ENHANCING HEALTHCARE WITH VIRTUAL REALITY

A THESIS SUBMITTED TO AUCKLAND UNIVERSITY OF TECHNOLOGY
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MASTER OF PHILOSOPHY

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Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning.

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Signature of candidate

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Abstract

Given the rising trend of natural and technological disasters in recent years, the demands for emergency responders are on the rise. One main challenge is how to cost-effectively train emergency responders. In this research, we aim to explore of the usage of Virtual Reality (VR) technology in an emergency healthcare training setting. We start with the following two research questions: (1) how to implement the VR technology to be used in the emergency healthcare training; and (2) how to evaluate the effectiveness of our implementation. To address the question (1), we construct emergency healthcare workflows from reference sources, convert them into process diagrams, and develop a VR software that allows users to carry out the processes a virtual environment. To address question (2), we design an experiment that collect participants' personal data (such as Age, Technical background) and the performance data (such as timespan, avatar moving distance) generated during the training sessions. Ten participants are recruited and each performs three training sessions. We evaluate the data collected and have the following three conclusions: (a) the technical background plays the most significant role among other features in our VR-based trainings; (b) despite the different backgrounds, the participants, after repeated trainings, can gain knowledge and improve their performance with reduced timespan; and (c) native language creates a preference bias among participants.

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Chapter 1

Introduction

Given the rising trend of natural and technological disasters in the past 30 years (CRED, 2016), the demands for emergency responders are on the rise. One main challenge is how to cost-effectively train emergency responders. Recent development of new digital technologies could provide a solution. Virtual Reality (VR) technology has become a hot topic in recent years due to the release of substantial commercial level hardware. Those commercial level products can provide a low-cost solution of experiencing VR technology, which makes it more accessible to the public. Additionally, the current VR technology can bring a full-immersive and interactable experience to users, thus it can be considered as an ideal solution to simulate and solve specific problems. Compared with the old generation of VR technology, the developing and deploying costs of current VR technology are significantly decreased. For instance, the price of an earlier commercial VR headset, 'i-Glasses' made by Virtual I/O in 1990s, was listed for $800USD (VRWiki, 1995). By contrast, the latest commercial product, 'Oculus-Go' made by Oculus in 2018, currently costs $249USD (Oculus, 2018).

The term "Virtual Reality" has been defined in early research. In the 1990s, Milgram & Kishino (1994) introduced the concept of a 'virtuality continuum', which can be used to classify different virtuality interfaces. In their research, VR was defined as "an environment in which the participant-observer is totally immersed in, and able to interact with, a completely synthetic world" (Milgram & Kishino, 1994). Billinghurst & Kato (1999) show that virtuality can be applied through research areas by developing two prototype mixed reality interfaces: 'WearCom' and 'Collaborative Web Space'. In recent years, with the development of new generation hardware, more research projects and industrial projects have started to use VR technology.

VR technology has been used in healthcare education research. Izard & Méndez (2016) developed a VR-based anatomy software which can be used to analyse and visualize the inner structures of human body. Kilmon et al. (2010) applied VR technology in nursing education field and found that VR technology can be appropriately used for emergency response simulation.

Moreover, researchers have explored applying VR technology to the healthcare training area specifically. Aggarwal et al. (2006), Larsen et al. (2009), Rizzo et al. (2006) demonstrate the applications of VR based laparoscopic training as well as evaluation methods.

Methodologies used to develop healthcare training software are introduced in previous research. Soderholm et al. (2008) developed a trauma healthcare telepresence and visualization software based on 3D technology. Hilton et al. (2011) demonstrated a systematic way of developing and evaluating VR based applications.

As abovementioned, VR research in recent years mostly focuses on specific healthcare problem solving (e.g. stroke rehabilitation, (Yamato et al., 2016)). There are a few explorations of using VR technology to train specific emergency healthcare skills (e.g. bleeding control, (Çakmak & Kühnapfel, 2000)). However, none of them attempted to train the entire emergency healthcare workflow. This thesis can fill the gaps between the implementation of VR technology and emergency healthcare workflow training.

As a major part of the research scope, we aim to develop an application based on virtual reality technology. This software should provides emergency healthcare training in an efficient way. The training contents will cover the major steps of the emergency healthcare workflow. Another major part of the research is evaluating the effectiveness of the training software.

In this research, we address two research questions as follows:

1. Research Question 1: How to implement the VR technology to emergency healthcare training?

   We plan to explore a methodology that can be used to implement the operations of traditional emergency healthcare training. The features of this methodology shall include the guideline of identifying emergency healthcare operations, converting emergency healthcare operations to program-recognizable processes, and appropriate software development methodology.

2. Research Question 2: What approaches can be applied to evaluate the effectiveness of VR-based emergency healthcare training?

   We plan to use our VR software to conduct VR emergency healthcare training sessions. The participants will be asked to wear a VR headset and perform the emergency healthcare operations by using VR controllers. Sensor data from both the VR headset and controllers will be collected by the VR software. We will analyse the sensor data in different dimensions, such as timespan and technical background, and try to find any correlations between those data dimensions.

In this thesis, we first review the relevant literature and address the related limitations found in Chapter 2. Followed by, Chapter 3, where we introduce the methodology we use for converting emergency healthcare operations to process diagram, developing the VR software, creating and performing experiments, and evaluating the experiment results. In Chapter 4, we indicate our analysis results based on our VR training experiments and highlight the most important findings. Discussions about the experiments results are given in Chapter 5. Finally, we concrete our conclusion in Chapter 6.

Chapter 2

Literature Review

2.1 Introduction

This thesis examines the effectiveness of emergency healthcare training by using current Virtual Reality (VR) technology as well as potential relationships which exist among trainee characteristics, training scenarios, VR techniques, and training efficiency. This part of the review will examine literature about a few major themes that help to conduct our research. Those themes include a brief history of VR, VR technology applied in healthcare aspects, and the design and assessment methodologies for VR based simulations.

2.2 A brief history of VR

VR defined by early taxonomy

Milgram & Kishino (1994) introduced the concept of 'virtuality continuum', putting the real environment at one end of the continuum, the virtual environment at the opposite extremum ,and both augmented reality (AR) and augmented virtuality (VR) in between. Scope of mixed reality (MR) covers all virtuality continuum as it includes environmental input, spatial sound, and location. Most current popular VR devices use ‘head-mounted displays’ (HMD) and they can fit on the ‘virtuality continuum’. For example, Oculus (2015) from Facebook is on the virtual end of the virtuality continuum as it creates a new virtual environment for the user to explore while Hololens (2015) from Microsoft is classified as augmented reality as it projects a virtual environment on top of reality to enhance the users experience of the real environment. The applicable fields of that hardware include general entertainment, gaming, business, manufacturing, quality assurance, telemedicine (Hasan & Yu, 2015).

Milgram and Kishino categorized mixed reality interfaces into six major classes. Class 2 is head-mounted displays (HMD), class 4 is HMD equipped with a video see-through capability, and Class 5 is "complete immersive graphic display" (Milgram & Kishino, 1994). These three classes will be considered as a feasible interaction pattern in this project. According to the virtuality continuum, augmented reality is defined closer to the real environment and augmented virtuality is defined as virtual environment oriented.

The research by Milgram and Kishino provides fundamental classifications of different hardware as well as recommendations for implementations of each classified hardware.

Early implementations

Based on the classifications of abovementioned virtuality continuum, Billinghurst & Kato (1999) designed two prototype MR interfaces: ‘WearCom’ and ‘Collaborative Web Space’. WearCom is designed to explore how wearable computers can be used to support remote collaboration, and the Collaborative Web Space interface is designed to test the assumption that mixed reality interfaces can enable multiple users in the same location to view and interact with shared virtual information spaces while also viewing the real world.

Their work has shown several examples of collaborative and world-stabilized information spaces. Users have access to their traditional tools and workplace in both face-to-face and remote collaboration allowing efficient teamwork.

Billinghurst and Kate's research demonstrates the possibility of using MR technology to provide interactions in specific areas. As their research was conducted 20 years ago, the technology itself was limited by the capability and cost of hardware.

Current VR technology

Since 2014, VR technology has becomes a hot topic due to the massive improvement of hardware in the commercial field. For educational and entertainment purposes, many companies have started to produce their commercial level of VR hardware.

Oculus was a Kickstarter company formed in 2012, and by 2014 showed a huge increase in its fund and market share. Since 2015, Oculus started to acquire other VR researching and producing companies, and it built a partnership with Samsung to develop Samsung Gear VR. In the meantime, Oculus released one of its most successful commercial VR headset: Oculus Rift. Oculus Rift (Oculus, 2015) is a immersive graphic display HMD. It supports third-party IDEs such as Unreal Engine and can be used for both the entertainment field and an industrial/professional assistance.

Microsoft Hololens (Hololens, 2015) is a mixed reality HMD, which can be categorised into class 6 of the mixed reality interface continuum. It combines real-world and virtual objects and providing both augmented reality and virtual reality experience to users. This programmable hardware can support various fields such as holograph projection, hews and information projection, game simulation, and 3D modeling.

HTC Vive, Google Cardboard, Epson Moverio BT Series, and Vuzix Series provide either a virtual reality or augmented reality experience (Hasan & Yu, 2015). The applicable fields of the hardware listed include general entertainment, gaming, general business, manufacturing, quality assurance, telemedicine, and others.

2.3 VR in Healthcare

Reviews of VR in healthcare

T. P. Chang & Weiner (2016)'s research demonstrated the concept of screen-based simulation (SBS) and 3-dimensional virtual reality (3D VR) and their implementations on paediatric emergency medicine (PEM). They introduced the types of SBS and 3D VR simulation as well as advantages and disadvantages of such simulation technologies over mannequin-based simulation (MBS). Examples relevant to PEM with different types of SBS and 3D VR are also provided.

According to the definitions given by Chang and Weiner, "screen-based simulation in PEM is a form of simulation in which a clinical scenario with 1 or more patients is presented through a digital screen surface". Their definition of SBS is similar to the definition of 'monitor-based video displays' which is given by Milgram & Kishino (1994). However, Chang and Weiner have extended such definitions regarding environment variables and different ways of interaction.

Four major types of SBS and 3D VR simulation relevant to PEM are introduced by Chang and Weiner, which include 'Virtual Patients', 'Virtual Worlds','Virtual Trainers' and 'Resource Management Simulations'. They addressed the descriptions for each simulation type as follows:

- Virtual Patients (VPs) allow the user to teach and assess knowledge, diagnostic skills, and management by using a virtual rendering of patients. The VPs will be represented in the form of an avatar, and such avatars could simulate high-stakes conditions that are difficult to obtain from the real environment. However, Chang and Weiner also point out that currently VPs have not yet shown improved outcome measures compared with other modes of teaching such as traditional lectures.

- Virtual Worlds (VWs) use virtual reality to immerse the learner within a virtual environment through a controllable avatar. This makes possibilities of movement and interactions with high-fidelity, expansive environments during the learning process. VWs also provide multi-patient interaction and Chang and Weiner claim that would be an effective way to simulate practice in disrupted environment as well as in clinical care space during the design phase.
- Virtual Trainers (VTs) more focus on hand-eye coordination and psycho-motor skills. Special hand-held devices such as a haptic simulator often been used for VT based learning.
- Resource Management Simulators are normally designed to demonstrate the amount of population patterns and to assess and manage environments. For instance, a mass-casualty disaster preparation and response in the PEM field.

Chang and Weiner also addressed the advantages and disadvantages of SBS and 3D VR over MBS. They claimed that the advantages of SBS and 3D VR include infinitely replicable simulations, the capability of multiple devices, portability and tractability that enables analysis of massive amounts of usage and performance data and that it does not require the presence of a live instructor. The disadvantages may only consider cost, technical problems and lower fidelity.

Nunes & Costa (2008)'s research show a general view of computational applications in the healthcare area and emphasise the use of VR technology. They also gave suggestions for relevant research areas that need to be done to make improvements for applying VR technology in healthcare field.

First, they examined the areas of 3D applications in healthcare. Two major implementation areas are shown according to their research: medical education and training, and rehabilitation. They pointed out that medical procedures training, the major subclass of Medical education and training, is perhaps the most used in the associated literature about virtual applications for training in the healthcare field. Virtual Atlas for anatomy studies is also mentioned in their research as an appropriate way to implement virtual reality technology in healthcare aspect.

