THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

ENGINEERING
DEPARTMENT OF ELECTRICAL, COMPUTER, AND SOFTWARE ENGINEERING

Part IV Research Project

Final Report

Seismic preparedness for the general public using virtual reality

Prepared by: Edwin Roesli

Project number: 36
Project partner: Chen Zhao
Main supervisor: Dr Nasser Giacaman
Second supervisor: Dr Quincy Ma

Declaration of Originality

This report is my own unaided work and was not copied from anyone or anywhere nor written in collaboration with any other person.
Author: Edwin Roesli
27th October 2019

Seismic preparedness for the general public using virtual reality

Edwin Roesli
Department of Electrical, Computer and Software Engineering
The University of Auckland, New Zealand

Abstract

New Zealand experiences a wide range of earthquakes on a regular basis. Avoidable casualties still occurd despite precautionary drills and documentation on the potential hazards during an earthquake. Causes may include wrong furniture placement, or the inability to identify the safest spot during an earthquake [1]. Predominant studies that have been made to raise a persons ability to prepare for earthquakes primarily focus on evacuation, or a high overview of what happens at the end of an earthquake [2, 3, 4]. These evacuation trainings are necessary; however, they do not focus on identifying why and how objects fall over, which can be very beneficial for users to know what furniture to lock down before the event of an earthquake. This paper presents a virtual reality application that trains users to develop connections between the behaviour of objects under an earthquake and their properties. Evaluations consisted of 31 participants shows that ultimately, users make the connection between the behaviour of an object with their properties much easier when using virtual reality as a training tool compared to traditional reading tools.

1 Introduction

Earthquakes are a natural disaster that, depending on the strength, can cause severe structural damage and cause severe physical and mental injuries to those who are unaware or uneducated in the procedures of an earthquake [5, 6, 7, 8]. Earthquake preparedness and safety knowledge are essential for everyone to know, especially for countries that experience an extensive range of earthquakes, such as New Zealand. New Zealand sits in the middle of two tectonic plates called the Australian plate and the Pacific plate. Because of this, New Zealand holds a lot of small fault lines, one of the major ones being the Alpine fault [7] which runs through the majority of New Zealand's South Island and can be seen from space due to its size. New Zealand is also known for being placed in the southwestern region of the Ring of Fire or also known as the Circum-Pacific belt. Around 80% of earthquakes occur in this region [9]. The high rate of earthquakes further emphasises the need for earthquake preparation lessons that are both retained and immersive to ensure public safety in cases where a high magnitude earthquake was to happen.

Taking past earthquakes, such as the 2011 magnitude 6.2 Christchurch earthquake [5], we witness that many injuries could have been avoided if proper anchoring to furniture was put in place [10, 11, 12]. Predominant research has found that around 63% overall have not prepared their furniture for anchoring [13]. These results gathered shows that more focus should be spent on teaching furniture anchoring [14, 15]. It was also found that people have learnt to value the importance of safety precautions, for example, structural integrity and safety precautions when in the middle of an earthquake [5]. Because of this, most people learn better through experience rather than reading precautionary steps through a guide [3, 16]. Experiencing an earthquake is a perilous and daunting experience so it would be very beneficial for people to experience the potential outcomes of an earthquake without the drawback of experiencing the mental trauma and physical wounds associated with it [1].

As hardware continues growing more powerful, software developers have the opportunity to make use of new hardware (such as the Oculus Rift, HTC Vive) to simulate a scenario mimicking a real-life scene such as an office or a room [17]. The use of virtual reality has been rising in popularity due to the everlasting opportunity that it has contributed to the gaming community [18, 19]. However, as well as gaming, virtual reality can be used as a learning tool [20]. As of now, using virtual reality as a learning medium is not so universal in current schooling settings. However, in the cases where it is used as a learning medium, it has shown excellent results, mainly in memory retention and ability to perform tasks taught by the tool [21, 22]. This increase in results can be shown through virtual reality's ability to completely immerse users in a detailed and vivid simulated world that interacts with the user giving them a sense of real experience. Virtual reality is especially useful in this project due to its ability to simulate an earthquake environment but also making sure that the user is safe and away from the dangers of a real earthquake [23].

Earthquakes end up resulting in structural damage, physical injuries and sometimes mental injuries. This project will primarily be targeting proactive safety which includes aspects like furniture anchoring and identifying how different furniture behave during an earthquake. We try to focus this project on pro-activeness rather than reactiveness; tThis is to limit the amount of movement and motion sickness that is associated with virtual reality to give the best possible experience attainable. The result of this research project should aim to answer these following research questions:

- RQ1: Effectiveness: Determine the effectiveness of training where the training result from people who trained to identify hazard through our virtual reality tool will be compared to those who trained through a traditional way of identifying hazard such as reading through hazard instructions.
- RQ2: Furniture behaviour: How do different properties of different objects impact their behaviour during an earthquake simulation.

The critical points this report will cover is why it is necessary people should be adequately educated when it comes to earthquake preparedness and the projected benefits that we will see if people are correctly educated on earthquake safety. This report will also cover the proposed research methodology, the specifics on how the virtual reality application was designed and the results we derived from our user studies.

