task. For the other items, the level remains the same and is never lower than at the beginning of the experiment.

Nevertheless, we believe that our results indicate that exposure to a calming natural VR environment can have a positive effect on the self-reported stress level of the participant after performing a stressful task. Therefore, one can motivate to repeat the whole thing with EEG and expect that this should also confirm these first preliminary results. One could also investigate why the calming effect of the natural environment is not as strong for anxiety-absent emotions.

4.1 Limitations

Of course, this pilot study has some limitations that should be addressed in the future. General points will be discussed first, followed by concrete restrictions using EEG and VR technology.

Some points have already been mentioned, such as the small sample size. As a result, the representativeness of this study is questionable. Added to this are the sample characteristics. Our participants are not representative representations of the targeted population in the areas of age, gender, ethnicity, and other demographic factors and thus limit the generalization of the results. Without a larger sample and a more diverse population, the findings from the data are less reliable.

Regarding the methodology, it can be said that the exact conditions and variables were kept as simple as possible. As long as no EEG is used and the data is based on self-report measures, the findings could contain bias, e.g. through the social desirability effects. However, this limitation of validity is to be expected in the context of a pilot study.

In addition, there are extraneous variables that the researcher cannot control. Nevertheless, these can influence the study results. In our case, for example, it could be that other circumstances in the experimenter's room lead to a reduction in the stress level, e.g. through the soothing voice of the experimenter.

To summarize, even if our chosen technologies favor reproducibility, the other circumstances, including the limited sample and simple experimental conditions, lead to reduced reproducibility.

Limitations of using EEG technology Regarding the limitations specific to EEG technology, there are two major points of results and implementation.

Concerning the results, EEG provides a limited spatial resolution. This makes it difficult to allocate the measured signals to specific brain regions (Luck, 2014). Thus, in our case, the wrong signal, namely not the stress level, could be incorrectly measured. In addition, there is a certain vulnerability to artifacts, which can lead to incorrect interpretation of the results. However, external and internal signal disturbances such as blinking or muscle activity can be corrected by extensive pre-processing and post-processing (Westerfield et al., 2001). The differentiation between the neural sources is similarly problematic. Due to the proximity and simultaneous activity of many neurons, it is difficult to identify which are responsible for the sought-after cognitive process of stress (Makeig et al., 2002).

There are two limiting factors regarding the implementation of EEG technology. First, the limited depth of penetration. By measuring signals from the most outer layers of the brain, the measurements related to the inner layers can be distorted (Nunez & Srinivasan, 2006). Second, a high level of concentration is required from the participants. The participants have to maintain concentration over a long period, which includes not only the test phase itself but also the time-consuming attachment of the EEG cap. When the potential discomfort of wearing the cap (and VR goggles) is compounded by difficult verbal information from a complex task, as in our presentation situation, or stressful conditions, concentration wanes more quickly (Davenport, Watts, & Williams, 2011).

Fatigue and reduced concentration that comes with the length of the experiment can lead to signal diversity. This actively influences the study results (Paraskevopoulos et al., 2014).

In summary, it can be said that with the increasing complexity of our study conditions, the desired results from the EEG measurement could become less precise and more falsified.

Limitations of using VR technology VR technology can also impose limitations on experimentation in terms of results, implementation, and other areas.

The implementation of VR experiments, for example, can mean a limited sample size. It can be especially difficult for small studies like ours to find a sample large enough for the results to be statistically valid. In addition, the cost of developing and implementing a VR study can be particularly expensive for small projects without the use of previous related experiments (Schultheis, Himelstein, & Rizzo, 2002). In addition, there are technical limitations that lead to disturbed or invalid data collection, for example, due to hardware or software malfunctions. An example of this is a fault in the VR headsets, which can lead to motion sickness and thus influence on performance and response behavior of the subjects in the experiment (Bohil, Alicea, & Biocca, 2011). It is also the case, depending on the VR environment, that the number of possible repetitions is limited and the experiment should be kept short for the sake of concentration and motion sickness. In our case, for example, seeing the same presentation or calming environment again might have a reduced effect compared to real-world settings, which always vary. Furthermore, ecological validity can be critical, as it increases with the enrichment of the VR environment with real real-world-like situations. However, more complex VR environments are not always the favorable option, for example, because they are more expensive or more error-prone.

