How effective is a virtual reality-based feedback system at reducing stress measured by changes in the user's heart rate?

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***Abstract*— THE medical applications of Virtual Reality (VR) are forever growing and more ways to harness this piece of equipment to benefit the progression of modern medicine are appearing. This dissertation ask's the question: How effective is a virtual reality-based feedback system at reducing stress measured by changes in the user's heart rate? Integrating a heartbeat sensor into the testing phase of the artefact accurately gauge's how effective Virtual Reality can be in reducing the stress levels of a user. This study collected both quantative and qualitative data to evaluate the systems effectiveness.The results of this test showed a statistically significant decrease in the users heart rate after the experiment indicating a decrease in physiological stress levels, and participants reporting feeling more relaxed. This research adopts a realistic approach to this problem and contributes to the ever-growing pool of knowledge based on VR's role in medicine.**

I. Introduction

VIRTUAL Reality (VR) has become increasingly important in the medical field and gives doctors an important tool to more effectively diagnose and treat patients [12]. It also provides support to patients in a less invasive, more cost effective format through the therapeutic effects that VR can provide if used correctly[14]. This is due to the immersive environments that can be created that aide patients in a way that more traditional methods cannot [15]. One of these areas is the effect that VR can have on patients recovering from a traumatic medical event such as surgery and the mental health benefits such as people being treated for conditions such as anxiety and depression.

Reversing this perspective it can also be used as a powerful tool in reducing anxiety and stress not just for the patients but also the doctors and nurses. By providing them with this powerful tool that can be used efficiently and quickly to reduce stress we can reduce burnout and improve their mental well-being therefore improving the overall quality of care that these healthcare workers can provide to patients [7].

It could be argued that stress reduction is a vital part of a patient's recovery and a form of early prevention from further health issues such as heart issues from increased levels of stress. It can help accelerate healing and provide an improvement in the overall quality of life and is less invasive compared to more traditional methods of stress management such as therapy or medication and much cheaper if done effectively [6]. There are some obvious limitations to accessibility depending on the kind of treatment that a patient is receiving. This platform provides an engaging personalised immersive experience in which a stress relieving environment gives real-time feedback to the users. While other studies have outlined the importance of VR and its effectiveness, few have explored the integration of a pulse monitor in order to measure the reduction in stress that is received in a certain environment, this study addresses this gap in knowledge.

This dissertation develops a VR system which gives the user real-time heart rate feedback and can give either doctor or patient a measurement of how the immersive environment in which they are placed can provide stress relief. The research part of the dissertation collects quantitative data from the heart rate monitor thats attached to the user and also provide qualitative data on how the experience made them feel. They also receive feedback on the emotional response received from the tests. By combining this data, this dissertation gives us an assessment on how VR can be used to reduce stress.

This dissertation holds potential for advances in the use of VR in hospitals and healthcare settings, from patients recovering from cases such as medically related trauma to anxiety and depression-related health issues. This form of treatment would offer a non-invasive, accessible and engaging alternative to traditional methods [**?**]. While previous studies explore the therapeutic potential of virtual reality not many show the potential that virtual reality has on affecting the levels of stress that someone can experience.

This dissertation starts by talking about the current literature surrounding the use of Virtual reality in a therapeutic way using a feedback system such as a pulse monitor, this is followed by the methodology used to create the virtual environment and the pulse monitoring system. it will then conclude with the data analysis and discussion about the results and conclusion on how it affects the implications for medical applications of VR.

II. Background

This literature review discusses and outlines how this research question is important to the broader current literature on the medical effects of VR and how it can be paired with a feedback system to closely analyse the success rate of the software created. The Two key themes looked at are: the effect of feedback systems in medicine and the effect of virtual reality in a therapeutic setting.

A. The Effect of Virtual Reality in Therapy

Vianez A. et al [1] conducted a focus study group of veterans with PTSD and found that Virtual Reality Exposure Therapy (VRET) could accurately and quickly diagnose and assist these veterans with rehabilitation from conflict-induced PTSD. Using VR Headsets showed that it was more effective compared to more traditional methods of treating PTSD and it was able to provide a form of VRET that would cost much more if it was not conducted within a virtual environment. They were able to stimulate thoughts and feelings with much more than just the headsets such as using smell, touch and sound. Whilst this method of exposure therapy may be effective without the headsets, compromising the user's vision and taking them into a different visual environment provided a much more effective form of exposure therapy. Despite the potential it showed the study emphasized that this was a very initial form of research and testing into this form of therapy would require further investigation if it were to become an official form of therapy. [2] F. Rousseaux et al. Conducted an in-depth analysis and experiment on how virtual reality and hypnosis can be used to help patients in an intensive care setting with anxiety and provide pain management. For this experiment Rousseaux took a group of 100 participants they were put into 4 respective control groups. The type of treatment they would be receiving between being hypnotised with Virtual Reality and without using Virtual Reality. In the findings there were no significant differences measured between these groups but they did find that relaxation increased and anxiety and pain decreased in all groups. As there were no significant difference between groups they could not affirm that one technique was better than the other. This study demonstrates the cost-effectiveness of using Virtual Reality compared to a more specialised method which requires more specialised training to operate (such as hypnosis) and shows us the accessibility and success of virtual reality in clinical settings. This study also builds upon what we already know about Virtual Reality in managing stress and anxiety, but it compares it to other forms of therapy and gives us a clear outline as to how VR can be used with other forms of therapy or by itself to receive the same results. Another example of how Virtual Reality can be used as a form of therapy is [3] S. A. Almedhesh et al, experiment on using Virtual Reality for low risk pregnant women going through a caesarean procedure, they found within this test that by incorporating virtual reality and 3D images mixed with calming music decreased the anxiety that the patient underwent Almedhesh also provided evidence backing up the claim that this experiment actually reduced the patients level of anxiety for up to 2 hours post-operation.

B. Heart Rate Monitoring in Medicine

Heart rate variability is an important measure of how someone might be feeling, a higher heart rate indicates higher levels of stress or physical exertion, and lower heart rates imply calm or resting. [4] Amir Hammami et al. Proposes a web-based monitoring system that tracks people's heart rate similar to this project. It also uses an Arduino micro-controller to monitor the user's heart rate and a small GPS microcontroller to monitor location using Google Maps. The intention of this is to provide a rapid response to extreme changes in heart rate that could imply a heart attack or some kind of cardiac incident, thereby increasing quality of care whilst giving patient freedom. The conclusion for this experiment isn't completely conclusive in its argument but it suggests that users could benefit from this application because of how it provides a form of quick and effective help to vulnerable people. This also supports the general question of this dissertation and provides some insight into the effectiveness of a heart rate monitor at diagnosing someone early, quickly and efficiently. [5] Ling Wang et al. Also researched into a stress detection system using ECG machines. The studies showed a 94.8 per cent reliability rate in detecting mood changes and stress levels in a patient using the heart rate variability measured from the ECG machines. Both of these studies highlight the reliability of heart rate variability and gives insight into how it can be used effectively in this project to achieve reliable and useful results. They both support the objective of utilizing VR based feedback systems and by integrating heart rate variability it helps provide real-time information into the level of relaxation and wellbeing of the user.

C. Virtual Reality in Medicine

The integration of VR into the medical field is a significant step forward. Having these technologies evolving constantly requires more planning in order for them to be able to be effectively integrated into Virtual Reality [13] M.Kouijzer et. al emphasize the importance of this concluding that "We recommend that the implementation of VR entails the entire process, from identifying barriers to developing and employing a coherent, multi-level implementation intervention with suitable strategies." This highlights the importance of ensuring that VR is not only practical but also sustainable within the medical field. if correctly implemented it can lead to improvements on healthcare staff for example S. Maltby et al. [16] successfully created a system which increased knowledge, confidence and awareness among all the staff and demonstrated the feasibility of virtual reality-based training in real-world situations. This aligns with the goal of this dissertation on reducing stress using a virtual environment and shows the importance of effective implementation from proper planning. Physcological measures of using virtual reality and gamification can help a struggling patient with overcoming low motivational engagement[22] and overcoming anxiety [23].