Nunes and Costa next introduced five grand challenges originally proposed by the Brazilian Computer Society and extended them specifically for VR applications in the healthcare area. The first challenge is related to handling a large volume of information distribution in the virtual environment. They suggested that it is necessary to create a particular pattern that can be used for better information transmission over VR applications. The second challenge relevant to simulation environment. Nunes and Costa emphasised the importance of immersive interaction provided from the VR application. New hardware models for VR healthcare technology are considered as the third challenge from Nunes and Costa's research. The fourth challenge mentioned the necessity of universal access to the current technology knowledge, which might benefit citizens as well as other organisations. Building a logical structure and development patterns for VR-oriented healthcare applications is the final challenge introduced by Nunes and Costa. Nunes and Costa's work outlined new perspectives of the existing grand challenges based on SBC's research for VR applications in healthcare domain.

Parsons & Rizzo (2008) reviewed effective outcomes of virtual reality exposure therapy (VRET) for anxiety and specific phobias. They examined 21 studies (300 subjects) which met the inclusion criteria. The specific anxiety areas and phobias reviewed include PTSD, social phobia, arachnophobia, acrophobia, agoraphobia, and aviophobia. Although there are limitations, such as lacking individual samples in specific anxiety or phobias, the research showed significant positive effects.

The conclusion made in Parsons and Rizzo's research shows that VRET had statistically significant effects on all affective domains, as well as all anxiety and phobia groupings evaluated.

Similar to Parsons's research, Meyerbroker & Emmelkamp (2010) systematically reviewed VRET in anxiety disorders in 2010. However, their research has shown that only in fear of flying and acrophobia, there is considerable evidence that VRET is indeed efficacious. In more complex anxiety disorders, as such panic disorder and social phobia which form the core clinical groups, first results of VRET are promising, but more and better-controlled studies are needed before the status of empirically supported treatment is reached. More severe cases of panic disorder with agoraphobia and social phobia are not often fully treated with existing methods.

They gave a few suggestions for future research. For instance, for patients with complex anxiety whom are naturally less inclined to seek treatment publicly, future research could aim to investigate whether initial sessions can be conducted at home via an internet port, where patients can login and start their first treatment sessions via VR.

Gaba (2004) claimed that simulation should be emphasised as a major method to improve the quality of healthcare in the future. He categorised 11 dimensions of diverse applications of simulation in healthcare. It was indicated that using VR was one of the significant ways to provide a fully interactive clinical work environment.

Meanwhile, Mantovani et al. (2003) show that VR technology can provide innovative training tools for healthcare professionals and has great potential to enhance the learning processes. Specifically, VR technology can provide high-level interaction with the learning content to foster active engagement. Their research shows VR contributes to raising motivation and interest, conditions that are recognized as crucial in the learning process. Moreover, learning experience based on VR technology provides a user with content that would be too difficult, too costly, or simply impossible to have in the real world. Finally, they claimed that the learning and performance style based on a VR environment makes the study process highly flexible and programmable, thus offering more study options. Mantovani et al. also mentioned that side effects might occurred for some users after exposure to immersive VR environments.

VR in healthcare education

The work from Izard & Méndez (2016) shows the teaching potential of applying VR in studies of human anatomy, where it can be used as a tool for education in medicine. They designed a VR system which allows the user to enter through virtual immersion and anatomically analyze human bone structure and visualize the cranium from both inside and out. Izard and Mendez noticed that although there are currently different VR technological applications available on the market which move around the inside of different parts of human body, many of them are just recorded by the 360-degree camera. Such stereoscopic vision systems have a strong limitation regarding view movement, user interaction, and etc. Therefore, their system emphasised and enhanced the possibility of interaction in their VR-based learning software.

Their system used Samsung Gear VR as a hardware solution, which may achieve an angle of vision up to 96 degrees and an interpupillary distance between 55 and 71mm. Also, Samsung Gear VR has a small touch screen which provides interaction between hardware and user. Asteion computed tomography was applied to a 3-D model generation for the system. After the model generation process, features of visualisation and interaction were implemented into the system. Finally, they "obtained a training tool for students of health sciences, allowing users to navigate around the inside of the cranium with a high degree of realism and also interact with the system to guide this navigation around the different parts of the anatomical structure" (Izard & Méndez, 2016).

Izard and Mendez found that VR techniques provide significant benefits compared to other traditional training tools according to the outcomes from their VR-based anatomical training system. The VR technology provides detailed human anatomy structure both from the inside and out, where large amounts of those structures cannot be observed directly through a simple video or static image. They believe that one of the most interesting aspects of VR techniques is that it can be manipulated and the user can interact with the generated virtual environment. The carefully designed visual experience could help users, such as students, to have a sense of control over the environment and it brought a contribution to the learning and training process in the medical field.

Kilmon et al. (2010) explored immersive virtual reality as a potential educational strategy for nursing education, especially targeting speed and accuracy of nurse response in specific emergency situations. According to their prior research, high-fidelity simulations were found to be quite useful for students, especially in situations that may be dangerous such as bomb threats, battlefield casualty treating, and etc. They first obtained visual images of drugs and equipment during a specific scene of clinical intervention (ie. cardiopulmonary resuscitation) and developed a highly realistic virtual crash cart based on those visual images. Then, they decided to use the touch screen monitor for interaction after trying several options which included finger sensors and GPS technology. They claimed the large touchscreen might enable the use of detailed representations of objects. Currently, the research team is trying to use more compact and user- friendly platforms that would make the program more widely available and easier to use. This has allowed them to adapt their virtual objects in some internet-based virtual worlds such as Second Life.

Their research shows a possible way to initialise a VR research and development project relevant to the healthcare field. Their simulation solution is trying to resolve the speed and accuracy issue during the VR based nursing training. They also suggested that it is necessary for design and programming technicians to work with educators and medical staff with a strong base of clinical expertise; in their case, such medical staff could be skilled registered nurses among others. Feedback for anticipated responses must be planned and programmed is another summarised opinion from their research.

VR in healthcare training

Aggarwal et al. (2006) successfully developed an evidence-based VR laparoscopic training curriculum for novice laparoscopic surgeons to achieve a proficient level of skill prior to participating in live cases. To achieve this target, the research team initialised two session implementation groups, which consisted of 10 experienced and 10 novice laparoscopic surgeons respectively. Those two groups were assigned to finish seven basic tasks over three difficulties in different virtual sessions. Learning outcomes of novices were collected and analysed after every 2 to 3 virtual sessions to ensure the quality of the study process. As a result, the curriculum was defined, and can serve to ensure that junior trainees have acquired prerequisite levels of skill prior to entering the operating room.

In Larsen et al. (2009)'s research, it was shown that VR technology can ease the learning curve of laparoscopic training in the operation theatre. The performance level of novices was increased to that of intermediately experienced laparoscopists and operation time was halved. They also discussed the issue of skill transfers between VR training and the real operating environment.

Rizzo et al. (2006) applied VR technology into exposure treatment for patients with PTSD from the Iraq war. They developed an application that contains different virtual scenes which simulate real scenes from modern warfare. The PTSD patients were asked to wear an HMD to expose themselves to those virtual scenes and caregivers could monitor their physiological parameters through another computer. Their research has shown that VR technology could bring multiple advantages to PTSD treatment in terms of cost and efficiency.

2.4 Other VR training systems

VR training in Mining industry

Schofield & Dasys (2009) reviewed a number of emergency response training simulation systems with VR technology in the mining application field within Australia and Canada. Their research successfully produced a large number of virtual mine training environments. However, some systems are under-utilised due to various limitations such as lacking consideration for long-term development and losing focus on requirements related to the goals, aspirations, and needs of the trainees. VR technology has better potential for emergency response training if these areas are addressed correctly.

Costa et al. (2014) designed a fully functional VR regional mine environment based on 2D plans for control group training. They found that this VR application allowed for effective training of groups during an emergency fire situation once communication and data requirements were incorporated. Their research indicated that VR could not only be used in a training aspect, but also in helping mine rescue teams to handle with emergency situations.

The National Institute for Occupational Safety and Health (NIOSH) in Pittsburgh, United States, developed a VR-simulator solution called The Mine Emergency Response Interactive Training Simulation (MERITS) in 2000 (National Institute for Occupational Safety and Health Office for Mine Safety and Health Research Pittsburgh Research Laboratory, 2000). The MERITS can provide various functionalities including allowing leadership evaluate their knowledge and skill personally, and integrating groups consisting of representatives from mining companies, labour, and government agencies together to practice working in simulated emergency situations.

Disaster training using VR

Hsu et al. (2013) reviewed VR-based simulation disaster training projects on governmental, academic and private levels in the United States. It was concluded that the VR-based platform showed significant potential advantages in disaster preparedness and emergency response training, compared with traditional forms of training. It was also made clear that a comparative research between VR-based and traditional modalities of disaster training is needed to explore the various aspects of realism, cost, and ultimately, disaster readiness.

V. Chang (2017) reviewed different examples of cloud computing VR. Those examples involve different aspects include healthcare, business, climate change, and natural disaster. Their research shown that emerging services and analytics can be supported by VR in above-mentioned aspects. Such visualized presentation can allow scientists to understand the complexity behind science and process large amount of data within second. Also, the general public without deep knowledge can understand part of the outputs as well.

Industry safety training using VR

Bhide et al. (2015) introduced the feasibility of constructive simulations for developing a framework for industrial health and safety to provide employees training in a simulated environment as well as their capability of taking actions in emergency situation. They believed that simulation based on VR technology could provide an engaging, effective experience while eliminating the risk present over the real-life situation.

Their study is relevant to the methods used in health and safety training based on the meta-analysis from Burke et al. (2006) conducted between 1971 to 2003. Burke et al.'s research pointed out the relative effectiveness of three types of methods, from least engaging (lecture, video, etc.), moderately engaging (programmed instructions) and most engaging (hands-on or behaviour modelling). Bhide et al. noticed that the more engaging the training conducted, the fewer injuries and accidents occurred in the workplace. Based on the abovementioned study, they broadly reformed and redefined the types of health and safety training into four classifications; ‘information based passive training’, ‘computer instructions based and learner-centred training’, ‘training with hands-on activities’ and ‘virtual reality simulation-based training’. They explored each of the training classifications, and determined training with hands-on activities, and VR simulations are more engaging methods over the other types.

They pointed out that although simulation-based training makes participants seem close to a real-world environment, it is difficult to understand or assess how the participants accept the virtual environment as reality. Therefore, specific physiological measures such as Electroencephalography are applied to obtain the emotional response from the participants during the virtual, constructive simulation.

2.5 Healthcare training evaluation

Research from Soderholm et al. (2008) demonstrated that 3D telepresence technology has the potential to provide richer visual information than current 2D video conferencing techniques and it improves emergency trauma healthcare if designed and implemented appropriately.

Based on their previous research (Sonnenwald et al., 2008), they emphasised two measurements to evaluate the result of 3D telepresence technology as applied in the emergency healthcare areas: : "task performance" and "self efficacy". Task performance refers to "the detailed examination of observable activity or behaviour associated with the execution or completion of a required function or unit of work" (McSH, 2008). Self efficacy refers to "a person’s judgement of their capability to perform a certain task" (Bandura, 2006). Sonnenwald et al’s research hypotheses include, 1) paramedics working in consultation with a physician via 3D telepresence technology will provide better medical care to trauma victims than paramedics working in collaboration via 2D video conferencing or paramedics working alone; and 2) paramedics working in consultation with a physician via 3D telepresence technology will report higher levels of self-efficacy than paramedics working in collaboration via 2D video conferencing or paramedics working alone.

To verify their research hypotheses, they designed an experiment and measured the results by the above mentioned task performance and self efficacy metrics. Also, paramedics' reflections on their performance was the third consideration noted. Two emergency healthcare experts collaborated with the two researchers during the experiment design and measurement phase to guarantee the correctness of experiment results. A well-designed 3D proxy was implemented to simulate the 3D conferencing between paramedic and consultant physician due to the technological limitation of 3D telepresence.

Sonnenwald et al.'s research shows positive results which can support their previous hypotheses. Additionally, the research demonstrated an appropriate way to assess the experiment results relevant to emergency healthcare when virtual objects are involved.

Hilton et al. (2011) show their efforts of developing and evaluating of a mixed reality (MR) system for stroke rehabilitation. They developed software to simulate a scenario making a hot drink. The scenario includes a sequence of producing tasks in a three-dimensional environment which contains kitchen objects. Real, physical objects are employed and responded with those virtual objects by using interfaces.

They first deconstructed the hot drink making scenario into small atomic tasks, then built different task chains. The users were asked to perform the entire scenarios based on those task chains. Sensors were employed to collect the user performance data. They made a recommendation for the MR system design approach, especially for stroke rehabilitation.

Their research demonstrated an appropriate way to design a virtual system for healthcare training. However, limitations also existed in their research. Their research used customised virtuality hardware, and it is hard to be implemented widely commercially. As a research-specified software, the extensibility was not a significant consideration. Therefore, it is not convenient enough to convert the current scenario to other training scenarios, such as Parkinson's disease rehabilitation.