With regard to the limitation of the results of VR experiments, it can firstly be mentioned that these are not always transferable to real-world situations and therefore a generalized application of the results can be critical (Bohil et al., 2011). Secondly, the partially limited possibility of holistically capturing a real-world situation in VR can lead to a limitation of external validity (Riva, Wiederhold, & Mantovani, 2019). An important example for our experiment would be the social interaction with the audience and their reaction to the subject's performance in the presentation setting of the experiment. Thirdly, there is a risk of bias if the VR environment is not developed with the highest precision. For example, preconceptions for stereotypes can arise from the negative portrayal of a certain group of people in the VR environment and have a long-lasting influence on the participants (Slater & Sanchez-Vives, 2016). As our pilot study is only conducted in a simple and inexpensive setting, the risk of bias is given.

The last point to mention is ethics. Participants need to know what to expect and how to stop the experiment at any time to reduce the impact on the participant's real life as much as possible. However, this can reduce or even distort the desired effect of the unexpected.

In summary, there are a variety of factors from technical and design limitations to validity and bias issues to ethical concerns that limit the use and outcome of the use of VR technologies in an experiment.

5 Conclusion

The current study aimed to investigate whether immersion in VR natural scenarios could be effective in reducing feelings of stress and anxiety. Exposure to nature is known to highly benefit mental health (Bratman et al., 2012). However, access to natural environments might not always be available, as in the case of individuals with physical or mental constraints, or even in front of the Covid-19 pandemic. Therefore, VR can represent a valuable alternative for providing access to calming virtual nature environments. Previous studies have found that natural scenarios in VR can effectively decrease anxiety or depression feelings in a variety of clinical and non-clinical subjects (Navarro-Haro et al., 2019; Browning et al., 2023; Reynolds et al., 2022).

Here, the results of our pilot study indicated a trend of anxiety reduction in the experimental group, which was exposed to the calming environment after the stress task. A follow-up study would be needed to investigate whether this effect can be replicated using a VR headset for full immersion, and whether EEG recordings would reflect a calming effect as well.

5.1 Future research and Outlook

In the last part of the conclusion, points for the development of the pilot study into a deep and far-reaching study and prospects for application will be presented shortly.

First, the insights gained from the limitations should be put into practice: in the future, the sample should be greatly expanded in size and diversity so that it is more representative and valid. Also crucial for validity is a more precise elaboration of the external variables and the VR environment. In addition, external conditions such as the explanation given to the participants about the study before the experiment starts should also be enriched to achieve more uniformity and thus comparability between the individual data. To increase ecological validity, the complexity of the environment should be increased and adapted to the real world. In addition, the questionnaire in the study should be replaced by an EEG device so that the falsification of data collection through various self-assessments is replaced by valid measurements.

Based on the results, the research field could be extended to other areas: which relaxation environment reduces stress faster (e.g. forest, beach, mountain, private environment, or social environment)? How would it affect the build-up of stress levels if a stress-reducing environment is used before the stressful situation?

Does the literature identify other external variables that lead to stress reduction? If so, how could these be combined with the stress-reducing environment?

Further research on such insights could be translated into targeted measures in the long term. For example, a personalized application could be invented that helps people who are facing a stressful situation to reduce the build-up of stress right from the beginning by using a stress-reducing environment in VR. Such applications could also be used for therapy and training purposes.

In summary, there is still much potential for improvement in future research and expansion of its framework. However, investing in further research is certainly worthwhile, as private as well as institutional use of applications based on it could well be imaginable and enriching.