D. The Use of ECG and EEG in measuring stress

Electriocardioghaphy (ECG) is a useful tool that can be used to assess levels of stress, ECG measures the heart rate variability a key indicator of stress. An example of this is how it was used by Ling Wang et al [5] to understand the stress levels of a patient with a 94.8% reliability rate. On the other hand using a machine such as en EEG monitor can be used to measure neuralogical changes in a participant an example of this being used is [21]K. A. Fadeev's study on "Too Real to Be Virtual: Autonomic and EEG Responses to Extreme Stress

Scenarios in Virtual Reality," in this study they assessed the neurological responses to "high stress" virutal environments using patients who had previously had bad experiences when using virtual reality. From these experiments they found that there was an increase in the participants BPM and their brain activity, from this the researchers inferred that there was a strong psyhcologigcal impact caused from virtual reality and that safety guidlines for virtual experiences need to be included. Using an EEG monitor with an ECG monitor can increase the reliability and will measure the brain activity of a participant. An example of this is [20] V. Aspiotis et al study of "Assessing Electroencephalography as a Stress Indicator: A VR High-Altitude Scenario Monitored through EEG and ECG," in this study they found that all markers of stress were indicated through Heart rate variability (HRV) in BPM through the ECG machine, all participants reported stress that matched the brain activity and there was a correlation found with perceived stress and HRV the researchers also found that through the EEG machine the brain activity shifted through stress and the expected outcome was not obtained. Instead a lower part of the brain showed more activity causing them to come to the conclusion that their findings challenge the old ideas of how we measure stress through brain activity.

III. Hypothesis and Research Question

The research question for this project is asking: How does a virtual reality-based feedback system influence the participant's stress levels, measured by changes in heart rate and heart rate variability, in terms of physiological outcomes and user experience? Hypothesis one hypothesises that stress reduction will be indicated by the changes in the heart rate due to variability before and after the experience therefore indicating that stress reduction has taken place hypothesis two hypothesises that the participants heart rate will decrease after the experiment has taken place. Hypothesis three hypothesises that the participant will have a high level of stress perception and they will report high levels of relaxation during the time spent in the environment.

Hypothesis	Hypothesis	Null Hypothesis
H1	Stress reduction as indicated by changes in the heart rate will occur during and after the experiment.	Stress reduction as indicated by changes in the heart rate will not occur during and after the experiment
H2	Participants heart rate will decrease after the experiment.	Participants heart rate will not decrease after the experiment
H3	Participants will report high levels of relaxation whilst in the virtual environment.	Participants will not report high levels of relaxation while in the virtual environment

TABLE I: Hypothesis Table

IV. Methodology

Before the experiment begins the chosen participants are asked to read through the Participant Information Figure 14 Sheet and fill out the consent form Figure 11. Any questions

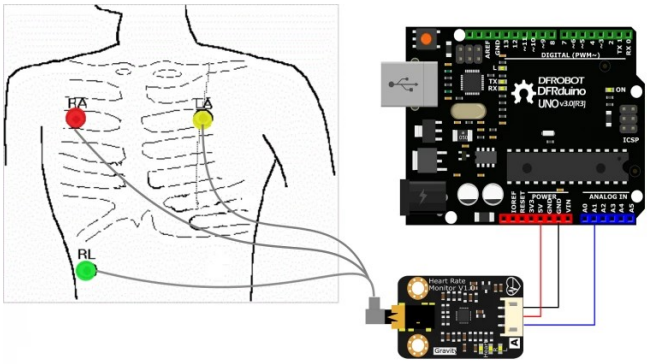


Fig. 1: ECG Monitor Placement

that the participant has will also be answered during this period. A short demonstration of how to use the headset and the headset's licence agreements are also be described, The ECG monitor will then be attached to the participant a diagram will be given to the participant making sure that they attach the correct electrodes to the participants chest or arms the participants were given an image for guidance on how and where to attach electrodes Figure 1. When they are ready a before experiment baseline reading of the participant's heart rate is taken. The ECG monitor is then removed from the participant and the participant then sits down and puts the headset on. At this stage, They enter a Virtual Environment designed specifically to relax the user incorporating elements such as calming music, small intractable events and beautiful scenery. After the experiment, the participant removes the headset and another reading of the participant's pulse is taken to be used to compare against the initial set taken before the experiment. During this experiment the researcher collects two types of data: A qualitative set and a quantitative set from each participant. The qualitative set is taken after the experiment has concluded in the form of a questionnaire Figure 13 and a short interview and the quantitative set is obtained through the LIKERT style questions and during the experiment from the pulse sensor attached to the user. The results from this are compared and help to answer the research questions.

V. Computing Artefact

The Computing artefact consist's of four main components to ensure that the experiment is executed correctly. Link to github page

A. Hardware

1) Virtual Reality Headset(VR Headset): The virtual experience uses this VR headset to display the virtual environment and place the participant into a relaxed state. This helps with fully immersing the participant into the world.

2) Headphones: Audio is played through a set of headphones for further immersion into the world that the participant is placed into.

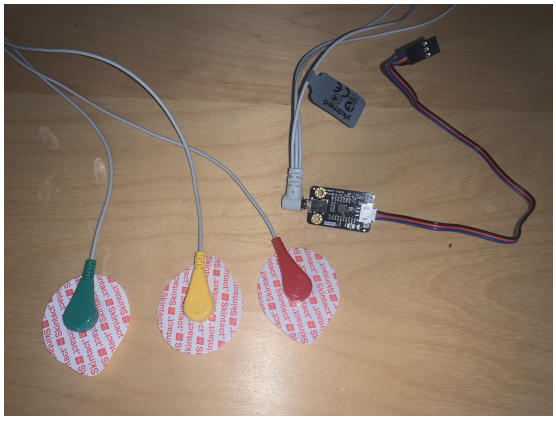


Fig. 2: EQG Monitor

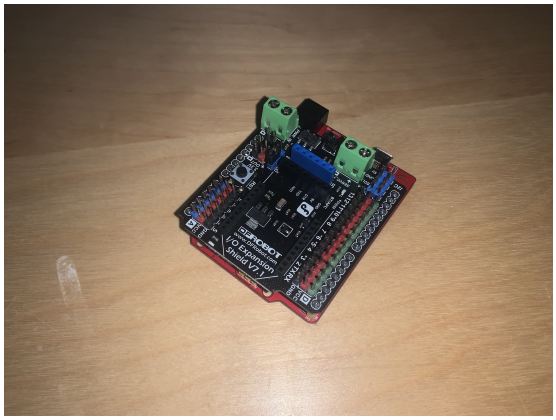


Fig. 3: The Arduino Board with the IO Expansion attached

3) Pulse Monitor: This is a crucial part of the experiment as this is what shall be used to measure the participant's heart rate. The pulse monitor used is interfaced with a Seeduino in order to collect these results. The pulse monitor used is the "DF Robot - Gravity: Analog Heart Rate Monitor Sensor (ECG) for Arduino".Figure 3 "The Gravity: IO Expansion Shield for Arduino V7.1" Figure 2 was added as a recommendation as the ECG Monitor came with cables that worked well with the expansion shield but it is not necessary to collect results . The ECG monitor used came with a library and a wiki page which is linked to Here

4) Seeduino: The V4.2 Seeduino is used to collect the ECG sensor readings.

B. Environment

The Environment is created in Unity and uses the XR Toolkit to interface the Virtual Reality headset with Unity. The participant is placed into an open environment where there are ambient sounds and soft lighting. There is small interactable events but the bulk of the environment is the general ambience of the scene. The most important factor that came into play when creating the environment that the participants would enter was making it user friendly and also calming.Figure 4 Figure 10

C. Refactoring

The Computing artefact was refactored to provide a more stable environment, as the arduino code was mostly done in the Arduino IDE there is not much evidence of refactoring but there are sporadic commits adding new and improved code excerpts and using the intended library to improve the data collection phase. Refactoring messages are included in the github.

VI. Validation and Verification

To ensure that the data collected was valid and reliable the ECG Heart rate monitor was tested at various stages of the data collection stage, and the verification methods were applied throughout these tests at different levels, unit testing was carried out by comparing the heart rate values with a smartwatch which was used to validate the validity of the sensor. Integration testing was carried out to ensure that the response time and the precision of the device was validated, testing the real-time reliability of the measuring device, System testing was used to validate the consistency of the heart rate data and made sure that over multiple sessions the variance of the heart rate readings was reliable, ensuring that stable readings were taken. acceptance testing was conducted throughout the experiment, every participant was asked how relaxing the experience was as a whole and the functionality of the device, combining these approaches made sure there was a structured evaluation of the accuracy, reliability and performance of the device therefore producing valid data collection results.