2 Literature review

2.1 Background

2.1.1 Earthquakes

Earthquakes are natural phenomena that cause death and destruction, ranging from physiological tremors to structural damage [24], and because of this fact, earthquakes should not be taken lightly. Earthquakes are caused by a sudden slip on a fault line. These fault line slips occur kilometres beneath the Earth's surface, and the amount of friction and tension before this slip determines the intensity of earthquake felt on the surface. The Circum-Pacific belt, also known as the Ring of Fire, is a significant area known for housing over 80% of all recorded earthquakes [9, 25]. The Circum-Pacific belt lies primarily in the border of the Pacific plate and covers the many countries such as New Zealand, Indonesia and Japan. Most of all, the strongest earthquakes are recorded within or near the Circum-Pacific belt. This piece of concerning information emphasises the importance of earthquake preparedness for everyone, especially to those living in an area of a high probability of earthquakes.

Disaster preparedness is a constant challenge filled with many hindrances and aversion, this can be further explained with the help of the protection motivation theory [26, 27]. The protection motivation theory states that an individual will adopt protective behaviours and actively attempt to reduce perceived threats based on four factors. These factors include the probability of occurrence, the perceived severity of the aggressive attack, the efficacy of the recommended preventive behaviour and the individual's belief in their innate ability to avoid aggressive events. This theory has the common theme that the motivation of preparedness comes from experiencing the severity of natural disasters. Such an increase in motivation can be shown in several studies and reports of previous major earthquake disasters [5].

2.1.2 Virtual reality

Virtual reality is described as a means to simulate a person's physical presence in an immersion and convincing environment [28]. These advanced pieces of technology project virtual reality in a more in-depth and detailed way which continues to narrow the gap between computer-generated graphics and reality. Predominant research is being done to investigate the possibility of virtualising other senses in virtual reality. This research will further add immersion and interactiveness. Virtual reality has also shown a more immersive feel through recent technologies such as the Leap Motion controllers and the virtual reality treadmills, which introduces a hands-free virtual reality environment. Virtual reality technologies are now more readily available due to the option of using mobile devices as a means of interacting with a virtual environment.

Loftin describes that the main differences seen in visualisations between virtual reality and conventional display technologies can be categorised between immersion, presence, multimodal displays and interaction [29]. Loftin primarily focuses on the idea that virtual reality has the added benefit of further confining the senses to the computer-generated images, which causes the user to be more immersed with the virtual environment. This immersion implies "freedom of distractions" which is achievable through confining the user's senses, which in most cases is sight. Loftin defines presence as the quality of the virtualised environment, which can be measured by the display fidelity, sensory richness and real-time behaviour. Real-time behaviour can also be related to the interaction seen in a virtual environment. Interaction refers to the systems ability to respond to interactions with the environment realistically and smoothly to keep that sense of immersion. Finally, multimodal displays can be seen as the use of various senses to create a sense of the perceived environment around them. Presently, virtual reality focuses primarily on the visual sense as that is arguably the most depended sense we use, but with future hardware developments, the use of other senses may also be available for the use of solidifying the sense of a simulated reality. Similar to Loftin's view of virtual reality, Steur defines virtual reality as a means of distorting a user's senses through the aid of a simulated environment [30].

In both cases, virtual reality is collectively defined as the use of computer-generated imaging to create an immersive and interactive environment in which an individual feels that they have their senses altered to create this simulated environment.

2.2 Related work

2.2.1 Earthquake simulations

There have been many implementations on earthquake simulations, an example being Yamashita et al. 's earthquake simulator which was designed to simulate how furniture fell in an earthquake [31]. Yamashita used unique augmented reality markers to create an augmented display on the mobile phone to demonstrate how particular objects will react in the case of an earthquake. At the end of Yamashita's experiment, it was observed that the participants made a better improvement in identifying hazardous areas, in addition to the success we also witness little to no progress in the participant's confidence during an earthquake. Such confidence can be applied through feedback through the tool or using serious game concepts to enforce their ability to judge dangerous areas confidently [32].

Yamamoto et al. follow a similar implementation, the significant differences being they used a virtual reality environment instead of an augmented reality version. Another significant difference is that to activate the earthquake simulation an external physical stimulus is required to calculate the strength of the earthquake [17]. Yamamoto took advantage of virtual reality's ability to immerse the user in the earthquake environment. However, one criticism that can be said is that the use of an external stimulus, in this case rocking floor, could prevent the user from learning as they are too distracted from the external stimulus.

Old fashioned earthquake simulations also include earthquake drills that people undertake to practice proper procedures to take during an Earthquake. Ramirez, Simpson and Vásquez all conducted studies to show the effect of these drills [4, 2, 33]. The collective findings include the overall effects of the drills prove less than practical for reasons such as individuals already have their procedures developed by their own families, participants treated the drills as a compulsory exercise with little meaning and that the drills were found to be less cost-efficient. Drills are a necessity;

They exercise procedures to take in case of a disaster, and they provide minimal knowledge of the potential dangers of the environment. Furthermore, they are non-immersive, which adds to the lack of focus during these drills.

2.2.2 Virtual reality as a learning tool

An experiment conducted by White et al. focused on determining the effectiveness of using a virtual reality simulator for performing surgery [21]. To evaluate the effectiveness of virtual reality training the patients the participants performed with were asked to fill out a form which lists the number of times they felt levels of pain which was separated to mild, moderate, severe and extreme. It was shown that the patients experienced less discomfort with the virtual reality trained participants, the study also describes the usefulness of simulations which included aspects such as cost efficiency practical training.