2.6 Conclusion

In this chapter, we first covered the history of virtual reality technology. This gives us a concrete idea of the classification of virtualities. Advantages and disadvantages of each viturality technology is indicated by the literatures as well as some early implementations. Secondly, we reviewed the different research regard the application of VR in various healthcare aspects. According to the widely read materials, we highlighted two research area that most apply VR technology; VR in healthcare education (e.g. anatomy demonstration) and using VR in medical training (e.g. laparoscopic surgeon training). Followed this, we reviewed literature regarding the use of VR in other training aspects. Emergency response training in the mining industry and disaster response circumstance are highlighted. Additionally, safety training in general industry has been reviewed. Finally, we reviewed the methodologies were used to develop and evaluate a VR implementation project in healthcare field.

According to our review, we found that although VR technology has been developed for many years, vast limitations still exist. We address the limitations as follows:

- Limitation 1:

  There is a lack of research on emergency healthcare workflow training, as most research focused on a specific field, not the entire workflow.

- Limitation 2:

  Most research used old generation VR technology, and only a few studies were conducted recently using new generation VR hardware.

- Limitation 3:

  There is a lack of evaluation models which can be used to precisely evaluate the performance of the user.

Chapter 3

Methodology

3.1 Introduction

We use quantitative research methodology to investigate how VR technology will benefit emergency healthcare training. Quantitative research is the systematic empirical investigation of observable phenomena via statistical, mathematical or computational techniques (Given, 2008). We design an experiment[1] that uses current VR technology to provide emergency healthcare training sessions to participants. Then we observe the efficiency of such VR-based emergency healthcare training by collecting data and analysis. We first look at the workflow of emergency healthcare and convert it into a process diagram. Then, we simplify and split the procedures in the process diagram into smaller blocks, named *Tasks*. Participants' performance metrics will be collected by the VR software while the training session is conducted. We categorise those data as *Performance Data*. Another area of data collection is relevant to trainees' personal information such as their gender, occupation, technical background, etc. We categorise such data as *Personal Data*. Combining performance data with personal data, we assess the extent of how virtual reality technology will improve emergency healthcare training.

[1] A demo link is available at https://youtu.be/6h0i3ytygUo

3.2 Workflow of Emergency Healthcare

This section indicates the three assessment components and significant steps in the Emergency Healthcare Workflow (EHW). Following, the concept of converting the EHW to a Process Diagram is indicated.

3.2.1 Emergency Healthcare Workflow (EHW)

The Emergency Healthcare Workflow (EHW) is strictly constructed based on various emergency healthcare training reference sources, for instance John (2018) and skills for life ltd. (2013). To initialise the processes, we reviewed the emergency healthcare training sessions from St John Ambulance, American Safety, First Aid International, etc. and categorised the emergency health care procedures into three segments. Those categories of procedures are *Initial Assessment*, *Secondary Assessment* and *Ongoing Assessment*.

Overall, the initial assessment will conduct a rapid assessment of the patient. Traditional rapid assessment methods such as consciousness level checking and body swiping are included. Also, essential information relevant to injury cause will be acquired during the rapid assessment. As the secondary assessment is expected to focus on soft tissue injuries, we addressed a soft tissue checking process in this segment. Once the secondary assessment is finished, we assume that patient has been allocated correctly to specific recovery position such as a recovery trolley or an emergency vehicle. Thus, the ongoing assessment followed by will be conducted by professional paramedics. The following sections will introduce the procedures of those three assessments in detail and indicate how we convert them into VR software.

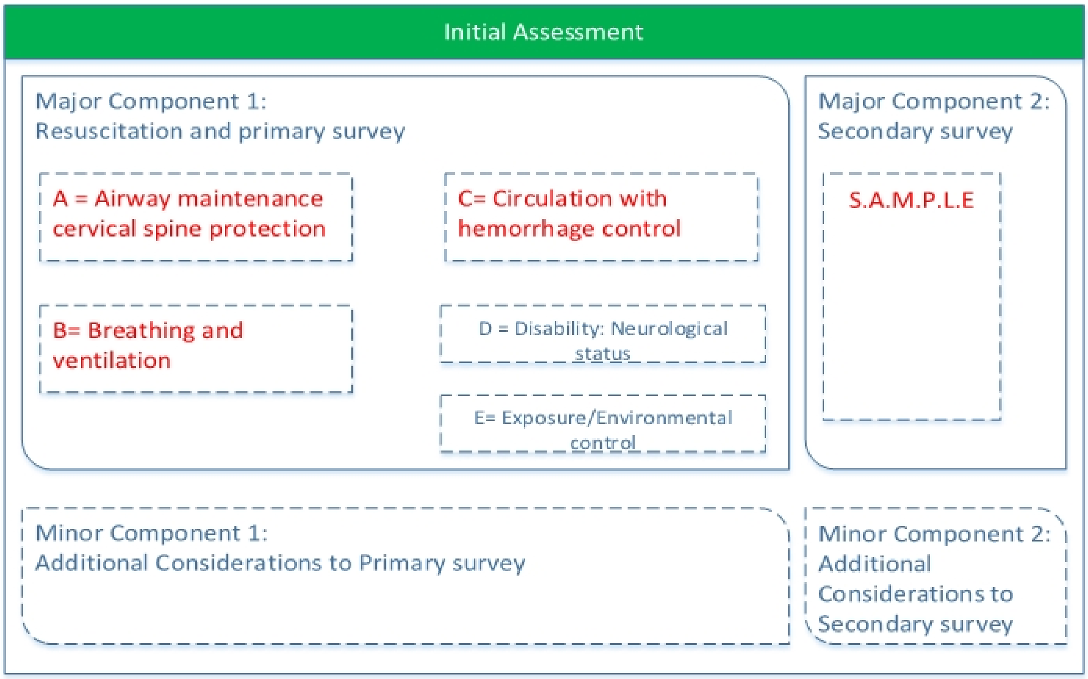


Figure 3.1: Initial assessment components

Initial Assessment

Based on analysis of different emergency healthcare training references, we defined two major components and two minor components as shown in Figure 3.1 to conduct the full initial assessment. Multiple tasks and procedures will be contained and organized structurally in each component.

The first major component is Resuscitation and Primary Survey. A traditional rapid assessment method, called the ABCDEs approach will be organized in this section. The mnemonic acronym ABCDEs refers to a general primary assessment approach which is widely used by most of the public healthcare service providers over several countries of the world, such as Public EMS in the United States and St John Ambulance of UK. As the largest healthcare service provider in New Zealand, St John Ambulance of New Zealand also uses the ABCDEs approach for performing an initial assessment of any unwell or deterioration of a patient (John, 2013).

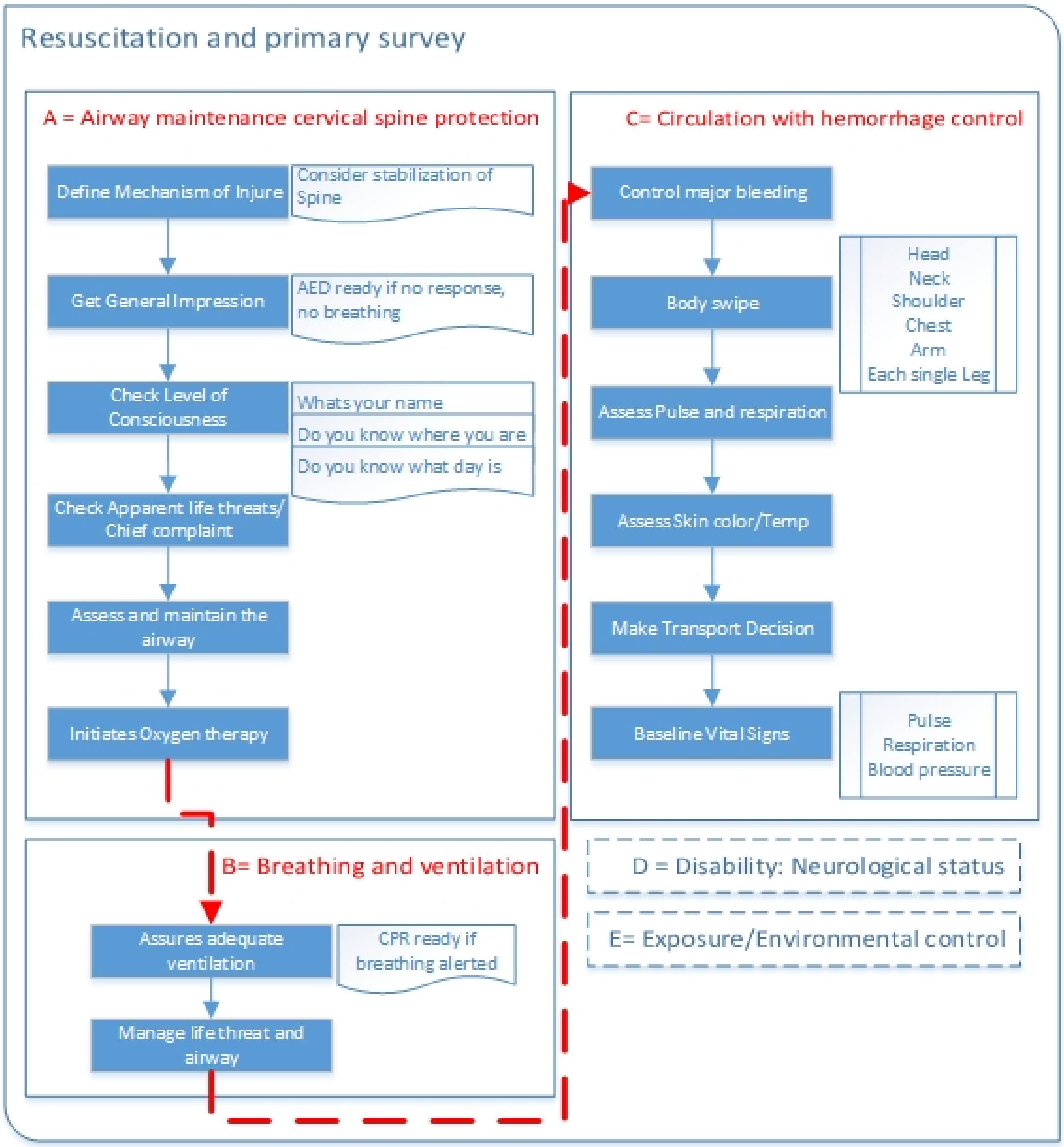


Figure 3.2: The Workflow of ABCDEs assessment

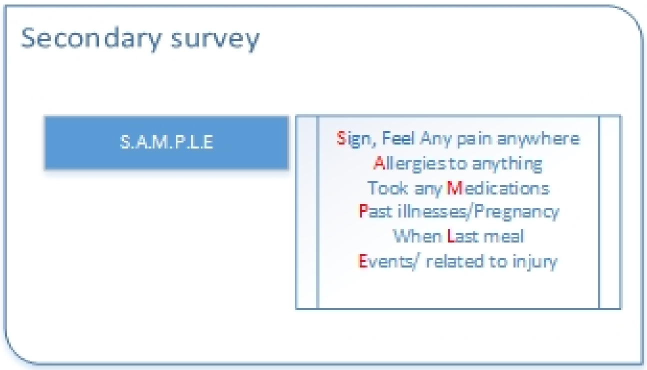


Figure 3.3: The S.A.M.P.L.E history

Specifically, ABCDE means *Airway maintenance cervical spine protection*, *Breathing and ventilation*, *Circulation with haemorrhage control*, *Disability neurological status* and *Exposure/Environmental control*, respectively. Each of the single terms in ABCDE represents a group of tasks which correspond to essential procedures to assess and maintain the baseline of vital signs. Those specified tasks are demonstrated in Figure 3.2.

The second major component is Secondary Survey. We set a SAMPLE history task in this component. SAMPLE history is a mnemonic acronym to remember key questions for a person's medical assessment (Ed Dickinson, 2008). Patients are expected to be asked questions related to their medical history in terms of *Signs*, *Allergies*, *Medications*, *Past illness*, *Last oral intake*, and *Events leading up to present illness*, respectively, as shown in Figure 3.3.

Two minor components are *Additional considerations to primary survey and resuscitation* and *Additional considerations to secondary survey*, which are alternative tasks that can be performed in the specific emergency situation. Tasks such as electrocardiography monitoring and urinary and gastric catheters are categorised into those components due to their complexity of procedure performance and requirement of additional healthcare equipment.