VII. Research Methods

This experiment adopts a pragmatic view, which asserts that knowledge is understood through practical applications and real-world outcomes This describes the outcomes as addressing particular and detailed problems instead of covering a wide aspect of issues. Ontologically this study adopts a more pluralist stance proposing that stress and relaxation are both measurable and that they can be understood through the methods that are used throughout this experiment both qualitative and quantitative. This shows the need to have a mixed approach to the question asked. Epistemologically this research uses mixed-method approaches of obtaining data through physiological measurements and user feedback to further the insight into how effective a virtual reality-based feedback system can be used to reduce stress effectively. Axiologically this research shows its focus on improving the well being of patients and improving overall therapeutic care. The study employs deductive reasoning and uses participant feedback and pulse monitor readings to ensure that all findings are relevant and grounded which keeps the experiment in line with the pragmatic paradigm and the emphasis on solving real world problems.

VIII. Ethical Considerations

In relation to Falmouth University's Ethical policies [11] this dissertation is considered **Medium Risk**. This also adheres

Fig. 4: Example of Player view in experience

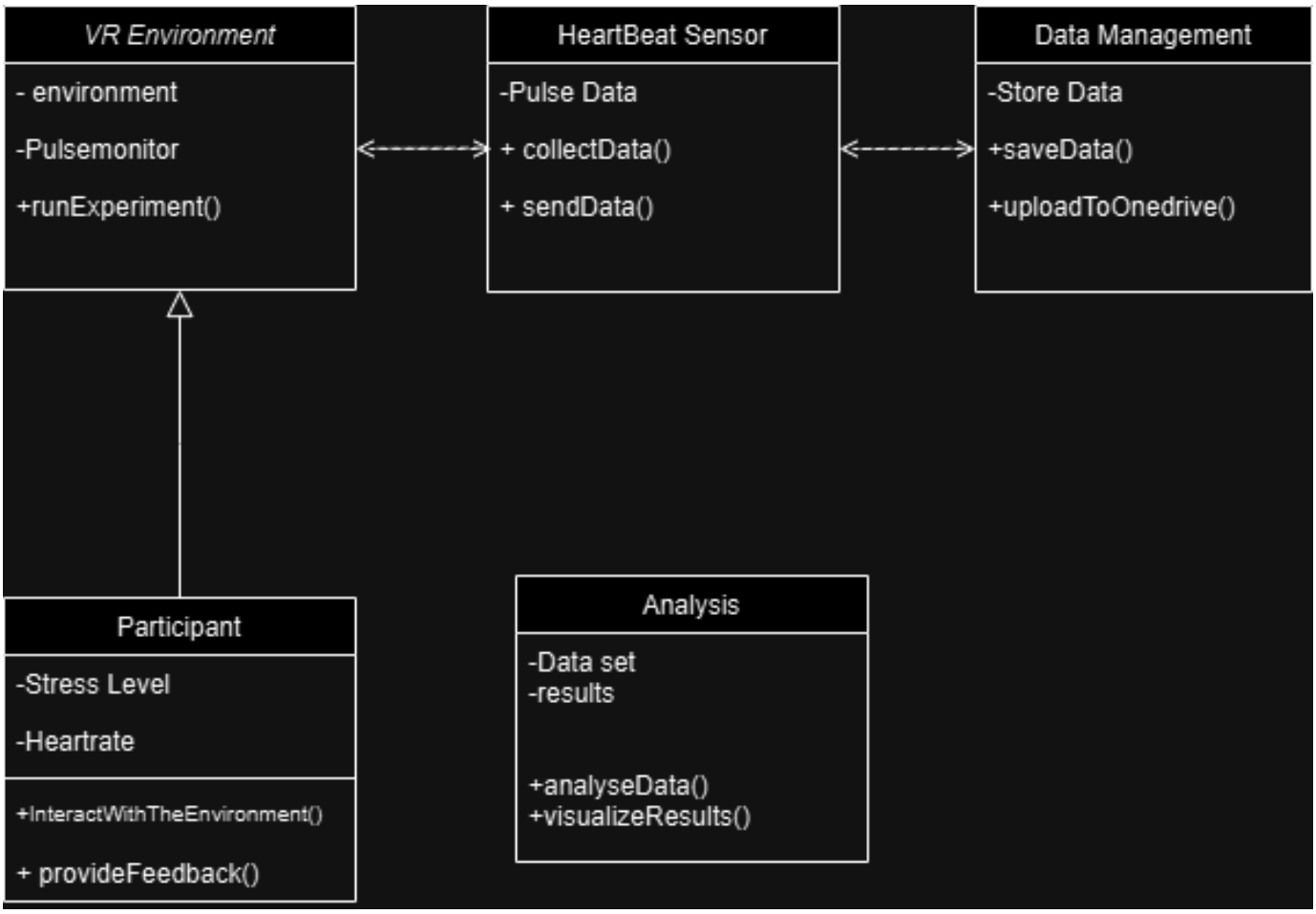


Fig. 5: UML Class Diagram for experiment

to the Nuremberg Code and the BCS Code of conduct [9][10]. The Ethics approval form was applied to and excepted here [18]. And Here

A. Legal

All data collection adhere's to GDPR[8] compliance and regulations. Informed consent is obtained from all participants and anonymized. All intellectual property such as assets, textures or software used are properly cited with the correct licencing. Participants can withdraw from the experiment at any point and their rights are communicated in the consent form that they are asked to sign before the experiment takes place.

B. Social

The environment is inclusive and accessible to all participants including those with debilitating disabilities. Triggering content or sensitive topics are not be included in the project, and the amount of time that the participant has to spend on this project is minimized to avoid stress or inconvenience.

C. Health and Safety

The participant have a safe space where they can interact with the Virtual Environment. Any tripping hazards are dealt with before the experiment takes place, and the user has been given clear instructions on how to operate the Virtual Headset and what to do if they feel any discomfort throughout the duration of the experiment. In case of cybersickness, the participant have been informed on what to do before the experiment takes place and they have been given a designated area in case they do experience nausea. The device has been properly sanitized between participant usage to avoid the spread of germs.

D. Professional

All findings are presented honestly and are not be fabricated or manipulated to fit a hypothesis. All interactions between researchers and participants are professional, clear and respectful. The participants are also be provided with a debriefing after the experiment has concluded which explain's the results of the experiment.

E. Sustainability

This project aims to be as ethically sustainable as possible. All devices used are not left running when not in use and waste has been minimized from the physical components. Any waste has been disposed of responsibly. There is also a re-usability application as the Arduino is not permanently configured as a pulse monitor so it could be re-used as something else at a later date.

IX. Scientific Hypothesis Testing

A. Data Gathering

1) Quantitative Data Collection: The Participants of the experiment enter the VR environment. They then have a wearable heartbeat sensor attached to their finger which record's their heart rate using an Arduino. Participants spend between 5 to 10 minutes in the environment. The participant's heart rate has been continually monitored during this time. When the experiment has concluded the data collected from the heartbeat sensor is read by the computer and formatted into a .csv file which is saved onto a secure Onedrive account using a sensible and clear naming convention such as "Participant1HeartBeatData" This data can then be used to calculate stress reduction by comparing the pre and post-session heart rates.

2) Qualitative Data Collection: To complement the Quantitative data, participants are asked to provide feedback through a short questionnaire. It include's open ended questions and LIKERT scale style questions about their experience and how it made them feel. They are also able to suggest ways that the experience overall could be improved afterwards. Selected individuals may be asked to provide a short interview where they can elaborate on any responses that they made after the experience.

B. Data Management

All data managed complies with[8] GDPR guidelines. The data collected include's the feedback from the participant's post-experiment and the pulse sensor data collected throughout the experiment, The pulse data is stored in a .csv format for use in python and the qualitative data is kept in a .txt file. Everyone in the experiment is kept anonymous and they are assigned unique ID's. All data is kept securely stored on an Onedrive account with two-factor authentication enabled and password protection. Automatic backups are enabled on the Onedrive account and a local backup is stored on a secure hard drive. No identifiable information is collected, only information that is relevant to the experiment is collected. Data is kept for one year after the dissertation is submitted and it is permanently deleted from all storage locations after this time. All information has been handled ethically, securely and in compliance with University standards.