Another study revolving around virtual reality is the study done by Huang et al. The study involved participants interacting with two virtual reality applications for the human anatomy and answering a questionnaire that contains their evaluation on the applications [34]. Overall, interaction and imagination were found to be the highlighting feature of virtual reality learning. Having access to a 3 dimensional and interactable view of the human anatomy helped the participants visualise key elements of the body and where they lie relative to the rest of the body rather than using a flat monitor or page to describe the placement of key body parts.

3 Project methodology

The development process for this project consists of 3 key areas: researching how different objects with different properties behave under the influence of an earthquake, development of the virtual reality application and the user evaluation. Each of these areas is essential to achieving the goal of this project.

3.1 Object behaviour reserach

To identify the main themes seen in the behaviours of different objects under the influence of an earthquake, we needed to conduct experiments. This research was split up into five diverse experiments which will be described in the 3.1 sub-section. All the experiments were done in unity. A recording script was created that, when attached to an object, it will record the change in x, y and z angle orientation compared to the original orientation, the script also records the change in displacement of the y value. The script stores all this information into an excel file, we then utilise a python script that takes the CSV file and generates a line graph each for the change in x, y, z angle orientation and change in displacement of the y value. After analysing the data generated from the graphs we then analyse these values to give us common themes that we can use to educate users about how different objects behave under an earthquake. Figure 1 shows an example of one of the experiments taken to determine the different behaviours of objects during an earthquake.

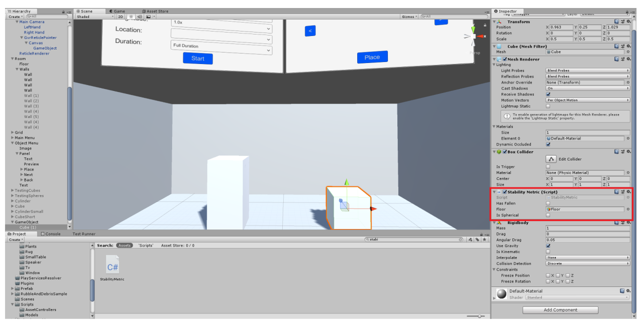

Figure 1: Experiment for testing the behaviours for objects with different heights

The primary purpose of this experiment is to test the behaviours of various models under an earthquake simulation developed using the Unity game engine. The series of experiments is based on the following points: Cube shape vs cylindrical shape, objects of different densities, how objects behave on sitting on different heights, objects that sit on top of multiple objects or one object and testing how objects of different heights behave. These series of experiments are each divided into three different parts. Room shaking on its x axis, room shaking on its y axis and room shaking on all of its axis.

Cube vs cylinder experiment

This experiment tests the behaviours between a circular based cylinder against a square-based cuboid. Each object has the same base area and same height. The independent variable here is the shape of the base area. Something to note in this experiment is that since Unity does not offer any cylinder collider support, we had to compromise with multiple box colliders that act as a cylinder collider. To accurately simulate the cylinder collider, we supplied a large number of box collider to make the edge as smooth as possible.

Objects with different densities experiment

Similar to the previous experiment, the control variables here are the heights of both objects. The box colliders and sensors are the same, and both objects have the same base area. The independent variable is the difference in masses with the same volume; hence, the difference in densities.

Objects that are placed at different heights experiment

This experiment deals with identical objects, but are placed on a different height. In this case, the object is placed on top of a 2-meter shelf.

Objects stacked on top of other objects experiment

This experiment deals with the behaviour of an object on top of another object. In one scenario the object is placed on top of a tall rectangular box where the base area is large enough to cover the object residing on top of it. In the other scenario, the object sits on top of the same tall rectangular object. However, the tall object is cut into three smaller cubes that sit on top of each other.

Objects with different heights experiment

This experiment deals with observing the behaviour of objects with different heights; in this experiment, we decided that the difference in height will be a factor of 2.

3.2 Mobile virtual reality application

This virtual reality application was created to develop users precognition of different type of objects in an earthquake. The Unity physics engine was primarily used for implementation. This consisted of simulating the interactions and behaviours in between objects. The application has three separate scenarios in which the user will utilise: the office, hospital and living room scene. These three scenes follow a similar learning module that will be explained in 3.2.2.

3.2.1 Earthquake simulation

To develop the earthquake simulation, we split our Unity game scene into two sections: room and furniture. The room consists of objects that are tied down to the ground and can be will simultaneously move with each other; for example, walls and user interface components will move as one. The furniture folder consists of objects within the room that will move in response to the movement of the room. Data is gathered from the Strong Motion Database [35]; this database contains the ground's x, y and z displacement during an earthquake. This data is then used to generate the motion of the room during an earthquake. To better immerse the user's experience, we referred to the Theory of Vibration's equation of motion [36] to simulate how a person's body will behave during an earthquake. The player's camera movement will be dwindled by the calculated value found from the equation. Therefore, it is then time-lagged in the x and z-direction. In addition to this, sound effects are added to simulate the rumbling of the earthquake as well as to object collisions. However, minor collision sounds are disregarded to allow the players to retain memory and focus [37, 38, 39]. Other features that aid with the immersion of the earthquake simulation is the addition of the water burst effect, which simulates the effect of a water pipe bursting. To retain the user's attention, we decided to keep the length of the simulated earthquake below 30 seconds for a more thorough analysis [40, 41, 42].