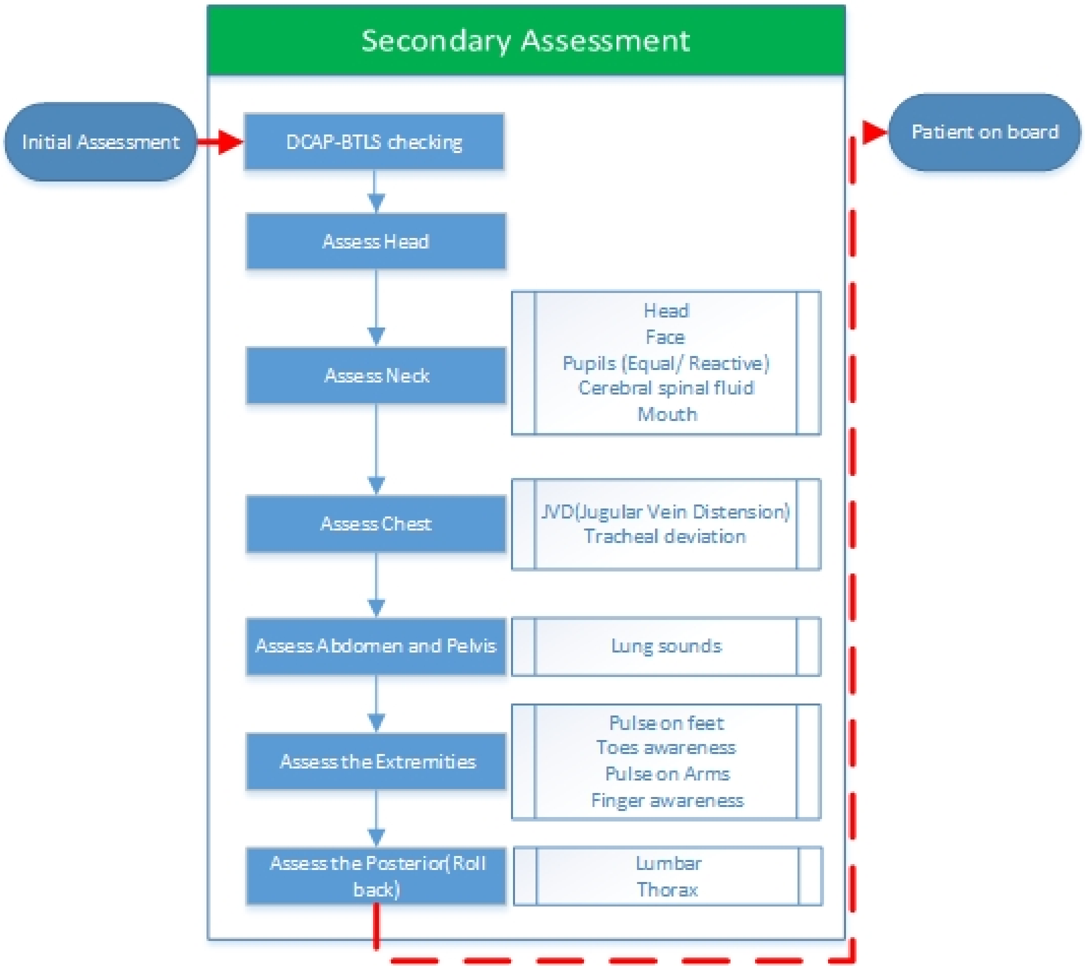


Figure 3.4: Secondary assessment components

Secondary Assessment

A secondary assessment is typically conducted after the initial assessment is completed and no life-threatening injuries are found or assessed. The purpose of conducting a secondary assessment is to collect as much information as possible that will assist the paramedics or doctors to diagnose the patient appropriately. In general, secondary assessment contains a 'head-to-toe' assessment of operations and can be addressed into multiple tasks in order. We considered the DCAP-BTLS checking processes as the only major component in secondary assessment. The processes of DCAP-BTLS are shown in Figure 3.4.

As the figure indicates, a total of six major assessments are contained in the DCAP-BTLS checking process. Each of them represents separated assessment procedures for a patient's head, neck, chest, abdomen and pelvis, extremities and posterior respectively. Soft tissues from the head such as facial skin, pupils, cerebral spinal fluid and mouth will be assessed during the head assessment performing, the first step of the DCAP-BTLS. Followed by the neck assessment that includes assessing for jugular vein distention (JVD) and tracheal deviation. The chest assessment is the third step of the DCAP-BTLS concentrating on feedback of lung sound. The rest of the body organ assessment includes abdomen and pelvis which will be assessed after the chest assessment is performed. The extremities assessment contains repeated assessment for pulses of both feet as well as arms and also assessing awareness for fingers and toes, in order. The final assessment of posterior will check the lumbar and thorax by rolling back the patient's body. In some emergency healthcare instructions or for particular emergency healthcare circumstances, additional ABCDE procedures are required to perform after the DCAP-BTLS check. Then after all the assessments are completed, the patient will be moved to the recovery position and be treated by an EMS team in the ongoing assessment process.

Ongoing Assessment

The ongoing assessment contains a repeat of the focused or rapid emergency department assessment of a pre-hospital patient to detect changes in condition and to judge the effectiveness of treatment before or during transport (*Medical Dictionary for the Health Professions and Nursing*, n.d). Normally, the ongoing assessment will be performed by EMS staffs such as paramedics and emergency medical technicians (EMTs).

As Figure 3.5 demonstrates, the major tasks which are defined in our emergency healthcare workflow include repeating initial assessment and keep tracking vital signs.

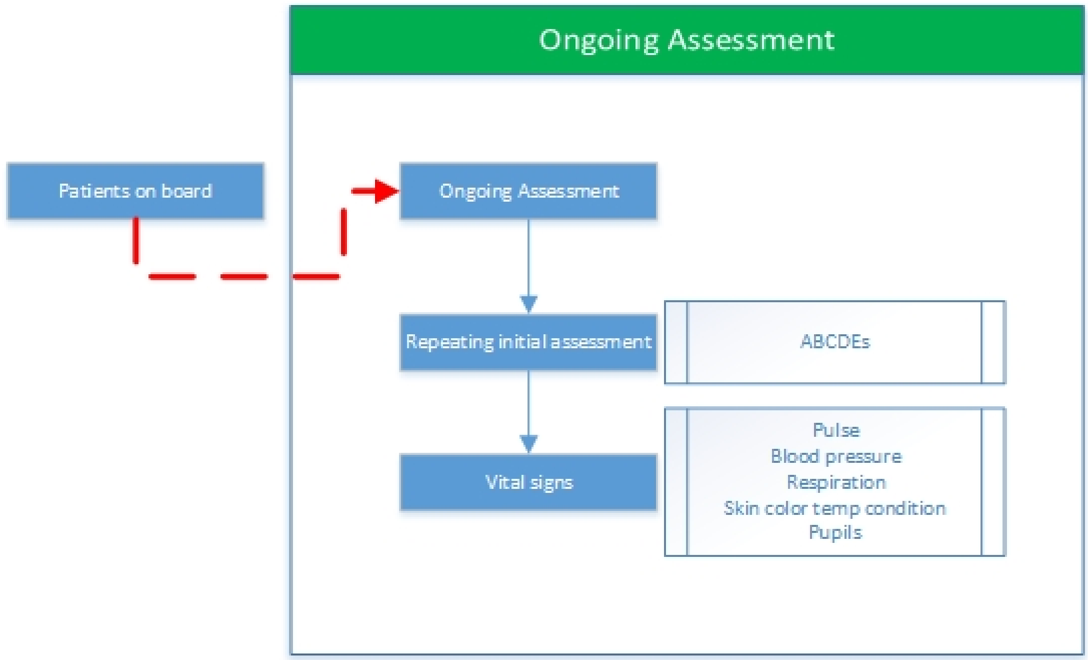


Figure 3.5: The Ongoing Assessment

3.2.2 Convert the EHW to Process Diagram

Identifying Tasks

Based on the emergency healthcare workflow, we created a program adaptable process form and defined all the previously mentioned operations as different *Tasks*. A group of actions contained in tasks which would be performed in particular emergency healthcare circumstances are defined as *Procedures*. Atomic operations in a specific procedure are defined as *Actions*. For instance, in the task 'Check level of consciousness', some procedures need to be done to determine the patient's consciousness level. Examples of those procedures include 'ask three basic consciousness checking questions' and 'observe patient's feedback and give response', etc. Each procedures is done by a group of actions. In the case 'ask three basic consciousness checking questions', the action group includes 'ask a question about patient's name', 'ask a question about time' and 'ask a question about current location'.

After giving the definitions of tasks, procedures and actions, 20 tasks in total are derived from the previously mentioned EHW. They are considered a baseline of the emergency healthcare workflow. 13 of them are extracted from initial assessment, and 7 of them are extracted from secondary assessment. No tasks are extracted from ongoing assessment because all of them are repeated operations from either initial assessment or secondary assessment. The full baseline tasks are shown in Table 3.1.

Task Formalization

In order to collect and analyse data more precisely, we formalized each task from the process diagram based on techniques from software engineering methodology. Furthermore, particular vital signs or event statuses in each task are properly defined as *Task Attributes*. The attributes will be involved while performing specific *Procedures*. Each formalized task will contain a group of procedures, some attributes, at least one input condition and one output result.

Figure 3.6 shows an example of a particular task process after formalization. As the figure indicates, this task intends to decide the level of consciousness for a patient by asking some simple questions and observing the feedback from those questions. First, the attribute 'level of consciousness' is identified and the contents of this attribute include various states of consciousness such as 'normal consciousness', 'confused', 'delirious' and 'somnolent'. Then, different procedures which may change the 'level of consciousness' attribute are identified and connected. Finally, the output of this attribute will be recorded after finalizing the task.

During the progress of task formalization, we found that some tasks such as SAMPLE history (T13) can be performed by oral interactions only. Those tasks are labelled additionally as 'Parallel Tasks', which means they can be performed with other non-parallel tasks simultaneously from a specific point of the EHW. The combination of parallel tasks and non-parallel tasks will create emergency healthcare circumstances that closer to situations that happened in the real world.

Table 3.1: Baseline Tasks of EHW

Task ID	Task Name	Additional Notes
Initial Assessment		
T1	Define mechanism of injury	Both patient's spine stabilization and environmental safety are two major considerations
T2	Get general impression	General impression acquired based on patient's feedback of response and breathing. Perform AED if required
T3	Check level of consciousness	Consciousness level will be decided by asking basic questions
T4	Check apparent life threats	Major bleeding is a priority consideration
T5	Assess and maintain airway	Open-airway procedures will be seriously considered if spine injury detected
T6	Initialize oxygen therapy	Optional task. Performed only as needed
T7	Assure adequate ventilation	CPR needs to be preformed if alerted breathing sign
T8	Control major bleeding	
T9	Body swipe	Broken bones or dislocated joints is a priority while swiping the body
T10	Assess pulse and respiration	
T11	Assess skin colour and body temperature	
T12	Make transport decision	
T13	SAMPLE history	SAMPLE history check performed only if patient's consciousness is above 'somnolent' level
Secondary Assessment		
T14	DCAP-BTLS Head	Performing assessments for head, face, pupils, and mouth
T15	DCAP-BTLS Neck	
T16	DCAP-BTLS Chest	Performing assessments for upper body organs
T17	DCAP-BTLS Abdomen and Pelvis	Performing assessments for lower body organs
T18	DCAP-BTLS Extremities	
T19	DCAP-BTLS Posterior	
T20	Patient on board	