C. Data Analysis

This mixed method approach ensures a valid analysis by comparing the qualitative and quantitative data to give us a clear insight into how it made the participant feel. The quantitative data is processed and analyzed in python and will calculate the two groups: The post-experiment heart rates and the heart rate before the experiment in a paired T-test and is then used to evaluate if the results are significant. A non-parametric equivalent such as a Wilcoxon Signed Rank test is used and can be used to assess the statistical changes of the heart rate. Correlation analysis can be used to explore

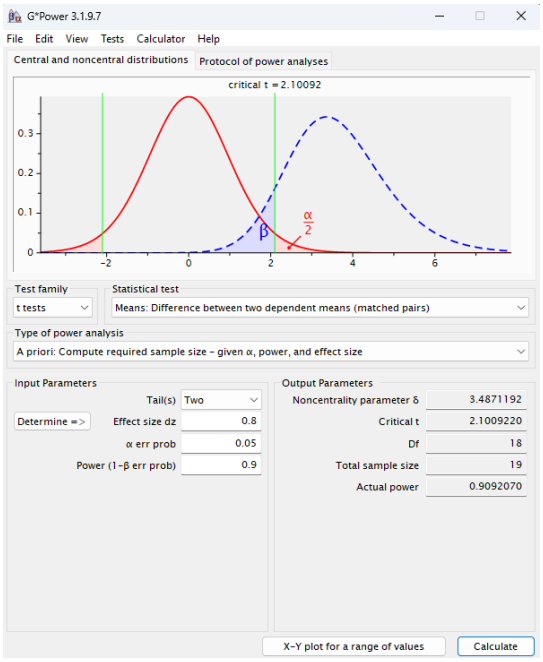


Fig. 6: G Power Analysis calculating Sample Size

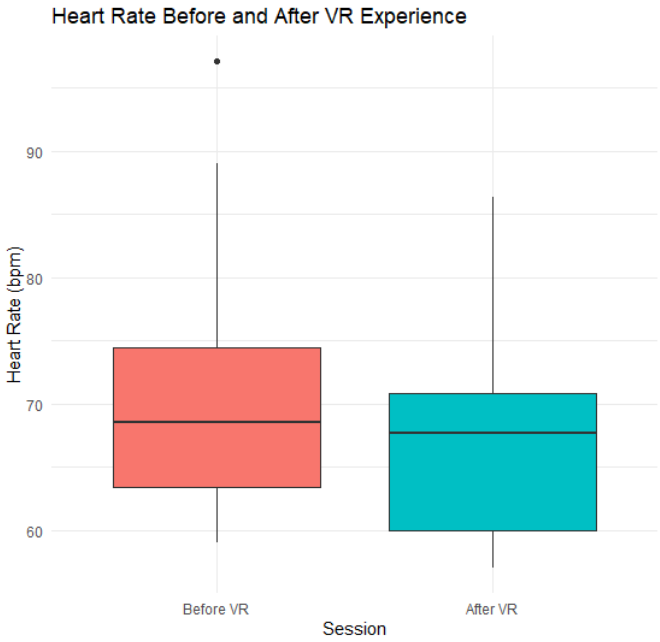


Fig. 7: Box Plot of the before and after BPM results

similarities in heart rate changes and qualitative feedback scores. The qualitative study is analysed to identify the patterns that were found between participants in their user experience. The feedback answers are given a subjective measurement on scoring them which allow's the researcher to conduct the correlation test.

D. Assumptions

It is assumed that for the paired T-Test the heart rate data is normally distributed and that data is continuous. For the correlation test it is believed that both variables are normally distributed and both the feedback answers and quantitative data is correlated.

X. Results

The results of the statistical analysis indicate that there was a reduction in heart rate after the experiment took place following the participants entering the virtual environment, the descriptive statistics show that the before experiment heart rate mean was 70.786 and the mean heart rate after was 66.91669 this suggests that there was a decrease in heart rate among the participants after the experiment had concluded. A paired T test confirmed that the test was statistically significant, with a P value of 0.0004963 and a mean difference of 3.85 Bpm and a 95 percent confidence interval of 1.94 to 5.76 bmp. As the P value is well below the value of 0.05 the null hypothesis suggesting that there is no difference in heart rate before and after the experiment is disapproved and the hypothesis stated is supported therefore these findings suggest that the Virtual Reality experience must have contributed to the relaxation of the participant indicated by the reduction of the participants heart rate before and after the experiment took place. Discussion of these results and the implications of these results align with the existing literature that Virtual Reality influences the stress levels of a participant.

TABLE II: Table of results from paired T-Test

Mean Before	**SD Before**	**Mean After**	**SD After**	**Mean Diff**	**P-Value**
70.768	10.04	66.92	7.98	-3.85	0.0005

XI. Discussion

The findings of this experiment supports both Hypothesis one and two and suggest that there is a direct connection between exposure to virtual reality and reduction in heart rate, indicating that there is a potential for Virtual reality to provide a relaxing effect on the user if that is what the experience is intended for. This supports the argument that Virtual reality has an effectiveness at managing and reducing stress and anxiety in healthcare settings.

For example, Almedesh [3]found that VR significantly decreased stress in patients undergoing a caesarean section. Rousseaux [2]also showed that virtual reality paired with other methods of therapy such as hypnotization was effective in managing anxiety and pain in intensive care units after cardiac surgery. Beverly [7] also reported that virtual reality provided a reduction in stress for healthcare workers on the frontlines during the pandemic. Stating that the relaxing and tranquil nature of the virtual experience was effective in reducing short term stress of these workers, but more research is needed to assess the effectiveness of virtual reality over time.

This study adapts upon this research, by providing further evidence that virtual reality can provide relaxation and a reduction in heart rate. This evidence is provided by the statistically significant drop-in heart rate that was observed from the data collected from participants. An explanation for this is the distracting and engaging nature that virtual reality provides, the added effects of a calming serene environment may have induced a feeling like viewing a beautiful landscape or to traditional relaxation techniques. From the findings it shows that there is a potential for virtual reality to be integrated into stress management programs for healthcare professionals, students and people who operate in stressful busy environments where a quick form of relaxation might be needed, future researchers should explore how differing environments might provide an effect on a user and how combining traditional relaxation methods such as guided meditation and guided imagery can be integrated into virtual reality to boost the heart rate difference and subsequently the levels of stress that were perceived from the results. Finally repeated exposure to virtual reality needs to be assessed to see if there is a result from constant use of virtual reality as a form of relaxation over time is effective.

The findings of this study suggest that virtual reality provides a relaxing effect, but several limitations must be acknowledged, first the sample size of the overall project was very small at only 19 people. Increasing the sample size may ensure that there is a more consistent group of results. This study did not include a control group which makes it difficult to assess if the reduction in heart rate was specifically because of the virtual reality, and if the participants would have received similar results from simply sitting in a chair and breathing deeply, future research could include a control group to test against the use of a virtual headset. further research is needed to assess the long-term effects that virtual reality has on exposure and to compare the effectiveness of this method to more traditional methods of relaxation such as [17] deep breathing or guided imagery.

A correlation test was planned but the lack of statistically significant correlation between the heart rate data obtained and the participant feedback form may suggest that physiological and self reported stress do not always align or that the small sample size and certain anomalous results meant that the effectiveness of the test was drastically reduced this could also be due to anomolous results, even though the correlation test was not statistically significant subjectively all participants reported feeling calm after the experiment had concluded this supports hypothesis three that the participants will report high levels of relaxation.

XII. Conclusion

In conclusion, the study provides sufficient evidence to suggest that using virtual reality can lead to a reduction in heart rate, this suggests that virtual reality can provide a relaxing effect to the user. There was a statistically significant drop in heart rate observed from the results taken during the experiment this supports the previous research that highlights the effectiveness of virtual reality in providing relief from stress and anxiety. The results of these experiments suggests that virtual reality could be integrated into stress management programmes for people working in high stakes high stress environments such as healthcare workers or students.

While the study does provide insight into the potential of virtual reality as a tool for relaxation, several limitations for this could be considered. The small sample size of 19 participants for the project and the absence of a control group variable could limit the generalizability of the results. for future work the sample size should be expanded to ensure that the experiment is easier to generalize and the long term effects should be assessed to discover the long-term impacts that virtual reality has on providing stress relief. Exploring the effects of combining traditional forms of relaxation and virtual reality could also contribute to the body of research.