3.2.2 Training modules

All three scenes follow a similar pattern of a question, answer and evaluate, as seen in figure 2. When the user first enters the scene, they will be presented with a question. This question will follow the users gaze for a fixed amount of time and will eventually disappear. After the question has disappeared, the user will be prompted to select the objects that answer the question. The scenario is split into multiple questions so that the user can focus on one specific point of the scene rather than to try and analyse the entire scenario as a whole. Analysing the scenario as a whole will make the user analyse too much information at one time and will have adverse effects [43]. Furthermore, a teleportation point has been implemented to ensure that the user will always have the most optimal viewing point of the objects in the scenario. We have also disabled these teleportation points and any other UI elements to ensure that the user is fully immersed during the earthquake.

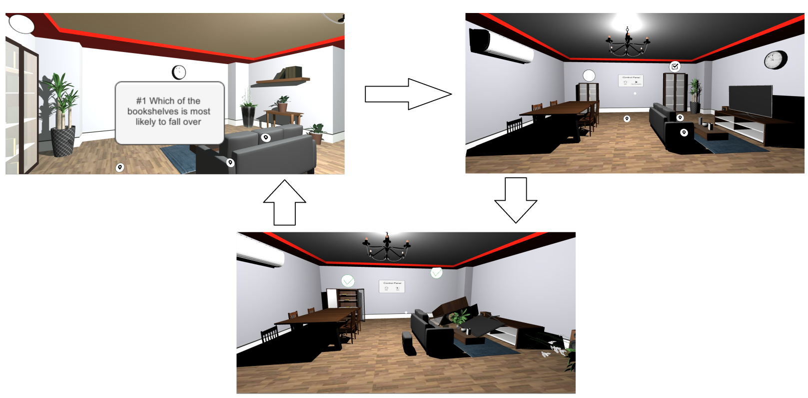

Figure 2: General flow of the training module

3.3 User evaluation

To acknowledge our first research question, we have proceeded to conduct a user evaluation to validate the effectiveness of a virtual reality application over more traditional earthquake preparedness training. Overall, we have collected 31 participants who were then split into two groups. As seen in figure 3 the general process for this evaluation is to have all the participants conduct a preliminary quiz and then have group A undergo the virtual reality training module while the control group reads the earthquake safety manual which underlies earthquake safety precautions as well as contains a summary of results seen in the experiment that was talked about in section 3.1. Both groups then take another quiz. After finishing the quiz, the groups will then swap training modules, so group A will now be reading the earthquake safety report, and the control group will be trying out the virtual reality application. Lastly, all participants will have to do a final quiz. After collecting all the data, we then carry out a statistical analysis of our data to answer whether or not virtual reality is more of a practical training module compared to traditional learning modules.

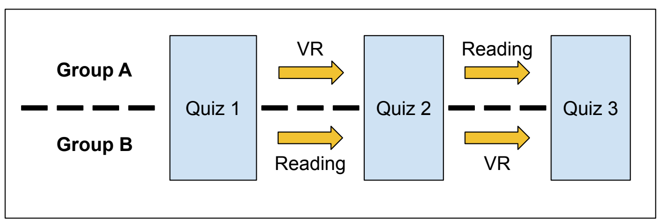

Figure 3: Summary of the evaluation plan

3.3.1 Quiz details

This section dives into more detail of what is seen and the purpose of the individual quizzes. Questions are linked between groups in such a way that questions corralate to one of the experiments seen in 3.1. This way, each quiz will be of equal difficulty and will test the user's ability on a specific topic.

- Pre quiz: This quiz is used to record the users a current level of knowledge on hazard identification. It also gathers knowledge of other information such as whether the user has been in an earthquake or whether they have had previous earthquake preparedness training.

- Mid quiz: This quiz is the primary set of data that we are going to base our conclusion on. In both groups, we will be analysing the set of data seen in this quiz and then compare that data to the data analysed in the pre-quiz. This will ideally find whether or not there is a significant difference between group A and the control group.

- Post quiz: The purpose of this quiz is to provide more evidence for the statistical analysis done on this evaluation since the results could be biased towards users who have a high learning ability. It gives the control group a chance at using virtual reality.

4 Evaluation results

4.1 Object behaviour results

As mentioned in section 3.1 we have conducted multiple experiments to find the behaviours of objects with different properties under an earthquake. Figure 4 shows how the vibrational magnitude of objects under an earthquake; we also store the time until an object topples over. To analyse the graphs generated, we take the peak points of the graphs and compare the values. In some cases, we also compare the rate of growth of the angular and y displacement. From this, we can whether objects with specific properties are more affected by an earthquake and in turn answer our second research question.

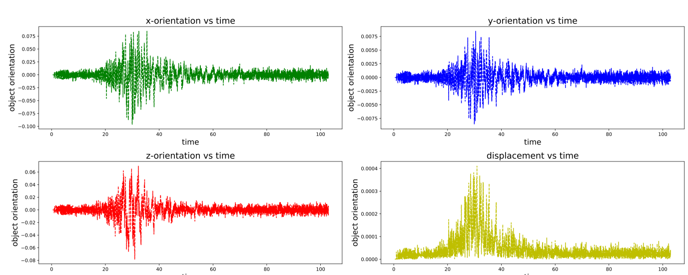

Figure 4: Angular and y displacement graphs for heights experiment

Cube vs cylinder experiment

From this experiment, we have found that, on average, square-based objects topple over first. However, this observation is only seen in the x and z-axis tests. The all axis test observed that circular objects with toppling over first. Upon further investigation, it was concluded that the square base had a weaker resistance toppling over in the x and z-axis due to the smaller width of the shape, whereas the circle base has a uniform width throughout. However, with the ALL test, we find that the square base stays up for longer in most situations. This is because of the stronger resistance to fall on the corners of the square (larger width compared to the circle).