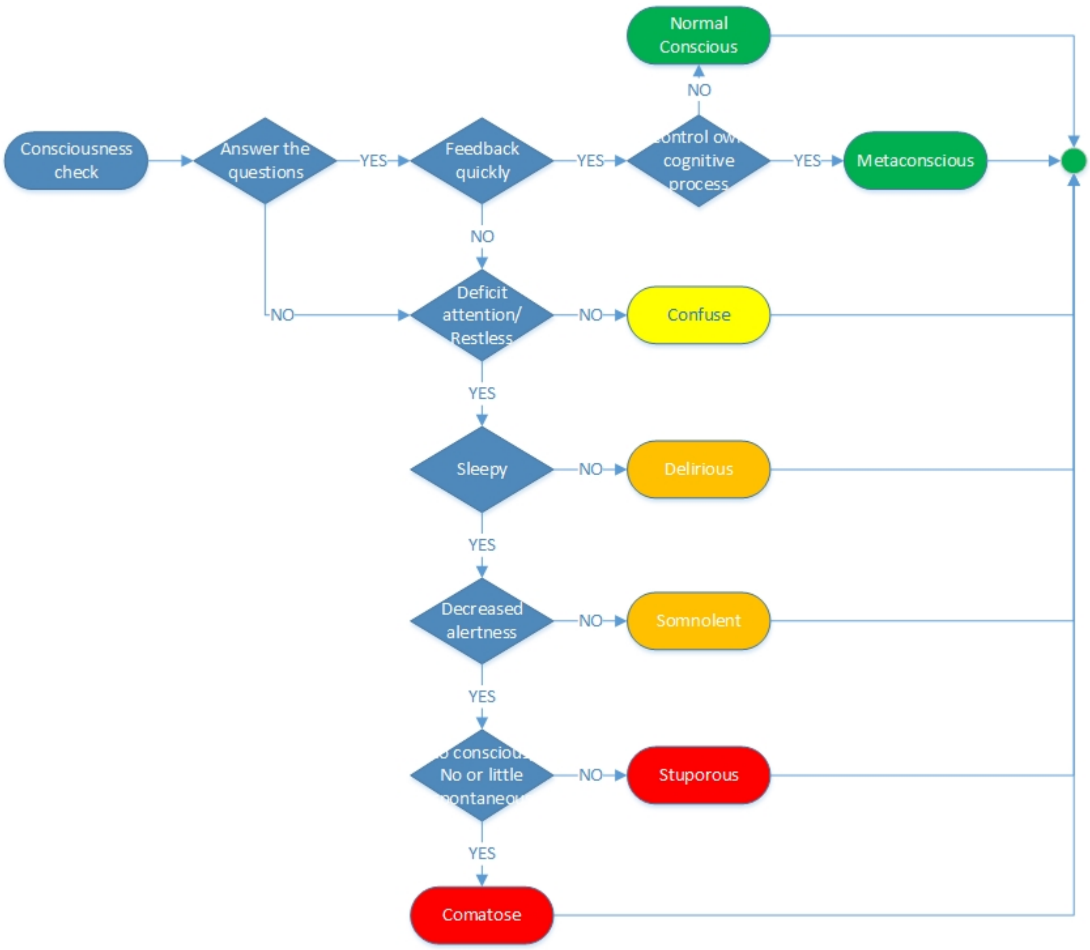


Figure 3.6: Processes of ‘Check level of consciousness’ task(T3)

Table 3.2 shows two instances of conducting the level of consciousness check based on abovementioned task formalization. In the first instance, a patient is determined to be of normal consciousness and in the second, the patient is found to be delirious. There are more procedural steps involved in the delirious case determine which abnormal state the patient is in.

Table 3.2: Instances of proceeding ‘Check level of consciousness’ task(T3)

PID	Procedure Description	Procedure Results
Instance 1: Determining ‘Normal Conscious’		
P1	Ask 3 basic consciousness checking questions	N/A - Go P2
P2	Observe the patient’s feedback about P1 (Does the patient answer the questions?)	YES - Go P3
P3	Observe the patient’s feedback about P2 (Does he/she feedback the question quickly?)	YES - Go P4
P4	Observe the patient’s feedback about P3 (Does he/she control his/her own cognitive process?)	NO - Go Final
Pfinal	Determining level of consciousness	Set value of attribute ‘Level of consciousness’ as ‘Normal Conscious’
Instance 2: Determining ‘Delirious’		
P1	Ask 3 basic consciousness checking questions	N/A - Go P2
P2	Observe the patient’s feedback about P1 (Does the patient answer the questions?)	YES - Go P3
P3	Observe the patient’s feedback about P2 (Does he/she feedback the question quickly?)	NO - Go P5
P5	Observe the patient’s feedback about P3 (Does he/she has deficit attention or restlessness?)	YES - Go P6
P6	Observe the patient’s feedback about P5 (Does he/she looks sleepy?)	NO - Go Final)
Pfinal	Determining level of consciousness	Set value of attribute ‘Level of consciousness’ as ‘Delirious’

3.3 Software Design and Development

This section indicates the processes of developing the VR emergency healthcare software. We first introduce the development methodology we are using for the project, then demonstrate the processes of developing the prototype and VR training software.

3.3.1 Development Methodology

In the software development phase of this research project, we use a traditional incremental build model as the main development methodology to conduct our progress and ensure the quality of the virtual reality software. When an incremental build model is applied on a software development process, the design, implementation, and test phases the from traditional waterfall model should be iterated incrementally until the software finally satisfies the requirements. Figure 3.7 indicates our initial incremental model for this research project.

The advantages of using an incremental build model are numerous. One of the major advantages is that by applying this methodology, we can maximize the scales of the software with the addition of iterative qualities within a limited development period. We have six months of software development from our initial timeline estimation. According to the workload estimation (e.g. LOC measuring and system component estimation), we find that the time span of applying a traditional waterfall methodology to this project will have an out of time limitation. Employ the incremental build model will give us the flexibility that we can adjust the development progress and quickly responded to any problems as they occur.

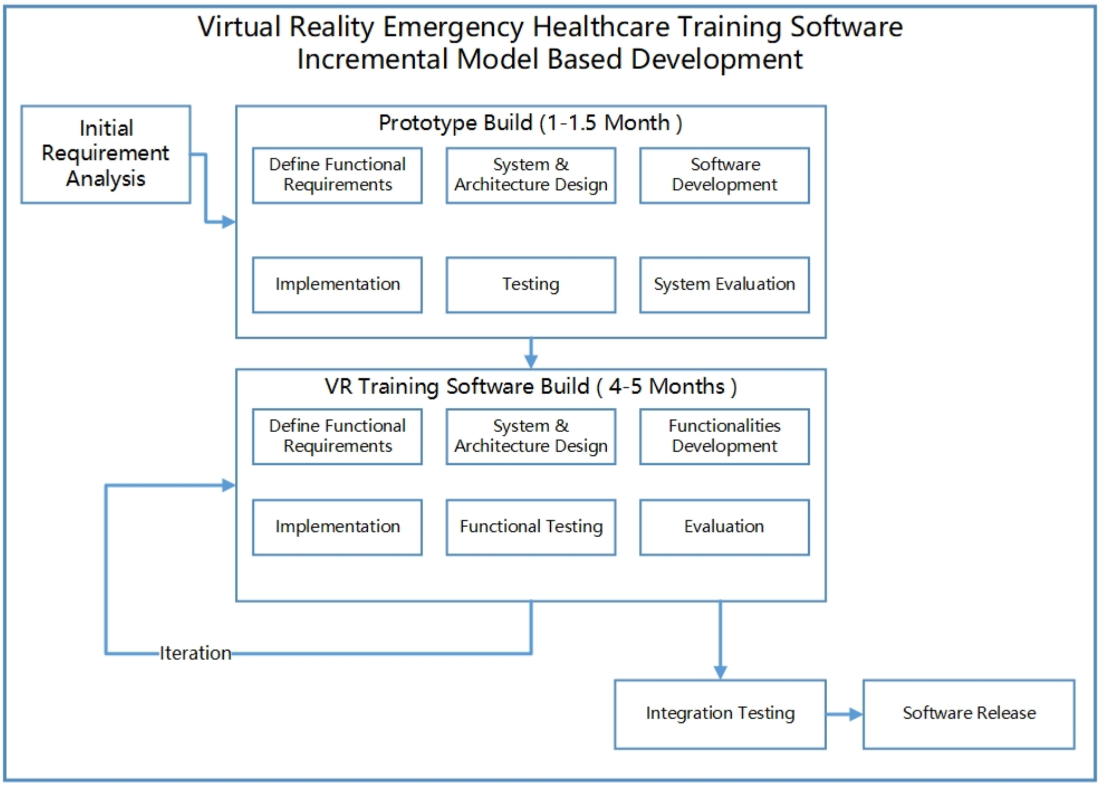


Figure 3.7: Incremental model for VR emergency healthcare training software

3.3.2 Prototype application development

Define functional requirements

Since we use incremental design methodology in this research project, a prototype application is required to demonstrate the feasibility of implementing such a VR application on the specific software platform. The main goal for the application is to test which development techniques and platforms are suitable for this research project in the perspectives of learning and use difficulty, extensibility, stability, compatibility with commercial VR hardware, etc.. Also, we want to test the possible ways we could implement the EHW tasks of Section 3.2 to the virtual world.

We first analyse functional requirements of the prototype application which should meet our goals mentioned before. After a team discussion, we addressed the prototype software requirements in the following perspectives: Environment, Player, Interactions, and Software Performance and Configuration. The detailed functional requirement lists are given in Appendix A.1.

We believe the functional requirements could satisfy our primary goals and provided guidelines for a similar development project in the future. We can incrementally improve our software by adding other relevant functionalities based on these requirements. We can also develop more software with similar functionalities by detailing or slightly changing these requirements.

Prototype system design

After defining the main functional requirements, we start to design the prototype software that meets such requirements. In this stage, we confirm the development platform, techniques, and design of the initial version of system architecture.

- Select software development platform

  Taking of the limited development time period into consideration, we decide to use commercial game engines that support VR technology as the main development platform. There are few commercial game engines which support VR technology in the market. After extensively reading literature and reviewing those game engines, we decide on two most popular engines as available options: Unity Engine from Unity Technologies and Unreal Engine from Epic Games. Based on reviews from Amiel (2015) and our own, we compare advantages and disadvantages of both engines and the evaluations are provided in Appendix A.3.

  We ultimately decide to use Unity Engine as the software development platform for our research. The reasons to support this decision are as below:

  1. Compared with Unreal Engine, Unity Engine is more suitable for intermediate or smaller size projects (less than 10000 LOC or less than 200 adjusted

functional points). By estimation and analysis of our requirements, we can define that our project size would between intermediate and small size.

2. Unity Engine has lower learning and developing costs than Unreal Engine, which means it has better adaptivity for an individual developer or small development group than Unreal Engine. Benefiting from this, the prototype software can be developed within a short period followed by the incremental process.

3. C-sharp scripting and major .Net Framework family members are fully supported by Unity Engine. As our research members are most familiar with .Net Framework, this advantage can obviously enhance our development progress.

Although our researchers are familiar with C-Sharp scripting language, we do not have experience with Unity Engine, including a unique syntax, APIs, architectures etc, designed for a standard game project. After quickly reviewing the major features and functionalities of Unity Engine, we outline a mind map as shown in Figure 3.8. This mind map lists all the relevant knowledge in Unity Engine that satisfies our initial requirements. As individual research developers, we follow all the pathways in this figure and learn the corresponding knowledge. For a team development project, we recommended different pathways for each development roles in the team. Examples of different learning pathways are provided in Appendix A.4.

- System design architecture

The system architecture also is considered when learning the basic knowledge of Unity Engine. We design a lightweight system architecture for this prototype software as Figure 3.9 demonstrates:

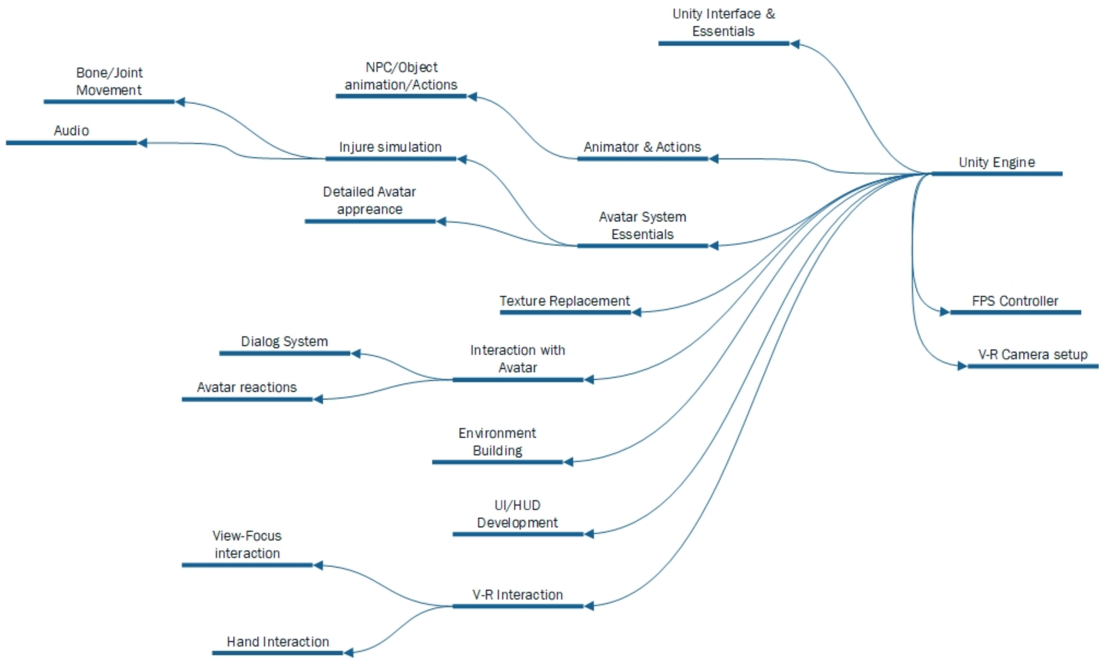


Figure 3.8: Mind Map for VR software development

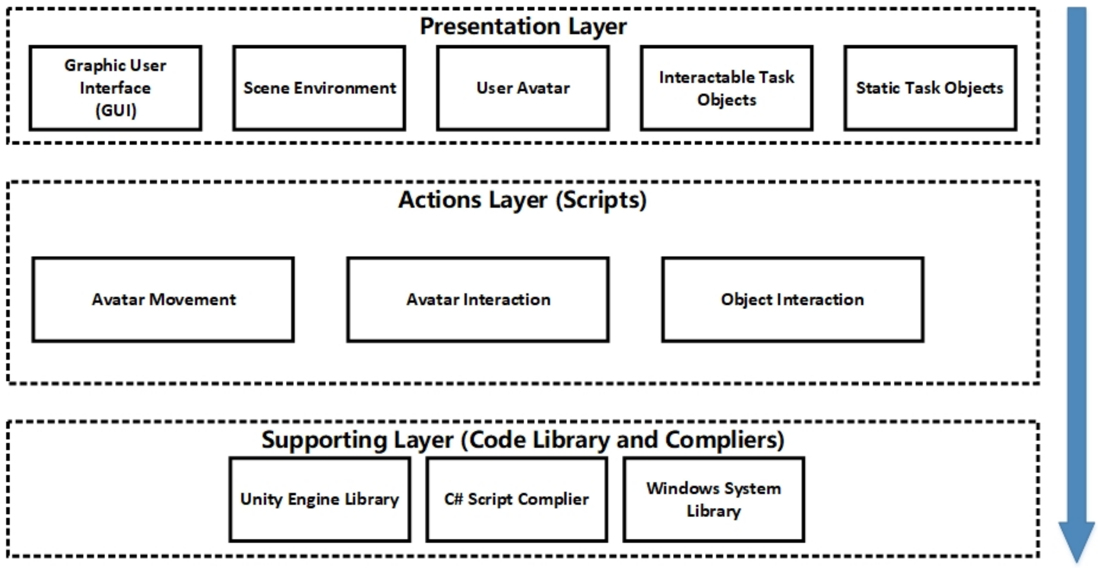


Figure 3.9: System Architecture of Prototype Software

According to the figure, there are three ordered major layers in the system architecture. The top layer is called the ‘Presentation Layer’, which offers a similar definition of the same name from classic 3-tiers software architecture (Eckerson, 1995). We defined that components and objects in this layer are responsible for managing all user-end interaction and visual presentation. The detailed functional description of the components in this layer are indicated in Appendix A.2.1.

The second layer is called ‘Actions Layer’. The components in this layer are designed to control the event logic for the upper layer. For instance, moving an avatar in the forward direction with velocity of 1 game unit per second when the ’W’ key is held is the event logic to the user avatar component of the presentation layer. The detailed functional description of the components in this layer are indicated in Appendix A.2.2.

The layer at the bottom is called the ‘Supporting Layer’. The components in this layer are encapsulated system components such as the code compiler, engine built-in compiler, etc.. They provide delegated manipulations that allow for the conversion of the messages from the Actions Layer to the hardware recognized instructions, and vice versa.

Implementation

After selecting the software development platform and designing the system architecture, we start to implement the components into a simple healthcare scenario. In this prototype scenario, we intend to build a car accident scene with a limited number of experimental tasks. These tasks include avatar movement, interaction by touching game objects, and interaction with game objects via speech.

We began by developing the components and objects within the Presentation Layer. As we have limited time to develop this prototype, we decide to use pre-defined Unity game objects called ‘Prefab’. Prefab allows the developer to store a ‘GameObject’ complete with components and properties. The prefab acts as a template from which the developer can create new object instances in the scene (Unity, 2018). By importing construction prefabs, we can instantly generate the virtual environment with only a few changes to materials and textures.

Once the virtual environment is built, more static and interactable objects are added. Those objects include cars, road obstructions, and a virtual patient, which together present a car accident scene. We demonstrates some example pictures in Appendix A.5 to show the progress of building the virtual environment.

In Unity Engine, a special game object called ‘Trigger’ can be set in the virtual environment and trigger events such as object interaction or animation. It is also a special property of the collider component, which can be turned to a trigger when a boolean parameter called ‘Is Trigger’ is set to true. The trigger can be set as a transparent object; therefore, players are abstracted from programming paradigms such as ‘once the avatar reaches a designated point, traffic begins to move, and otherwise, the traffic is immobile’, which provides an unrealistic user experience yet saves computing resources. Like other game objects in Unity Engine, multiple scripts can be attached to one trigger. Therefore, one trigger can spark complicated events or manage multiple objects simultaneously. Further descriptions of the trigger mechanism is shown in Appendix A.6.

We created different interactions events such as touching an object, audio playing, and speech interaction in this prototyped software. Then those events are attached to different interactable objects and controlled by the scripts in Actions Layer. By arranging those interaction events, we implemented a simple scenario such that a player (the person in control of the avatar) walks to a car accident scene, ask questions to a patient, and receives audio feedback from him.

After implementing a simple graphic user interface (GUI), we tested the software

Figure 3.10: The prototyped car accident scene

once the visual resolution was deemed acceptable by VR devices as shown in Figure 3.11. The Unity Engine has integrated tools to build such special resolution format and simulate the VR device's screen, which allows developers to test their software without connecting any real VR devices.

Evaluation

The prototype software allowed us to get familiar with the syntax and design techniques of Unity Engine as well as converting the emergency healthcare workflow to a virtual world. However, according to our evaluation, there are still improvements to be done for next iterations of development or for the VR software that will be used for the research experiment of this project. Three possible improvements to address are: design more flexible software architecture, apply advanced environment models and textures, and implementation based on a real VR device. The details of each possible improvement are indicated in Appendix A.7.

Figure 3.11: VR Device Simulator

3.3.3 Emergency healthcare training software development

Functional requirements and non functional requirements

The requirement analysis of the emergency healthcare training software is based on the similar work from the prototype software. After evaluating the prototype software, we confirmed that most of the requirements from the prototype development could be reused. However, the scales of them need to be adjusted, and the details of the requirements need to be defined as well. Also, because we need to map the tasks from the EHW to the emergency healthcare training software, we must define new requirements to satisfy those task activities.

Unlike the prototype software which only contains very simple tasks, the emergency healthcare training software contains two scenarios, and each of them contain 10 major tasks. The environment setting of each scenario is simulating Auckland and Christchurch cities, respectively. We have 32 subtasks total within the major tasks. Each subtask's requirement is well defined and allows mapping from the components of the EHW. The following subsection 3.3.3 provides details of how the EHW are mapped to different subtasks.

System architecture

We re-designed the system architecture of the software. The new system architecture has better extensibility and flexibility. The current system architecture has three major advantages. First, general functions such as 'teleporting' and 'use Object' have been analysed and abstracted. Those functions have been designed as shared events in the system and thus, can be called by any subtasks. Shared events are highly reusable classes, thus the programming workload can be reduced significantly. Secondly, based on the features mentioned above, we are able to extend the functionalities of the software quickly.

Figure 3.12 indicates the full system architecture of the training software. Compared with prototype architecture in Figure 3.9, this system architecture has more components and layers. The components in the 'Presentation Layer' are same to prototype architecture, as the visual effects and display are still same. We add more functionalities as well as objects within the components held in the presentation layer.

Significant improvements are made in the second layer. First, we change the scope of the functionalities that the components control. In this version of the software, components in the second layer control all the logic events such as 'triggering event' and 'object interaction'. Therefore, we changed the name of the layer to 'Logical Events Layer' from 'Actions Layer'. Furthermore, we classified different logical events into three major categories: 'task specified events', 'shared events' and 'oculus events', respectively.

1. Task Specified Events

   The task specified events component provides methods to a specific task. For instance, when a procedure in a subtask is finished, and following procedures needs to be triggered, a pre-scripted method will keep listening to the scenario and call the task specified methods to proceed this triggering event. To maximize

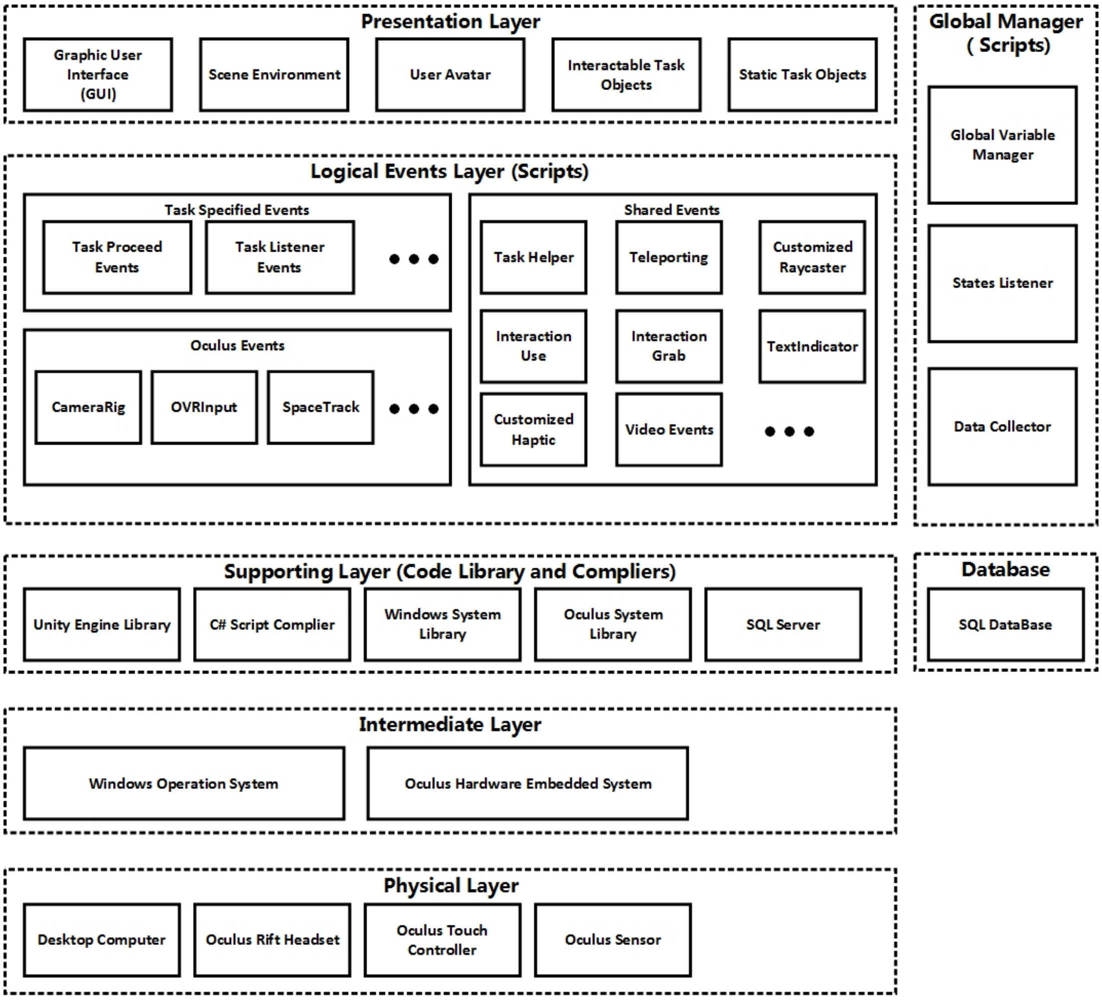


Figure 3.12: System Architecture of the Emergency Healthcare Training Software

the extensibility of the software, a task specified method only changes its local variables to proceed the events and keeps isolated from other methods. When and how to call the task specified methods is controlled by a component called 'Global Manager', which has global access permission to be introduced later in this thesis.

2. Shared Events

   The shared events component provides general methods that can be utilized among different tasks. For example, methods such as 'grabbing interaction' and 'touching interaction' are widely used in different tasks. We assembled those general methods into this component, and they can be called or instanced when required. The Global Manager layer also controls the shared events.

3. Oculus Events

   The hardware producer Oculus also provides framework and APIs that contains essential functionalities for their production. We use some pre-defined classess such as 'CameraRig' and 'OVRInput' in this software to provide interaction between the user and the VR hardware. Also, we use APIs provided by Oculus to collect high accuracy sensor data from the VR hardware.