Overall this paper expands upon the role of virtual reality and its place in stress management, but further exploration is needed to be able to understand the long-term effects that this would have upon a participant and the long-term benefits that may come with it.

Appendix

A. Statistics Addendum

Listing 1: Example of Data analysis in R Studio

```
#load heart rate data
    data <- read.csv("ParticipantHeartRateData
.csv")
# Perform a paired t-test
t_test_result <- t.test(dataPreHR, dataPostHR,
paired = TRUE)
# Print the results
print(t_test_result)
data <- data %>% mutate(HR_Difference = PreHR
- PostHR)
# calculating Heart rate diffirence
correlation <- cor.test(dataHR_Difference,
dataRelaxationScore, method = "pearson")
# subjective measurement of user feedback via
questionarre
print(correlation)
```

Listing 2: Paired T.test of Before and After heart rate means

```
#Set file path
setwd("C:/Users/kardi/OneDrive - Falmouth
    University/Dissertation Results")
#Load Heart rate means
means <- read.csv("All Data Combined.csv")
means <- means[order(means$Participant,
    means$Session),]
# Reshape to wide format
means_wide <- reshape(means, idvar = "
    Participant", timevar = "Session",
    direction = "wide")
# t.test
t_test_result <- t.test(
    means_wide$MeanHeartRate.Before,
    means_wide$MeanHeartRate.After, paired =
    TRUE)
# Output results
print(t_test_result)
```

Listing 3: Creating Box Plot for heart rate data

```
library(ggplot2)
#set directory and load ggplot2
setwd("C:/Users/kardi/OneDrive - Falmouth
    University/Dissertation Results")
#read the csv file
data <- read.csv("IntegrationTest.csv")
# convert timestamp column to a datetime
    format for plotting
data$Timestamp <- as.POSIXct(strptime(
    data$Timestamp, format="%H:%M:%S"))
#create line plot to visualize heart rate
    changes
ggplot(data, aes(x = Timestamp, y = HeartRate)
    ) +
  geom_line(color = "black") +
  geom_point(color = "black") +
  labs(title = "Heart Rate Over Time",
       x = "Timestamp",
       y = "Heart Rate (bpm)") +
       #scale the time to display every data
           point at 10 seconds apart
  scale_x_datetime(labels = scales::
      date_format("%H:%M:%S"),
                   breaks = seq(from = min(
                       data$Timestamp),
                                to = max(
                                    data$Timestamp
                                    ),
                                by = "10 sec")
                                    ) +
  theme_minimal()
```

Level	Manual Testing	Automated Testing	Profiling
Unit	Peer reviews the functionality of the project	Simulating the heart rate data to validate the sensor functionality	Analysing the performance of the heart rate sensor in collecting data
Integration	Testing how the ergonomics of the sensor while holding the controllers	Automated tests to simulate sensor inputs	Measuring the response time and accuracy of the sensor
System	Checklist of intended heartbeat sensor objectives	Smoke Testing heart rate sensor collecting data	Profiling heart rate data consistency across testing sessions taking the average heart rate and the variance
Acceptance	Peer testing for feedback on intended sensor functionality and usability	N/A	Evaluating overall performance during the testing

Fig. 8: Table 1 - Testing Approaches

B. Testing Addendum

TEST PLAN

C. Test Summary

This test plan follows an Agile testing method integrating testing throughout each development sprint to make sure that each iteration of the project meets quality standards. The testing evaluate's the accuracy of the heart rate data and how the pulse sensor performs. How functional and usable the Virtual Environment is. This is focusing on Unit, Integration, System and Acceptance testing at appropriate stages. Testing how the components work it also tests the system isolated, together and as a whole to make sure it meets the functional requirements and the intended goals.

D. Testing Resources

The researcher and peers carry out the Unit, Integration, System tests and Integration tests. The VR headset desktop machines and the heartbeat sensor is needed to carry out these tests. The software that is needed includes Unity for the environment and Arduino libraries.

E. Scope of Testing

In Scope The tests that are in scope for this project include:

1) Heart Beat sensor: Making sure that the sensor captures heart rate data
2) Virtual Environment: Making sure that the environment is functional
3) Testing if the heart rate changes are visible and accurate
4) Making sure that the experience is comfortable for users

Out Of Scope

1) Comparing multiple virtual environments
2) Heart rate monitoring in the long term

F. Testing Approaches

Testing using the Agile method gives a clear understanding of the model's functionality at the end of each sprint.

G. Testing Schedule

The testing schedule commenced in January and finished early in March, it consists of four 2 week sprints. The results of these sprints are presented and the final build is signed off in early March for the data collection phase of the experiment.

H. Risks

There may be certain inaccuracies with the ECG heart rate sensor this can be mitigated early in the sprints by extensive testing on just the accuracy of the heart rate sensor. Virtual Reality has to render the scene from two different eye positions which could cause issues to the environment if it is not properly optimized during the system tests that have been carried out and will result in a lower frame rate and risk of VR related motion sickness. These tests are using participants which means that the sample size and time to test need to be seriously taken into account as the intended participants may not be available when they are needed. To mitigate this, flexible testing and scheduling needs to be in place to make sure that this participant data can be collected when the project is cleared.

I. Quality Assurance Tests

A Comparison test of the arduino ECG machine and using a smartwatch the "COROS Pace 3" a heart beat was noted down every 10 seconds from the COROS Pace 3 and the usual data collection script was run at the same time, afterwards

using the time stamps the excel doucment produced from the arduino was edited to only include the beats that correlated with the ones that were noted down. Each heartbeat was reletively similar but it should be noted that the arduino's value is averaged and smoothed to take into account internal noise within the board. towards the end of the test you can see the heart beats follow the same trend and are only different by 1 or 2 bpm.

TABLE III: Comparison of Heart Rate Measurements: Arduino ECG vs Smartwatch

Arduino ECG (BPM)	Smartwatch (BPM)
51	58
62	61
57	65
61	60
61	64
55	64
71	61
58	61
54	69
54	59
66	64
62	61
61	59
60	61
62	61
59	60
58	60
56	60
69	68
59	62
57	60
65	64
66	60
58	62
60	62
60	62
59	62

An integration test took place using peers to test how responsive the ECG monitor was and to validate if the results that it produced were reliable enough. As you can see from Figure 9

Participant	Did you experience any discomfort during the experiment?
1	2
2	2
3	1
4	2
5	2
6	1
7	1
8	1
9	1
10	1
11	1
12	1
13	1
14	2
15	1
16	1
17	1
18	1
19	1

TABLE IV: Participant responses to discomfort during the experiment (1 = No, 2 = Little Discomfort, 3 = Moderat Discomfort, 4 = Severe Discomfort)

J. Critical Reflection Addendum

K. Introduction

This project has offered a chance to explore and interesting field of virtual reality and how biofeedback can be used to advance the therapeutic effects that virtual reality can provide, throughout the development of the experience I was able to practically apply what I had discovered from a wider range of applications in this field. I also encountered a series of challenges during this development cycle which provided me areas to improve. My first major challenge was the integration of my heartbeat sensor into the project, it lacked proper documentation and had many electrical issues. I also struggled with finding a suitable environment asset for my project as most were not intended for a virtual experience and instead caused massive performance issues. I had difficulty learning R studio under the time constraints that were given and the rushed data collection stage of the project meant that I experienced heightened levels of anxiety. Lastly my project scope was very ambitious and too wide causing necessary compromises to be settled on.

L. Learning R Studio and data management

One of the key challenges that I faced during this stage of the project was learning R studio at a rapid pace although I have had previous experience using data analysis programmes such as Python's Pandas, R Studio was new to me the process of learning how to clean analyse and present the data whilst also collecting data and maintaining my environment meant that this became quite overwhelming. This skill was essential for my future development in my intended career in immersive technology because of the importance of data interpretation to validate and understand what works well in a user experience and what could require improvement. I was able to make this adaptation and properly interpret and display my findings throughout my dissertation. A SMART action that I will take on is to properly learn how to use R studio using proper documentation every week with the goal of being able to properly understand R studio and not rely on YouTube videos or Forum posts to be able to analyse data.