Objects with different densities experiment

In this experiment, we have found that objects with a higher density will shake more vigorously compared to less dense objects. We have also found that in most cases, denser objects topple over earlier compared to the less dense object, which means that denser objects are more unstable in an earthquake. This is more adamantly shown in the graphs generated, which describes that less dense objects can withstand a more considerable amount of angular and y displacement before toppling over.

Objects that are placed at different heights experiment

We have observed that the graph representing an object placed at a higher point shows an exponential increase in angular displacement which indicates that objects placed at a higher point are more likely to less stable compared to an object situated on the ground.

Objects stacked on top of other objects experiment

The time taken for both objects to topple over is very close together; however, due to the instability of the stacked objects, the object placed above the stacked box falls first. Furthermore, in all cases, we see that the angular and y displacements display higher values in the stacked objects. Therefore, we can conclude that objects sitting on top of stacked objects are less stable than a solid object.

Objects with different heights experiment

In this final experiment, we observe that the shorter object did not fall over, whereas the taller object falls on average at the 29.4 second mark. Furthermore, the recorded graph shows a general trend of a more significant angular displacement on taller objects. From this, we can conclude that taller objects are more unstable than shorter objects.

4.2 User evaluation analysis

Table 1 describes the result of the statistical analysis conducted on the quizzes that all participants took. The next three subsections will talk about this in greater detail.

Table 1: Statistical analysis table

	Quiz 1		Quiz 2		Quiz 3	
Group A (VR first)	minimum	0	minimum	2	minimum	2
	lower-quartile	1	lower-quartile	3	lower-quartile	3
	median	2	median	4	median	4
	higher-quartile	2.5	higher-quartile	5	higher-quartile	4
	maximum	4	maximum	5	maximum	5
	z-value:		-3.2958			
	p-value:		0.00048			
	w-value:		0 (Critical value: 15)			
			z-value:		-0.1777	
			p-value:		n/a	
			w-value:		21 (Critical value: 3)	
Group B (Reading first)	minimum	0	minimum	0	minimum	2
	lower-quartile	1	lower-quartile	2.5	lower-quartile	4
	median	2	median	3	median	4
	higher-quartile	2	higher-quartile	4	higher-quartile	5
	maximum	3	maximum	4	maximum	5
	z-value:		-2.1315			
	p-value:		0.01659			
	w-value:		62 (Critical value: 64)			
			z-value:		-2.0896	
			p-value:		0.01831	
			w-value:		7 (critical value: 5)	
Group A vs Group B	U-value:	118.5	U-value:	60.5	U-value:	98
	z-value:	-0.03953	z-value:	2.33218	z-value:	0.84986
	p-value:	0.9681	p-value:	0.0198	p-value:	0.39532

Key	
	Wilcoxon Signed-Ranked Test
	Mann-Whitney U Test

Wilcoxon Signed-Ranked population value	
RED border	n>=10
PINK border	n<10

4.2.1 Pre-quiz analysis

To avoid statistical bias such as one group having a high score on the preliminary test, we need to analyse the data recorded from the pre-quiz. To achieve this, we must conduct a Kolmogorov-Smirnov Test of Normality. This test identifies whether a groups data set is normally distributed or not. Determining whether or not the data set is normally distributed is essential as it indicates what kind of test we must conduct on the 2 data sets. What we found was that neither group was normally distributed; this means that a Mann-Whitney U test was conducted to determine whether or not the 2 data sets had significant differences between them. The result from the Mann-Whitney U test shows a p-value of 0.9681. With a test statistic of 5%, we can say that there is not enough statistical evidence to prove that the two data sets significantly differ. Furthermore, we see a u-value of 118.5; coupled with a critical value of 70, we have further evidence to claim that no evidence justifies the two groups differing in test scores. Conducting a Mann-Whitney U test in the initial quiz validates that the two groups are initially on the same knowledge level and thus further validates our evaluation.

4.2.2 Mid quiz analysis

Similar to the pre-quiz analysis, we need to conduct a Kolmogorov-Smirnov Test of Normality on group A and the control group, after confirming that both groups are not normally distributed, we conducted another Mann-Whitney U test. The result of this test gives us a p-value of 0.0198, a test statistic of 5% and given that the u-value is 60.5 which is lower than the critical value of 70, we can claim there is enough evidence that there exists a knowledge gap between group A and the control group after undergoing the first training module. The Mann-Whitney U test conducted only tests if the exists a gap between the two groups without specifying which groups scored higher. Therefore, a Wilcoxon Signed-Ranks Test is used to test whether or not a group has improved after the first training module. Group A's analysis outputs a p-value of 0.00048, z-value of -3.2958 and a w-value of 0, whereas the control group's analysis outputs a p-value of 0.01659, z-value of -2.1315 and a w-value of 62. In this statistical test both p and w value can be used to determine the whether we accept or reject the null hypothesis that claims that there is no improvement seen during the training session; the only difference is that the p-value is favoured when there is a sample size greater than 20, but the w value can only be used when sample size is less than 10. Sample size decreases when a person has the same number of correct answers in both data sets. By analysing the data given, we can say that both groups have improved scores due to the p-value being less than the test statistic, 5%. We also see that both w-values are below their respective critical values which further indicates the improvement of the users. However, to answer RQ1, we can say that virtual reality training is more effective in teaching hazard and object behaviour identification compared to traditional reading methods. This is because the significantly lower z-value in group A's result indicates that group A has a higher chance to prove that the group has improved which means a higher rise in scores must have been observed. We also see that the w-value is significantly lower than the critical value compared to the control group, which further emphasises the fact that virtual reality training is more effective.