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A Supplementary Materials

Ava put on her VR headset with delight
And suddenly, she was soaring in flight
Through mountains and oceans, with a grin
The possibilities seemed endless, within
But one day, something strange occurred
Ava found herself feeling quite absurd
As much as she loved her virtual world
Her real life seemed to become unfurled
Her friends and family grew worried and sad
As Ava became more and more isolated and mad
They tried to connect with her, but in vain
For Ava was too deep in her virtual domain
One day, a wise old man came to her aid
And said, ”Ava, it's not just about the game you've played
Virtual reality is a tool to enhance your life
But you must balance it with the real world's strife”
With those words, Ava began to see
That virtual reality could never truly be
A substitute for the real joys and fun
Of being with loved ones and in the sun
And so, Ava took off her headset and smiled
She felt like she had been lost for a while
But now she knew that real life was worth the ride
And with a renewed spirit, she walked outside. Once upon a time, there was a girl named Ava
Who loved to explore and discover, ah ha!
She stumbled upon a new technology one day
Virtual reality, where she could play and play
Ava put on her VR headset with delight
And suddenly, she was soaring in flight
Through mountains and oceans, with a grin
The possibilities seemed endless, within
But one day, something strange occurred
Ava found herself feeling quite absurd
As much as she loved her virtual world
Her real life seemed to become unfurled
Her friends and family grew worried and sad
As Ava became more and more isolated and mad
They tried to connect with her, but in vain
For Ava was too deep in her virtual domain
One day, a wise old man came to her aid
And said, "Ava, it's not just about the game you've played
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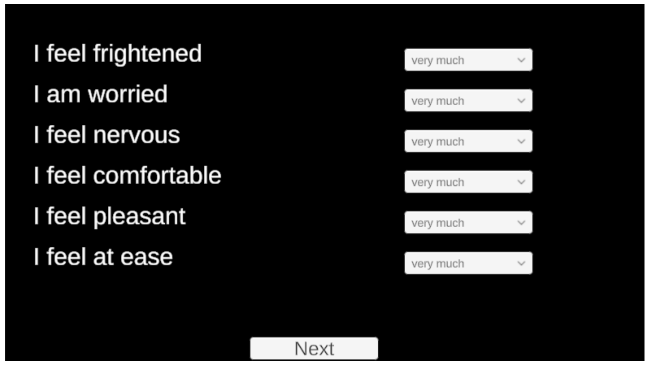
Of being with loved ones and in the sun
And so, Ava took off her headset and smiled
She felt like she had been lost for a while
But now she knew that real life was worth the ride
And with a renewed spirit, she walked outside.

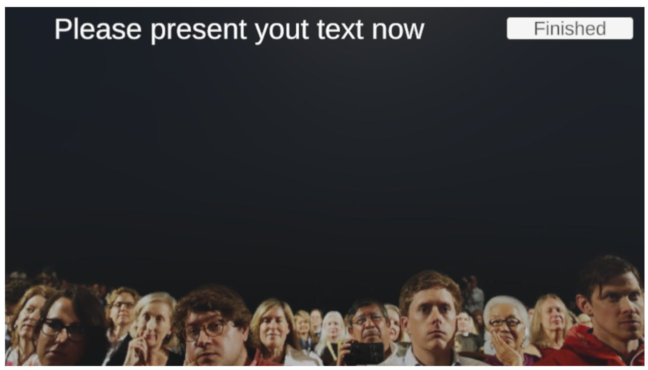
Fig. 3: This poem was generated by Open AI's ChatGPT-3.5, which was prompted to generate a short story about virtual reality that was easy to remember and could be used in a Trier Social Stress Test (Kirschbaum et al., 1993) scenario.

	not at all	*somewhat*	*moderately so*	*very much so*
I feel frightened	O	O	O	O
I am worried	O	O	O	O
I feel nervous	O	O	O	O
I feel comfortable	O	O	O	O
I feel pleasant	O	O	O	O
I feel at ease	O	O	O	O

Table 1: The shortened 6-item STAI-S questionnaire developed by Chlan et al. (2003), that was used to measure the participants stress and anxiety levels before receiving the stressful task, after conducting the task and again after a certain time of completing the task.



(a)



(b)

(c)

Fig. 4: The main scenes of the experiment on a computer screen. 4a shows the questionnaire (screen overlay) with a dropdown menu with four options (based on 1) where the participants can choose and if finished, click the Next-Button to get to the next part of the experiment. 4b shows the screen overlay the participants see that should simulate a crowd watching and listening to the presentation with the option to click the Finished-Button if finished earlier. 4c shows the simulated forest with the options to look around with the mouse and move with the keys w,a,s,d.