M. Sensor Integration

Another challenge that I faced during the development of the project was the integration of my heartbeat sensor. I initially decided on choosing my heartbeat sensor based of affordability and availability but the heart beat sensor that arrived had no documentation and did not output any raw data when plugged into an Arduino board. After help from university technicians I instead decided to choose a more reliable heartbeat sensor, while I did eventually manage to get this working the output wasn't reliable enough to base my research off and I then decided to go with an ECG monitor from the same company this turned out to be a success and provided me with stable and reliable heart rate readings. This experience highlighted the importance of thorough research and planning when selecting hardware that would be used for a project like this. I prioritised cost over performance and

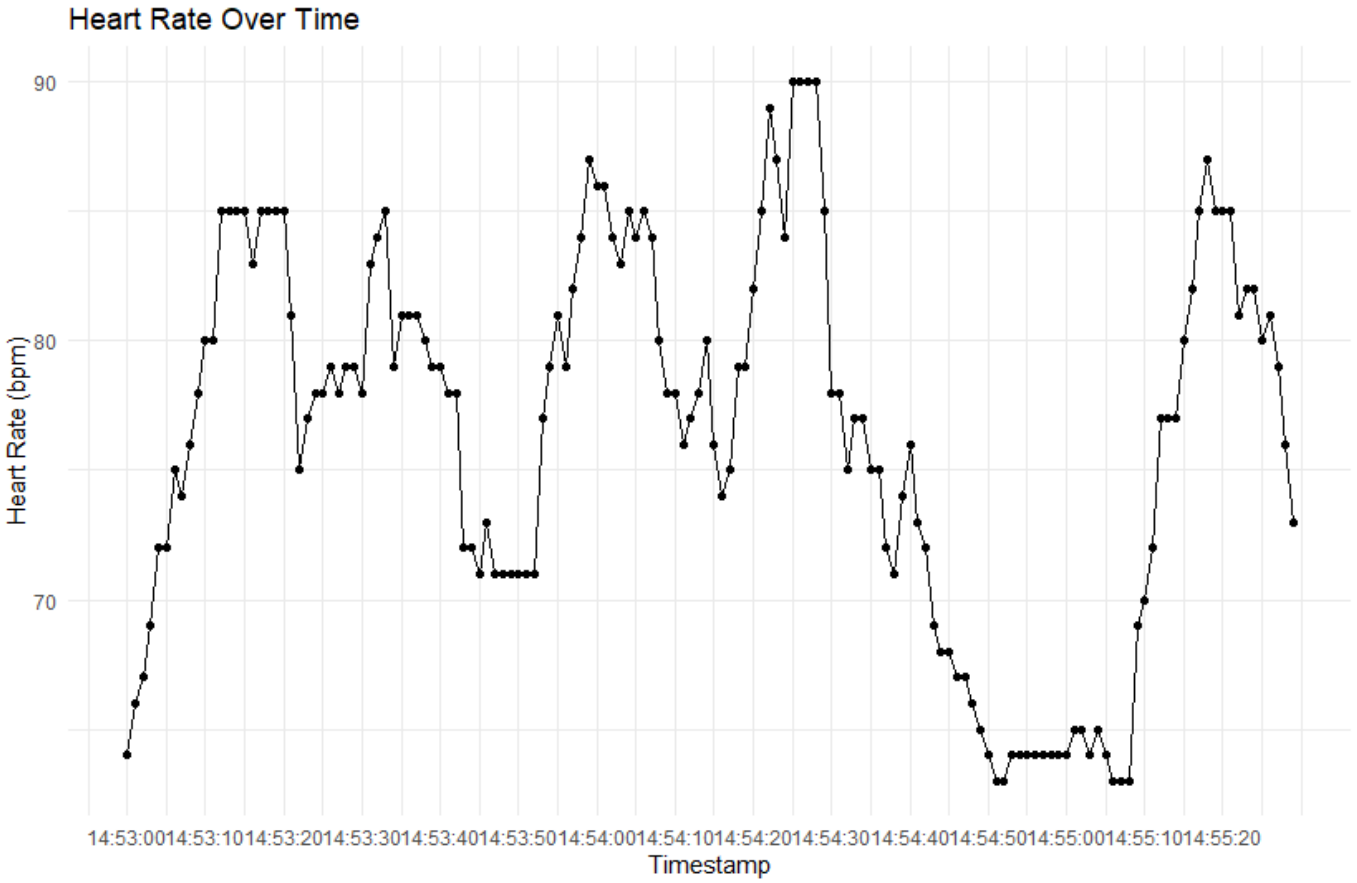


Fig. 9: Integration Testing Monitors Functionality when moving

reliability, which caused unnecessary blockers and delays to the progression of the project. This challenge highlighted the importance of clear plan when working with external devices such as this. Going forward I will assess all the hardware options in front of me and prioritise reliability over cost. My SMART action is to develop a hardware evaluation checklist over the next weeks and list the backup options that I would have in case the chosen hardware was to fail.

N. Unity Integration and Asset management

A significant problem that I faced during the project was finding suitable assets for my environment that I would be creating off of the unity asset store. I initially relied heavily on the assets that I found from a quick search on the asset store however many of these assets had hundreds of thousands of polygons and were not suitable for performance within virtual reality. To combat this issue I tried to split up these assets and troubleshoot ways that I could improve performance within the virtual environment, this proved to be effective but it meant that a level of detail was missing from the world. This forced me to think of more ways around these issues and re evaluate how I selected these assets and the techniques I could use. In the end I settled on using level of detail (LOD) adjustments from faraway assets and hiding missing pieces of environment using thick trees and foliage. This gave me a clearer understand of the limitations that could be faced when developing within virtual reality and in retrospect I should have thought about this when I was developing the environment and taken more time to nullify these issues. My SMART action moving forward is to create a plan of my environment before my next development. This will include testing assets that might be suitable for my given environment to make sure they don't adversely affect the environment's performance by including this into my next project I can save a lot of time spent on troubleshooting on performance.

O. Time Pressure and Anxiety Faced during the data collection

Another challenge I faced was the time management and time pressure faced from the data collection phase of the project. I had underestimated the time that would be lost on integrating a proper heart beat sensor and I had lost crucial amount of time that could have been spent on rectruiting participants this cause me a lot of stress because I had initially estimated that each participant would take 30 minute in each environment. This meant that I was running out of time to complete my data collection phase and I instead had to cut down the amount of time that a participant spent in an environment. Because of my mixed method approach of collecting data this meant that I was not limiting myself when it came to the data analysis section as I had plenty of results from each participant. Effective time management is crucial to

the data collection phase of any experiment as its arguably the most important step when creating a researched based paper. My SMART action is to build a development timeline which outlines the amount of time each section of an experiment needs to be completed I will visualise this on a week by week calendar and make it apart of my initial planning. I will implement this method into my next project.

P. Coordinating Participant Timeslots

Another unexpected challenge I faced was the scheduling and coordination of participants coopertation in the project, as the project reached the stage of data collection I realised that I had less time than I though to collect data, most participants had their own commitments and this led to delays in participation and data collection. I often found that I would have to change my own scheduling to fit around another participants timetable this was manageable but I had my own deadlines and tasks to think about and rescheduling and delaying the data collection was causing the level of anxiety to be increased. I didn't anticipate how complex managing even a small number of participants whilst under time constraints would be. This experience has taught me the importance of proper scheduling and clear communication but also about patience and understanding the expectations of other people early. I should have started enquiring to people about participating earlier than I had and only because of the close proximity of most of the participants and how generous they were with their time I was able to complete the data collection stage of this project. My SMART action for this challenge would be to develop a clear scheduling system for any future study and reaching out at least three weeks in advance to participants including a booking system in order to give both me and the participants plenty of pre warning.

Q. Scoping of the Project

Another challenge that I faced was how I scoped the project during the initial design of the project. I wanted to include a range of features that I had discovered from my research on the field of biofeedback and previous research that had integrated this with virtual reality, as development progressed I realised that I had overestimated the scope of the project and I needed to rapidly downscope what I had initially planned. Although the final result was fully functional there were areas within the virtual environment that I would have liked to be more interactive and could have had a greater impact on the results taken. I learnt that ambition with a project such as this must be balanced with feasibility especially when working under a deadline. My SMART action for this challenge would be to implement a prioritization system from Not Important to very important categorising each section will make scoping easier for my next project and will prevent over scoping from occurring.