4.2.3 Post quiz analysis

When analysing the post quiz results, we observe that both the data set of group A and the control group fail the normality test. The Mann-Whitney U test gives an output of 0.395 coupled with a test statistic of 5% as well as a u-value of 98 which is greater than the critical value of 70 indicates that there is no significant evidence that there exists a gap in knowledge between the two groups. To further analyse this data set, group A's mid quiz and post quiz has been put through a Wilxocon Signed-Ranks test, the outcome of this test does not produce any p-value, the reason being that there were too many pairs with the same result which reduces the sample size number. Therefore we must use the w-value which outputs a value of 21 which is higher than its critical score of 3. This indicates that there is not enough statistical evidence to claim that there is learning happening between the two tests. However, the result of placing the control group under the same statistical test shows a p-value of 0.0183, which is below the 5% test statistic. However, we observe that we get a w-value of 7, which is slightly greater than the critical value of 5. Here we have a situation where it passes one statistical test but fails another. Therefore we can say that there is some evidence to claim that there the control group shows signs of learning during the virtual reality training module even after the reading. The statistical analysis made on the post analysis quiz gives further validity since we analyse that there is sufficient evidence to say that both groups do not have significant differences to each other based on the Mann-Whitney test outputting a p-value of 0.395. This outcome is foreseen due to both groups having been trained through both methods.

Threats to validity

In this user evaluation, we have only managed to recruit 31 participants to be a part of our experiment. A larger sample size is more beneficial since it gives more validity to the results shown in our analysis. However, due to time and budget constraints, only 31 participants were gathered. This lack of participants is noticeable in the Wilcoxon Signed-Ranked test conducted between quiz two and quiz three of the control group; In this test, we observe that the two values, z-value and p-value output two different conclusions which are possibly due to the lack of sample size. Another threat to our validity is the fact that our quizzes only contains five questions each. Due to the low question pool and the low sample size, the regression testing conducted ended up with a very low r squared value. Ideally, a larger question pool that maintains equal difficulty as well as maintains the links themes found in the object behaviour research.

5 Conclusion

Future work

There are many features that the application could be improved on, for example, the addition of new scenes as well as manually setting the in-game earthquake simulator's magnitude level. However, a pressing issue that was abundantly mentioned in the feedback provided is the motion sickness that users have experienced during the simulation. This could be because of many reasons, some of which may be due to the high detailed assets used [44], this factor may have reduced the frame rate of the mobile device when gazing at high detailed assets. Another possibility could be that no physical forces were felt in the outside world or the added functionality of the camera shaking [45, 46]. Further research needs to be conducted to ensure that this, and any other potential symptoms are resolved [47, 48]. Predominant research has experimented on 3d room capture technology; a future prospect may include integration with this upcoming technology to simulate your room and put it under a simulated earthquake [49, 50, 51].

We have also developed a recording tool that manages to record what answers the user gives when conducting the training module, as well as recording what the user gazes at during their time in the scene. No data analysis has been made on this data set during this project so some work for the future could consist of understanding what core concepts people are having a hard time grasping or whether their attention during the training is at the right place.

Conclusion

The primary goal of this research project was to identify whether or not virtual reality training or traditional earthquake preparedness training is more effective in teaching earthquake preparedness. To achieve this we had to research the behaviours of objects with different properties, a summary of findings shows us that square-based objects are more stable than circular ones, high density objects are more prone to toppling over, objects placed on a higher places are more unstable, object placed on stacked on multiple objects are more unstable and taller objects are more unstable compared to shorter objects. In addition to this, we had to develop a virtual reality training module as well as a user evaluation to test the validity of our claim. Our statistical analysis conducted on the results of the quizzes concluded that both virtual reality training and reading provided an increase in understanding on the behaviours of objects under an earthquake, however more so with the virtual reality training. After switching the training modules between groups we observe that the two groups results are similar. However, the control group had an increase in the score, whereas group A did not.

References

[1] A. Rustemli and A. N. Karanci, "Correlates of earthquake cognitions and preparedness behavior in a victimized population," *The Journal of social psychology*, vol. 139, no. 1, pp. 91–101, 1999. doi: 10.1080/00224549909598364.

[2] D. M. Simpson, "Earthquake drills and simulations in community-based training and preparedness programmes," *Disasters*, vol. 26, no. 1, pp. 55–69, 2002. doi: 10.1111/1467-7717.00191; 01.

[3] C. Li, W. Liang, C. Quigley, Y. Zhao, and L. Yu, "Earthquake safety training through virtual drills," *IEEE Transactions on Visualization and Computer Graphics*, vol. 23, no. 4, pp. 1275–1284, 2017. ID: 1.

[4] M. Ramirez, K. Kubicek, C. Peek-Asa, and M. Wong, "Accountability and assessment of emergency drill performance at schools," *Family and Community Health*, vol. 32, no. 2, pp. 105–114, 2009. cited By 16.