Parallel to the 'presentation layer' and 'logical events layer', we add a layer called 'Global Manager'. The global manager has four major functionalities, which include controlling all task events, transmitting data and variables between tasks, recording the task status and performance data, and collecting sensor data. The components from the presentation and logical events layers do not directly communicate with each other, they rely on receiving instructions from the global manager. The purpose of designing this central controlling component is to keep the different layers independent and provides extensibility in future development. For instance, if any new tasks or components need to be added in the software, we can add the task-specific scripts in the 'logical events layer', and add calls to those new scripts in the global manager without modifying other existing code. This design pattern is widely used in industry products.

Beneath the 'logical events layer' is the 'supporting layer'. The components in this layer are similar to the prototype architecture, with the addition of two new components. The Oculus System Library is an assembly library provided by Oculus, which provides software that drives the Oculus Hardware. The MS-SQL Server is used to store the data collected from the participants.

The fifth layer is called 'intermediate layer'. Operation System and Embedded System components are addressed with this layer. In this research project, we used Windows 10 operating system and the hardware embedded system provided by Oculus.

The fundamental layer is called the 'physical layer'. No software is involved in this layer. We used this layer to address what physical hardware is used, and other products can replace that hardware in the future.

As mentioned before, the core design concept of this architecture is to keep each layer independent of others. Therefore, layers and components can be replaced or extended without much re-programming work. By applying this architecture, we can develop two emergency healthcare training scenarios within a very short period as planned.

Task representation

After designing the system architecture, we start to design the contents of each emergency healthcare training session for the software. We first map the EHW (evaluated in Section 3.2) into the content sequence.

Based on the EHW baseline task table, we identify 10 major tasks which contain 30 subtasks in total. Some tasks such as AED and CPR in the EHW require further emergency healthcare techniques and knowledge. Therefore, our training software does not implement those tasks. Lastly, we add an extra major task that contains a tutorial of essential interactions such as ‘teleporting’ and ‘grabbing objects’ in the VR environment. Table 3.3 indicates the mapping of major tasks.

Table 3.3: Mapping the EHW baseline tasks as major tasks in the VR software

MajID	Task Name	EHW Baseline Task ID (From Table 3.1)
Initial Assessment		
0	Tutorial of interactions	N/A
1	Define mechanism of injury and level of consciousness	T1-T3
2	Check apparent life threats	T4
3	Assess and maintain airway	T5
4	Body swipe	T9
5	Assess pulse and respiration	T10
6	Assess skin colour and body temperature	T11
7	Transportation decision	T12
8	SAMPLE history	T13
Secondary Assessment		
9	DCAP-BTLS	T14-T19

Incremental developing process

After define the contents of the training scenario, we started to develop the VR training software by using the incremental developing methodology as proposed in Figure 3.7.

In the first iteration, we built the main framework of the system architecture. There are milestones achieved in this iteration. First, all layers except the ‘database’ layer are built. Components which support VR interaction are built and tested in this iteration as the future developments rely on those interactions. Secondly, the static scene of the scenario is built, which contains all the static objects with model and textures. Finally, shared events such as ‘task helper’ are partially developed. The duration of the first iteration is 2 months, including all development phases.

In the second iteration, we implement all major tasks and subtasks. All the functional

Figure 3.13: Bird's-eye View of Scenario 1 Environment

components in the presentation and logical event layers are finished. We also designed the relational database to store the performance data and personal data. The duration of the second iteration is about 2 months, including all development phases.

We finished the major content of scenario 1 and started integration testing from the third iteration on. The researchers tested the entire scenario by themselves and re-designed procedures that may confuse participants with weak technical backgrounds. Existing bugs are fixed in this iteration as well. Figure 3.13 displays the environment of scenario 1 from a bird's-eye view. As shown, some landmarks such as the Sky Tower from Auckland have been built into the scene. We aim to take advantage of VR technology and provide an immersive experience to the participants. The duration of the third iteration is about 1 month, including all development phases except the requirement analysis and system design.

In the fourth iteration, we finalized scenario 1 and started to develop scenario 2. Due to the flexible architecture and reusable components, we are able to immigrate the tasks in scenario 1 to scenario 2 within an extremely short time. We spent only 2 weeks to

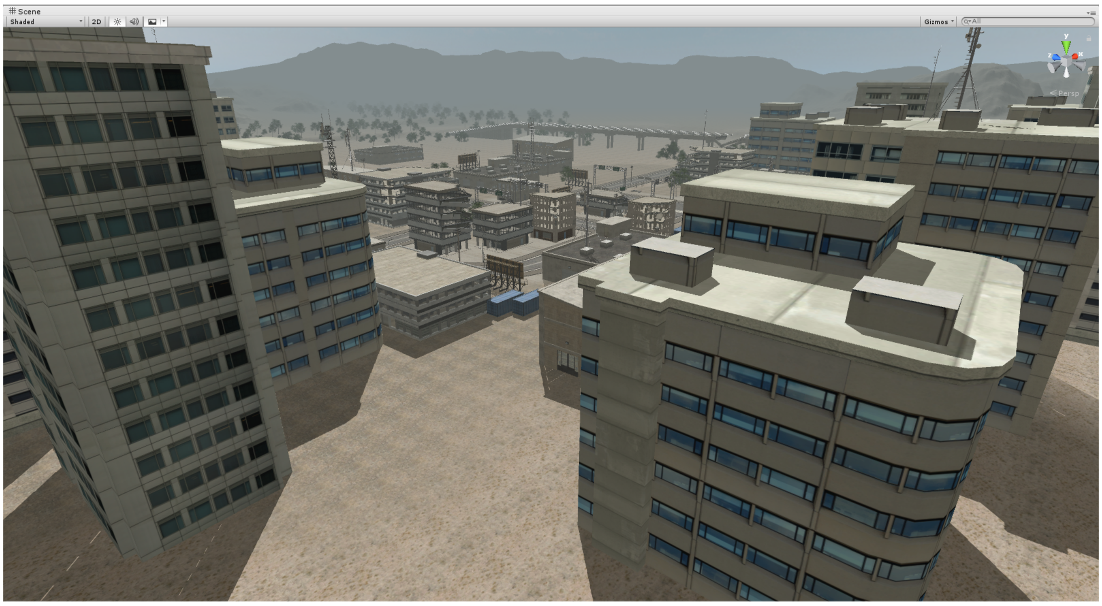


Figure 3.14: Bird's-eye View of Scenario 2 Environment

build the entire framework and major components for scenario 2. Figure 3.14 displays the environment of scenario 2 from a bird's-eye view. The whole duration of the fourth iteration is about 3 weeks, includes all development phases except requirement analysis and system Design.

In the final iteration, we finalized scenario 2. A few new tasks are added at the beginning of the scenario 2. After designing and implementing those new tasks, we started integration testing for scenario 2. Also the 'data loader' component is developed to write the required data into the SQL database. The duration of the final iteration is 3 weeks, including all development phases except requirement analysis.

Overall, we spent 6.5 months and iterated the project five times to finish the VR emergency healthcare training software, with 2 scenarios and 10 major tasks for each scenario. Figure 3.15 indicates the structure of the training software.

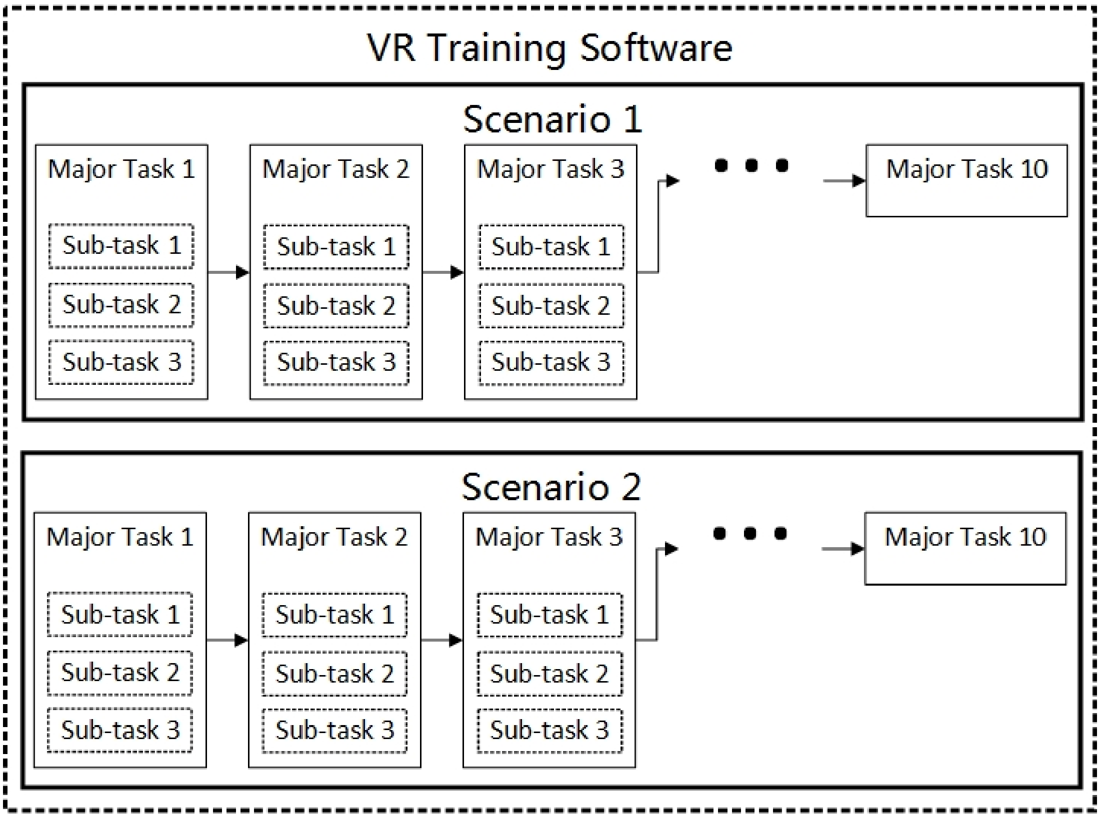


Figure 3.15: Structure of VR training software

3.4 Data Collections

In this research project, we aim to evaluate how VR technology would work in the emergency healthcare training field. To measure the efficiency of such training, we decided to conduct a virtual reality EHW training experiments with participants to gather and analyse data.

As mentioned in the literature, Aggarwal et al. (2006) used VR technology to train their participants. We notice that three of major data items they collected are 'timespan', 'distance' and 'personal Feature', respectively. In the research, they evaluated the training results based on the timespan for each session, the moving distance of the virtual scalpel and vital signs such as blood pressure. We collect similar data items to evaluate our research experiment.

We plan to collect two types of data during the experiment stage: Personal Data and Performance Data. The *Personal Data* is planned to be gathered before the virtual reality EHW training session starts, and the *Performance Data* is planned to be collected during the training session. The *Performance data* includes two major data formats, sensor data and media stream data. The sensor data includes various float numeric items which represent current states of the training session, such as the movement distance of the participant's virtual avatar in the virtual environment. Those data are updated in real-time during the training session and collected automatically by the VR software. The media stream data is collected by two cameras during the training session. The purposes of collecting media stream data is to assist us to analyse the participant's performing behaviours and record if any special actions were performed which could not be presented or reflected by the sensor data. The following subsections indicated the detailed data items we decided to collect. Table 3.4 indicates terminologies of the data item representations.

Table 3.4: Data Item Terminologies

Collection Status	Description
ER	End of the recruitment stage
T	During the training session
ET	End of the training session (Aggregated automatically by software)

3.4.1 Personal Data Items

Table 3.5 indicates all the data items of the Personal Data we are collecting. In general, we plan to collect data including name, age, technical background, educational background, prior-emergency healthcare knowledge, and prior-VR experience.

The age group definitions are given in Table 3.6. There are four total age groups are defined. Age Category Irepresents the young participants aged from 18 (minimal legible age approved by the ethics committee). The upper bound of age groups is 56, which we consider that the learning efficiency above this age cannot be assessed appropriately by our methodology.

Table 3.7 indicates the definitions of different technical background groups. In this assessing dimension, we distinguish the participants by their frequency of using smart devices as well as their understanding of information technology.

Table 3.8 indicates the definitions of different educational background groups. The NZQF introduced 10 levels of qualifications, and we extracted those qualifications into 5 different groups, making the analytical results more abstracted.

Table 3.9 indicates the classifications of prior-emergency healthcare training experience given to the participants. In assessing this dimension, we distinguish the participants by whether they have been trained by certified institutions (hold a first responder certificate or not).