R. Reflective Conclusion

Overall the project has been a massive learning experience for me and I have learned many new skills throughout the development process, it has forced me to learn new software skills and has tested my skills with hardware. I understand that some of the issues that I faced were caused because I lacked proper planning and required improvement in those areas. The six SMART actions that I will take going forward

1) I will read through the official R studio documentation to build a better understanding of how to use R studio reducing the number of tutorials I need to be able to use R studio.
2) I will create a hardware checklist with focus on reliability documentation and include backup options for future projects.
3) I will research unity asset ahead of time to ensure that the virtual environment has proper performance and reduce the time that would be spent troubleshooting.
4) I will build a development timeline which will help me manage tests more efficiently and consider unforeseen delays
5) I will start the recruitment for participants earlier and create a booking system to avoid scheduling system to avoid scheduling conflicts and last-minute changes.
6) I will use a prioritization checklist to categorize features by importance and avoid over scoping in future projects.

Listing 4: Arduino Code for ECG Monitor

```
#include "HeartSpeed.h"

HeartSpeed heartspeed(A1);                    //
    /<The serial port for at observe pulse.
//HeartSpeed heartspeed(A1,RAW_DATA);
    ///<The serial port mapper, observation of
     ECG diagram.
const int NumReadings = 10;
int heartbeatreadings[NumReadings];
int readIndex = 0;
int total = 0;
int average = 0;
/* Print the position result */
void mycb(uint8_t rawData, int value)
{
  if(rawData){
    Serial.println(value);
  }else{
    total -= heartbeatreadings[readIndex]; //
        subtracts the oldest reading from the
        total
    heartbeatreadings[readIndex] = value; //
        stores the new value in the array
    total += heartbeatreadings[readIndex]; //
        add the new value to the overall total

    readIndex = (readIndex + 1) % NumReadings;
    average = total / NumReadings;
    Serial.print("HeartRate␣Value␣=␣"); Serial
        .println(average); // Outputs the
        average of current and last heart beat
         reading in order to minimize noise
        fluctuation
  }
}
void setup() {
  Serial.begin(115200);
  heartspeed.setCB(mycb);     ///Callback
      function.
```

```
  heartspeed.begin(); // start heartrate
      monitoring

  for (int i = 0; i <NumReadings; i++){
    heartbeatreadings[i] = 0;
  }
}

void loop() {

}
```

Listing 5: Creating and writing to CSV file

```
import serial
import csv
import time

# Serial Port Configuration
arduino_port = 'COM3'
baud_rate = 115200

# Create a unique filename for each session
def generate_filename(participant_number):
    timestamp = time.strftime('%Y%m%d_%H%M%S')
    return f"participant␣No.{
        participant_number}
        Beforeheart_rate_session_{timestamp}.
        csv"

# Establish Serial Connection
try:
    ser = serial.Serial(arduino_port,
        baud_rate, timeout=1)
    time.sleep(2)  # Wait for connection to
        stabilize
    print(f"Connected␣to␣{arduino_port}")
except serial.SerialException as e:
    print(f"Unable␣to␣open␣{arduino_port}.␣{e}
        ")
    exit(1)

# Data Collection Function
def record_session(participant_number):
    buffer = []
    readings_skipped = 0

    # Create a new CSV file for each session
    csv_filename = generate_filename(
        participant_number)
    with open(csv_filename, "w", newline="")
        as file:
        writer = csv.writer(file)
        writer.writerow(["Timestamp", "Heart␣
            Rate"])
        print(f"participant␣No.{
            participant_number}␣New␣session␣
            started.␣Data␣will␣be␣saved␣to:␣{
            csv_filename}")

        try:
            while True:
                if ser.in_waiting > 0:
                    # Read and clean incoming
                        data
                    raw_data = ser.readline().
                        decode('utf-8').strip
                        ()
                    print (raw_data)

                    # Extract valid heart rate
                        values (digits only)
                    heart_rate = ''.join(
                        filter(str.isdigit,
                        raw_data))

                    if heart_rate:
                        timestamp = time.
                            strftime('%Y-%m-%d
                            ␣%H:%M:%S')
                        if readings_skipped <
                            15:
                            readings_skipped
                                +=1
                            print("Calibration
                                ␣in␣progress")
                            continue

                        buffer.append((
                            timestamp, int(
                            heart_rate)))
                        print(f"Buffered:␣{
                            timestamp}␣-␣{
                            heart_rate}␣BPM")

                    # Write buffered data in
                        chunks
                    if len(buffer) >= 10:
                        buffer.sort(key=lambda
                             x: x[0])  # Sort
                            by timestamp
                        writer.writerows(
                            buffer)
                        file.flush()  # Ensure
                             immediate write
                            to disk
                        print(f"Saved␣{len(
                            buffer)}␣records␣
                            to␣CSV.")
                        buffer.clear()

                    if len(buffer) == 100:
                        buffer.sort(key=lambda
                             x: x[0])  # Sort
                            by timestamp
                        writer.writerows(
                            buffer)
                        file.flush()  # Ensure
                             immediate write
                            to disk
                        print(f"SAVED␣{len(
                            buffer)}␣RECORDS␣
                            TO␣CSV␣EXPERIMENT␣
                            CAN␣BE␣STOPPED!")
                        buffer.clear()

        except KeyboardInterrupt:
            print("\nSession␣ended.␣Finalizing
                ␣data...")

            # Write any remaining buffered
                data
            if buffer:
                buffer.sort(key=lambda x: x
                    [0])
                writer.writerows(buffer)
                print(f"Final␣{len(buffer)}␣
                    records␣saved␣to␣CSV.")
```

```
# Main Loop: Handle multiple sessions
while True:
    participant_number = input("Enter␣
        participant␣number:")
    record_session(participant_number)
    print("\nNew␣participant?␣Press␣Enter␣to␣
        start␣a␣new␣session␣or␣Ctrl+C␣to␣exit.
        ")
    input()
```

Fig. 10: Birds Eye view of scene

S. Potential Implications

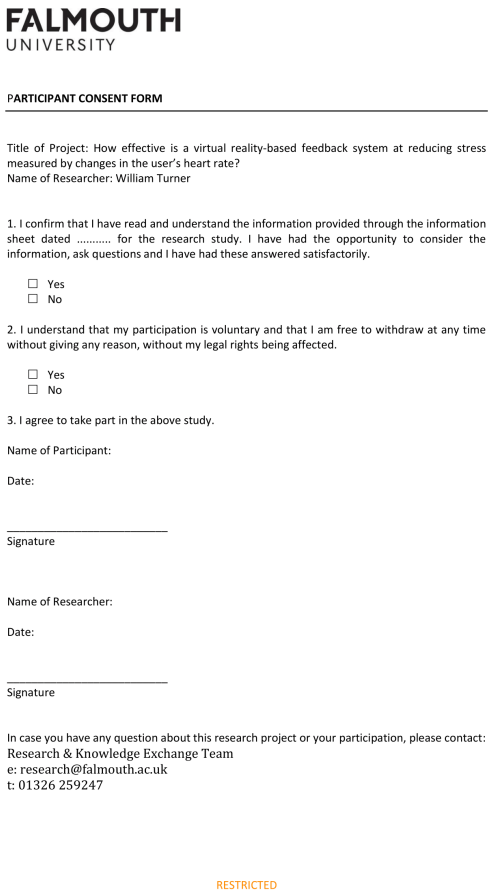
The findings from this dissertation have potential for significant implications on Virtual Reality in the medical field, by showing that it is a viable form of stress relief and could work from day to day. This study contributes to the broader aspect of therapeutic procedures and integration of real life therapeutic methods into virtual spaces and has the ability to enhance both virtual and traditional therapies.

T. Pathways To Impact

This work impacts the way that we use Virtual Reality as a form of stress management and by integrating the feedback system (heart rate data) with an immersive experience. This study provides feasibility into the effectiveness of VR and could increase the use of this technology. Using a wearable sensor paves the way for real time and specific stress indications which would therefore increase the accessibility of mental health support.

U. Future Work

The future of this project could expand upon what is already known, such as increasing the number of environments, the number of sounds and interactable events that the experience contains and assessing how this increase affects the outcome of the heart rate data by testing over a longer period of time with a larger amount of people. The integration of more sensors and properly integrating the sensor with the environment to provide real time feedback within the experience could also be an interesting topic to cover. Attempting to personalise the experience dependent on the levels of stress but also for user preference could provide an even further understanding on how this technology can be used as an effective form of stress management.