[5] D. Johnston, S. Standring, K. Ronan, M. Lindell, T. Wilson, J. Cousins, E. Aldridge, M. W. Ardagh, J. M. Deely, S. Jensen, T. Kirsch, and R. Bissell, "The 2010/2011 canterbury earthquakes: Context and cause of injury," *Natural Hazards*, vol. 73, no. 2, pp. 627–637, 2014. Cited By :27.

[6] Q. Meng, S. Ni, A. Guo, and Y. Zhou, "Ground surface deformation caused by the m w 5.8 early strong aftershock following the 13 november 2016 m w 7.8 kaikoura mainshock," *Seismological Research Letters*, vol. 89, no. 6, pp. 2214–2226, 2018.

[7] T. R. Robinson and T. R. H. Davies, "Review article: Potential geomorphic consequences of a future great (mw combining double low line 8.0+) alpine fault earthquake, south island, new zealand," *Natural Hazards and Earth System Sciences*, vol. 13, no. 9, pp. 2279–2299, 2013. Cited By :22.

[8] Q. Liu, M. Jiang, Y. Yang, H. Zhou, Y. Zhou, M. Yang, H. Xu, and Y. Ji, "Prevalence of posttraumatic stress disorder (ptsd) and its correlates among junior high school students at 53 months after experiencing an earthquake," *Disaster Medicine and Public Health Preparedness*, vol. 13, no. 3, pp. 414–418, 2019.

[9] L. Yin, X. Li, W. Zheng, Z. Yin, L. Song, L. Ge, and Q. Zeng, "Fractal dimension analysis for seismicity spatial and temporal distribution in the circum-pacific seismic belt," *Journal of Earth System Science*, vol. 128, no. 1, 2019.

[10] S. McBride, J. Becker, and D. Johnston, "Exploring the barriers for people taking protective actions during the 2012 and 2015 new zealand shakeout drills," *International Journal of Disaster Risk Reduction*, vol. 37, 2019.

[11] H. K. Armenian, A. Melkonian, E. K. Noji, and A. P. Hovanesian, "Deaths and injuries due to the earthquake in Armenia: a cohort approach.," *International Journal of Epidemiology*, vol. 26, pp. 806–813, 08 1997.

[12] "Profile of injuries arising from the 2005 kashmir earthquake: The first 72h," *Injury*, vol. 39, no. 5, pp. 554 – 560, 2008.

[13] T. Haraoka, S. Hayasaka, C. Murata, T. Yamaoka, and T. Ojima, "Factors related to furniture anchoring: A method for reducing harm during earthquakes," *Disaster Medicine and Public Health Preparedness*, vol. 7, no. 1, pp. 55–64, 2013. Cited By :1.

[14] L. Jones and M. Benthien, "Putting down roots in earthquake country," 2011. Available at `https://www.earthquakecountry.org/library/PuttingDownRootsSoCal2011.pdf`.

[15] *Peace of Mind in Earthquake Country: How to Save Your Home, Business, and Life.* 2008.

[16] R. Lovreglio, V. Gonzalez, R. Amor, M. Spearpoint, J. Thomas, M. Trotter, and R. Sacks, "The need for enhancing earthquake evacuee safety by using virtual reality serious games."

[17] T. Yamamoto and S. Mizuno, "Development of a earthquake simulator on a smartphone," in *2018 International Workshop on Advanced Image Technology (IWAIT)*, pp. 1–4, 2018. ID: 1.

[18] A. Rajan, N. Nassiri, V. Akre, R. Ravikumar, A. Nabeel, M. Buti, and F. Salah, "Virtual reality gaming addiction," pp. 358–363, 2019.

[19] J. Urbani, M. Al-Sada, S. Ranade, M. Zhang, and T. Nakajima, "War bots: Combining virtual and augmented realities for an immersive and enjoyable gaming experience," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 10507 LNCS, pp. 379–382, 2017.

[20] H. Maertens, A. Madani, T. Landry, F. Vermassen, I. Van Herzeele, and R. Aggarwal, “Systematic review of e-learning for surgical training,” *The British journal of surgery*, vol. 103, no. 11, pp. 1428–1437, 2016.

[21] I. White, B. Buchberg, V. Tsikitis, D. Herzig, J. Vetto, and K. Lu, “A virtual reality endoscopic simulator augments general surgery resident cancer education as measured by performance improvement,” *Journal of Cancer Education*, vol. 29, no. 2, pp. 333–336, 2014. ID: TN-springer-jour10.1007/s13187-014-0610-5.

[22] E. Krokos, C. Plaisant, and A. Varshney, “Virtual memory palaces: immersion aids recall,” *Virtual Reality*, vol. 23, no. 1, pp. 1–15, 2019. ID: Krokos2019.

[23] E. Kwegyir-Afful, M. Lindholm, S. Tilabi, S. Tajudeen, and J. Kantola, “Optimizing occupational safety through 3-d simulation and immersive virtual reality,” *Advances in Intelligent Systems and Computing*, vol. 958, pp. 97–107, 2020.

[24] S. L. Nimmagadda and H. Dreher, “Ontology based data warehouse modeling and mining of earthquake data: prediction analysis along eurasian-australian continental plates,” in *2007 5th IEEE International Conference on Industrial Informatics*, vol. 1, pp. 597–602, June 2007.

[25] S. J. Duda, “Secular seismic energy release in the circum-pacific belt,” *Tectonophysics*, vol. 2, no. 5, pp. 409 – 452, 1965.