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PARTICIPANT CONSENT FORM

Title of Project: How effective is a virtual reality-based feedback system at reducing stress measured by changes in the user's heart rate?
Name of Researcher: William Turner

1. I confirm that I have read and understand the information provided through the information sheet dated ..... for the research study. I have had the opportunity to consider the information, ask questions and I have had these answered satisfactorily.

☐ Yes
☐ No

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.

☐ Yes
☐ No

3. I agree to take part in the above study.

Name of Participant:

Date:

_____
Signature

Name of Researcher:

Date:

_____
Signature

In case you have any question about this research project or your participation, please contact:
Research & Knowledge Exchange Team
e: research@falmouth.ac.uk
t: 01326 259247

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Fig. 11: Consent Form

Heart Rate Data Questionarre

* Required

1. **Participant Number**

2. **How would you rate your levels of stress <u>Before</u> the experience?**

	Very High	High	Moderate	Low	Very Low
Statement 1	◯	◯	◯	◯	◯

3. **How would you rate your stress level <u>During</u> the VR experience?**

	Very High	High	Moderate	Low	Very Low
Statement 1	◯	◯	◯	◯	◯

4. **How would you rate your levels of stress <u>After</u> the experience?**

	Very High	High	Moderate	Low	Very Low
Statement 1	◯	◯	◯	◯	◯

5. **How relaxing was the experience?**

	Very Relaxing	Relaxing	Neutral	Slightly Relaxing	Not Relaxing
Statement 1	◯	◯	◯	◯	◯

6. **Did you experience any discomfort during the experiment?**

	No Discomfort	Little Discomfort	Moderate Discomfort	Severe Discomfort
Statement 1	◯	◯	◯	◯

7. **Do you have any feedback in how the experiment could be improved?**

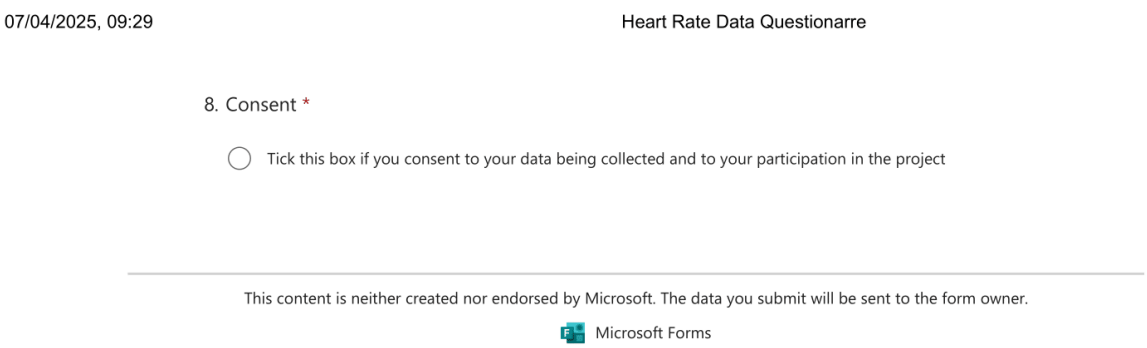
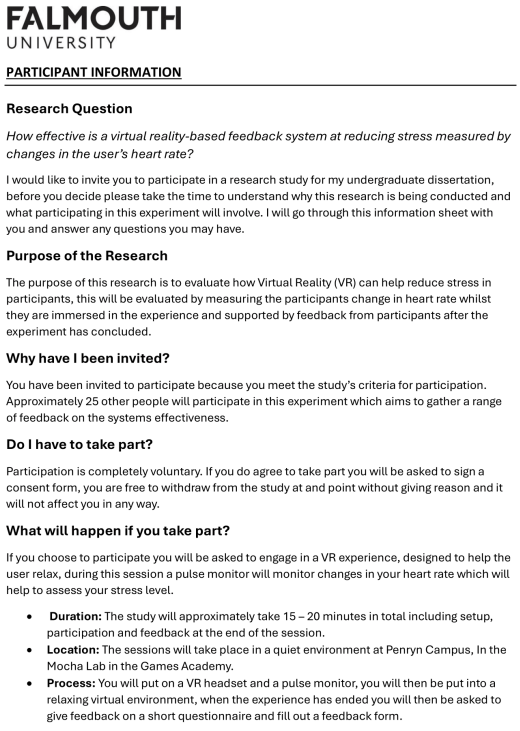


Fig. 13: Questionarre Sheet



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PARTICIPANT INFORMATION

Research Question

How effective is a virtual reality-based feedback system at reducing stress measured by changes in the user's heart rate?

I would like to invite you to participate in a research study for my undergraduate dissertation, before you decide please take the time to understand why this research is being conducted and what participating in this experiment will involve. I will go through this information sheet with you and answer any questions you may have.

Purpose of the Research

The purpose of this research is to evaluate how Virtual Reality (VR) can help reduce stress in participants, this will be evaluated by measuring the participants change in heart rate whilst they are immersed in the experience and supported by feedback from participants after the experiment has concluded.

Why have I been invited?

You have been invited to participate because you meet the study's criteria for participation. Approximately 25 other people will participate in this experiment which aims to gather a range of feedback on the systems effectiveness.

Do I have to take part?

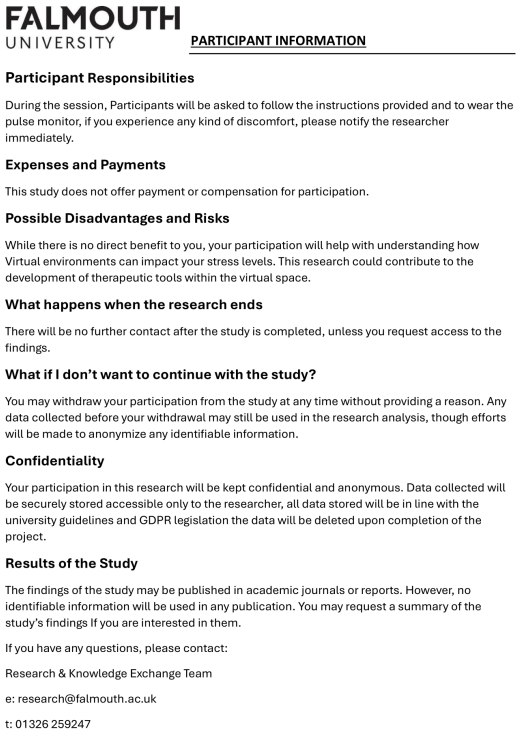
Participation is completely voluntary. If you do agree to take part you will be asked to sign a consent form, you are free to withdraw from the study at and point without giving reason and it will not affect you in any way.

What will happen if you take part?

If you choose to participate you will be asked to engage in a VR experience, designed to help the user relax, during this session a pulse monitor will monitor changes in your heart rate which will help to assess your stress level.

- **Duration:** The study will approximately take 15 – 20 minutes in total including setup, participation and feedback at the end of the session.
- **Location:** The sessions will take place in a quiet environment at Penryn Campus, In the Mocha Lab in the Games Academy.
- **Process:** You will put on a VR headset and a pulse monitor, you will then be put into a relaxing virtual environment, when the experience has ended you will then be asked to give feedback on a short questionnaire and fill out a feedback form.

Fig. 14: Participant Information Sheet



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PARTICIPANT INFORMATION

Participant Responsibilities

During the session, Participants will be asked to follow the instructions provided and to wear the pulse monitor, if you experience any kind of discomfort, please notify the researcher immediately.

Expenses and Payments

This study does not offer payment or compensation for participation.

Possible Disadvantages and Risks

While there is no direct benefit to you, your participation will help with understanding how Virtual environments can impact your stress levels. This research could contribute to the development of therapeutic tools within the virtual space.

What happens when the research ends

There will be no further contact after the study is completed, unless you request access to the findings.

What if I don't want to continue with the study?

You may withdraw your participation from the study at any time without providing a reason. Any data collected before your withdrawal may still be used in the research analysis, though efforts will be made to anonymize any identifiable information.

Confidentiality

Your participation in this research will be kept confidential and anonymous. Data collected will be securely stored accessible only to the researcher, all data stored will be in line with the university guidelines and GDPR legislation the data will be deleted upon completion of the project.

Results of the Study

The findings of the study may be published in academic journals or reports. However, no identifiable information will be used in any publication. You may request a summary of the study's findings If you are interested in them.

If you have any questions, please contact:

Research & Knowledge Exchange Team

e: research@falmouth.ac.uk

t: 01326 259247

Fig. 15: Participant Information Sheet

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