[26] D. L. FLOYD, S. PRENTICE-DUNN, and R. W. ROGERS, “A meta-analysis of research on protection motivation theory,” *Journal of applied social psychology.*, vol. 30, no. 2, pp. 407–429, 2000.

[27] J. F. Tunner, E. Day, and M. R. Crask, “Protection motivation theory: An extension of fear appeals theory in communication",” *Journal of Business Research*, vol. 19, no. 4, pp. 267 – 276, 1989.

[28] J. Wolfartsberger, “Analyzing the potential of virtual reality for engineering design review,” *Automation in Construction*, vol. 104, pp. 27 – 37, 2019.

[29] R. Bowen Loftin, J. Chen, and L. Rosenblum, *Visualization using virtual reality*. 2005. cited By 4.

[30] J. Steuer, “Defining virtual reality: Dimensions determining telepresence,” *Journal of Communication*, vol. 42, no. 4, pp. 73–93, 1992. cited By 1680.

[31] N. Yamashita, H. Taki, and M. Soga, “A learning support environment for earthquake disaster with a simulation of furniture falling by mobile ar,” in *2012 International Conference on Information Technology Based Higher Education and Training (ITHET)*, pp. 1–5, 2012. ID: 1.

[32] A. Hanandeh, Z. Abdullah, and J. Harun, “The effects of a serious game activity and learning tasks on students' motivation towards reading skill,” in *2018 IEEE 10th International Conference on Engineering Education (ICEED)*, pp. 214–219, Nov 2018.

[33] A. Vasquez, K. Marinkovic, M. Bernales, J. Leon, J. GonzÃ¡lez, and S. Castro, “Children's views on evacuation drills and school preparedness: Mapping experiences and unfolding perspectives,” *International Journal of Disaster Risk Reduction*, vol. 28, pp. 165 – 175, 2018.

[34] H.-M. Huang, U. Rauch, and S.-S. Liaw, “Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach,” *Computers and Education*, vol. 55, no. 3, pp. 1171–1182, 2010. cited By 163.

[35] “New zealand strong-motion database.” Available at `https://www.geonet.org.nz/data/types/strong_motion`,.

[36] W. T. Thomson, *Theory of vibration*. Allen et Unwin, 1983.

[37] Y. K. Choi, S. mi Lee, and H. Li, “Audio and visual distractions and implicit brand memory: A study of video game players,” *Journal of Advertising*, vol. 42, no. 2-3, pp. 219–227, 2013.

[38] J. J. B. Morgan, “The effect of sound distraction upon memory,” *The American Journal of Psychology*, vol. 28, no. 2, pp. 191–208, 1917.

[39] P. B. Nelson, “Sound in the classroom: Why children need quiet,” *ASHRAE Journal*, vol. 45, p. 22, 02 2003. Copyright - Copyright American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. Feb 2003; Last updated - 2012-04-04; CODEN - ASHRAA.

[40] C. Papagno and G. Vallar, “Phonological short-term memory and the learning of novel words: The effect of phonological similarity and item length,” *The Quarterly Journal of Experimental Psychology Section A*, vol. 44, no. 1, pp. 47–67, 1992.

[41] A. Chickering and Z. Gamson, “Seven principles for good practice in undergraduate education,” *AAHE Bulletin*, vol. 3, p. 7, 1987.

[42] L. Fiorella and R. E. Mayer, “Role of expectations and explanations in learning by teaching,” *Contemporary Educational Psychology*, vol. 39, no. 2, pp. 75 – 85, 2014.

[43] S. A. Ambrose, M. W. Bridges, M. DiPietro, and M. C. L. andMarie K. Norman, *How Learning Works: Seven Research-Based Principles for Smart Teaching*. Jossey Bass, 2010.

[44] J. J. LaViola, Jr., “A discussion of cybersickness in virtual environments,” *SIGCHI Bull.*, vol. 32, pp. 47–56, Jan. 2000.

[45] P. DiZio and J. R. Lackner, “Spatial orientation, adaptation, and motion sickness in real and virtual environments,” *Presence: Teleoperators and Virtual Environments*, vol. 1, no. 3, pp. 319–328, 1992.

[46] M. E. McCauley and T. J. Sharkey, “Cybersickness: Perception of self-motion in virtual environments,” *Presence: Teleoperators and Virtual Environments*, vol. 1, no. 3, pp. 311–318, 1992.

[47] C. Regan, “An investigation into nausea and other side-effects of head-coupled immersive virtual reality,” *Virtual Reality*, vol. 1, pp. 17–31, Jun 1995.

[48] S. V. G. Cobb, S. Nichols, A. Ramsey, and J. R. Wilson, “Virtual reality-induced symptoms and effects (vrise),” *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 2, pp. 169–186, 1999.

[49] B.-S. Hua, Q.-H. Pham, D. Nguyen, M.-K. Tran, L.-F. Yu, and S.-K. Yeung, “Scenenn: A scene meshes dataset with annotations,” pp. 92–101, 2016.

[50] W. Liang, Y. Zhao, Y. Zhu, and S. Zhu, “Evaluating human cognition of containing relations with physical simulation,” 07 2015.

[51] L. Yu, S. Yeung, Y. Tai, and S. Lin, “Shading-based shape refinement of rgb-d images,” in *2013 IEEE Conference on Computer Vision and Pattern Recognition*, pp. 1415–1422, June 2013.