Table 3.10 indicates the classifications of prior-virtual reality experience given to the participants. In assessing this dimension, we distinguish the participants by the

Table 3.5: Personal Data Items

Data Item	Collection Status	Description
Name	ER	The name of the participant. However, according to our information security and privacy policies defined, the name of the participants are used only for communication purposes and removed from experiment results.
Age Group	ER	The age groups of the participants categorized into 4 age groups (Age Category I to IV).
Technical background	ER	The technical background of the participants, such as familiarity of smart devices and computers. We categorized them into 4 groups (TechBKG I to IV)
Educational background	ER	The educational background of the participants, we grouped them by using the New Zealand Qualification Framework (NZQF).
Prior knowledge of emergency healthcare	ER	The participant's previous understanding or knowledge of emergency healthcare. We categorized them into 4 groups (HealthcareBKG I to IV).
Prior experience of virtual reality	ER	The previous experience of virtual reality technology, categorized into 4 groups (VRExp Category I to IV).

Table 3.6: Age Group Definitions

Group Name	Definition
Age Category I	Age between 18-29, including 29.
Age Category II	Age between 30-39, including 39.
Age Category III	Age between 40-55, including 55.
Age Category IV	Age above 56.

Table 3.7: Technical Background Group Definitions

Group Name	Definition
TechBKG I	Rarely use smart devices or a computer.
TechBKG II	Frequently use smart devices or a computer.
TechBKG III	Have an understanding of smart devices or a computer in different aspects. Know some relevant information technology knowledge (e.g. Programming, Software Engineering, ICT services, etc.).
TechBKG IV	Very familiar with information technologies, could be industry professionals or IT academic members, etc..

Table 3.8: Educational Background Group Definitions

Group Name	Definition
Education BKG I	All the rest.
Education BKG II	Finished Certificate Course or Programme. Or any recognized certification holder, or study in progress.
Education BKG III	Recognized Bachelor Degree or Undergraduate Diploma holder, or study in progress.
Education BKG IV	Recognized Master Degree or Postgraduate Diploma holder, or study in progress.
Education BKG V	Recognized PhD degree holder, or study in progress.

Table 3.9: Prior-Emergency Healthcare Training Experience Group Definitions

Group Name	Definition
HealthcareBKG I	No prior emergency healthcare training experience.
HealthcareBKG II	Finished relevant training course before, but not a certified first responder.
HealthcareBKG III	Used to be a certified first responder, but the certification is expired or not permitted any more.
HealthcareBKG IV	A certified responder with valid certification.

number of their previous VR experiences.

Table 3.10: Prior Virtual Reality Experience Group Definitions

Group Name	Definition
VRExp Category I	Never experienced any VR devices and applications.
VRExp Category II	Experienced less than ten times of VR devices and applications.
VRExp Category III	Experienced at least ten times of VR devices and applications.
VRExp Category IV	A VR hardware or VR application developer.

The personal data are acquired after the participants signed the Consent Form, which is the most critical step of the recruitment process. We will introduce the full path-flow of the recruitment process in the Section 3.5.

3.4.2 Performance Data Items

Table 3.11 indicates all the data items of the Performance Data to be collected.

The VR software automatically collects the sensor data, and each data record is written in string format in a text file. We also developed an application called 'data loader', which allows us to convert and import that data file into an MS-SQL server database for long-term management purposes. We export the media stream data from the cameras and saved them to an external hard-drive. Those media stream data are edited after all experiments are finished. The timeline of videos from three devices(2 cameras and a screen capture) are adjusted and synchronised, and finally, they are displayed in a multi-view screen as Figure 3.16 demonstrates.

3.5 Participant Recruitment

After designing the experiment and developing the VR software, we prepared to recruit participants who are interested about this research project. We first set up the recruited

Table 3.11: Performance Data Items

Data Item	Collection Status	Description
Sensor Data Items		
Total time cost	ET	The total time for a participant to finish the full training session.
Total tasks performed	ET	The total number of tasks performed by a participant in a full training session.
DisBodyTotal	ET	The total movement distance of the avatar in a full training session.
DisLControllerTotal	ET	The total movement distance of the left controller relative to the avatar body in a full training session.
DisRControllerTotal	ET	The total movement distance of the right controller relative to the avatar body in a full training session.
Major task ID	T	The major task ID, as defined before.
Subtask ID	T	The subtask ID, as defined before.
Task time cost	T	The time cost for a single subtask in a training session.
DisBody	T	The movement distance of the avatar in a single subtask.
DisLController	T	The movement distance of the left controller relative to the avatar body in a single subtask.
DisRController	T	The movement distance of the right controller relative to the avatar body in a single subtask.
Media Stream Data Items		
Video Stream from front-head camera	T	The minimum resolution of the video stream from the front-head camera should be 720P.
Audio stream from front-head camera	T	
Video stream from side-camera	T	The minimum resolution of the video stream from the front-top camera should 480P.
Audio stream from side-camera	T	
Video stream from Screen Record	T	The minimum resolution of the video stream from screen recording should be 480P.

Figure 3.16: The Multi-view Screen

principles that would apply to recruiting participants.

Based on the principles, we design a recruitment protocol for participants. The recruitment protocol includes four major sections; the criteria of the experiment invitation, the workflow of the entire recruitment process, the schedule for participant recruitment, and information security policies. The details of the recruitment protocols are given in Appendix A.8.

3.5.1 Criteria of Experiment Invitation

In this section, we define the criteria in which participants should be invited to the experiments. In general, we assume that each participant should be interested in this research project and be able to perform simple actions such as using a controller, grabbing objects, and body movement in the real world. Based on this rule, we extend the inclusion criteria as follows:

1. The ages of chosen participants should between 20 and 55 (include 20 and 55).

2. The chosen participants should be able to perform actions such as pressing buttons, grabbing objects, and independent body movement.

3. The chosen participants should be able to communicate with and speak fluent

English.

For the first inclusion criteria, a few considerations were taken while setting the upper and lower bounds for the age limitations of participants. The priority consideration was the adaptability of learning new things as defined physically, mentally, emotionally, or spiritually. For instance, a 70 year old male might have more extensive healthcare knowledge than a 30 year female. However, his physical adaptability to VR technology might be worse than average due to a result of natural aging.

The main concern of the second inclusion criteria is that action performances are required in some tasks in the experiments. To collect data with correct accuracy, the chosen participants should meet this criterion.

Speech recognition is one of the main interactions method widely used in the task design of this research project. Therefore, the chosen participants should also have enough abilities to interact using English.

3.6 Experiment Set-up

3.6.1 Experiment Devices

As mentioned before, in this research project we use Oculus VR hardware to provide an immersive training experience. There are three Oculus devices we used, which include the Oculus Rift Virtual Reality Headset, Oculus Sensors, and Oculus touch controller. Those Oculus devices are used to collaborate with the VR software and to collect task performance data from participants during the experiment. Additionally, we use two cameras to capture motion videos from participants for analysis purposes. A test video can be viewed on the Youtube[2] website.

[2] The link of this video is https://www.youtube.com/watch?v=6h0i3ytygUo

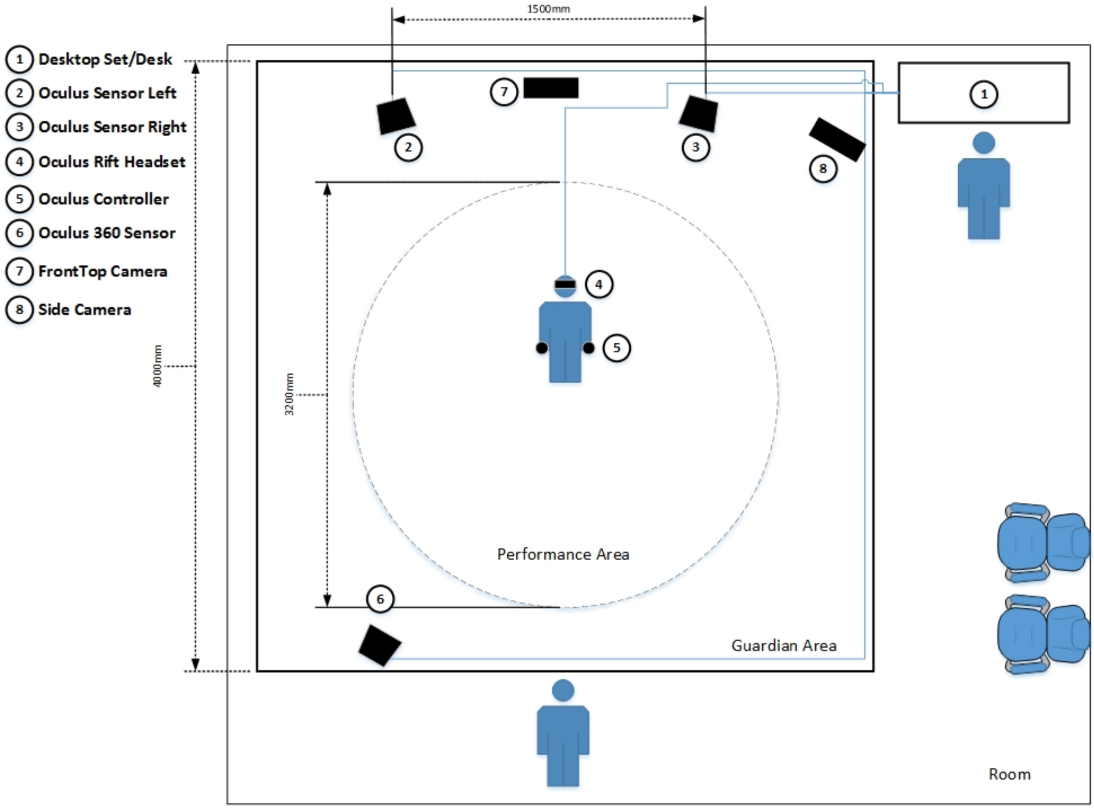


Figure 3.17: Experiment Environment Set up

To run the essential applications such as the VR software, data collector, MS-SQL-Server etc., we use a high configuration desktop. This desktop matches the recommended specifications from both Oculus and Unity Engine.

All the device descriptions and example pictures are shown in Appendix A.9.

3.6.2 Experiment Environment Set Up

Hardware Setup

We conduct the experiments in the Centre of Artificial Intelligence Research (CAIR), WT411 of AUT city campus. To achieve the best configuration required by VR sets, the minimal size of the room must be larger or equal to 40 square meters. Figure 3.17 indicates the experiment environment and equipment more precisely.

Participants, also known as trainees in this research, will be asked to wear the Oculus Rift headset and hold Oculus controller while performing emergency healthcare procedures instructed our VR software. The Oculus Rift headset and Oculus controller is indicated as number 4 and 5, respectfully, in Figure 3.17.

The participant needs to perform his/her procedures within a circled area range, 3200mm diameter approximately. A larger space called the Watching Area overlaps with this Performance Area, and there are no physical obstructions in those areas. If the participant's body moves out of the Performance Area or recording sensors start to lose track consistently, research staff will remind him/her by voice first, and then by walking into Watching Area or Performance Area to help the participant to correct his/her position as needed.

Three Oculus motion capture sensors are at the front-left, front-right and back-left positions respectively, which is indicated by numbers 2, 3 and 6 in Figure 3.17. Those sensors will keep tracking constellations of IR LEDs from the headset and controllers and translate participant's movement and actions in the virtual environment. The minimum distance between the two front-side sensors is 1500mm, and the minimum distance between the front-left sensor and the back-left sensor is 3500mm.

Two cameras will be set at the front-central and either front-right or front-left positions. Both of the camera videos are used to record participant's performance in real world and considered as a backup device to adjust and correct the timeline of the performance. The height of front-central digital camera will be set at approximately 1600mm to record the whole Watching Area. The height of side camera will be set at 1600mm-1700mm.

There is a desk for the desktop which will be running the VR software. The position of the desk is located at a corner of the room, which is indicated as number 1 in Figure 3.17. Chairs are also set in the room to let the participants to have rest after they finished or interrupted their experiment. During the experiment, we added an extra desk at the

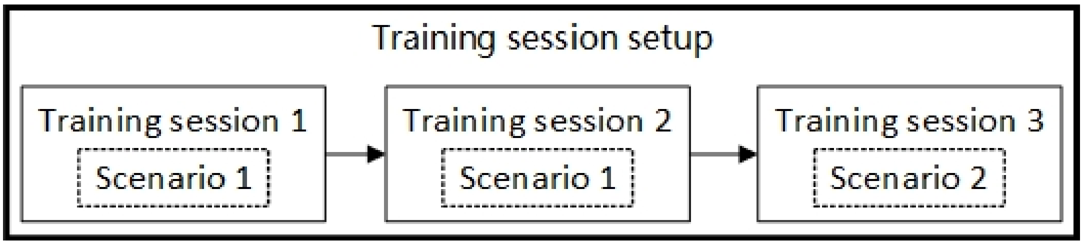


Figure 3.18: Training session set-up

observation area to acquire a better view, which is not displayed in the setup figure.

Training Sessions Set-Up

Figure 3.18 indicates how we set-up the training sessions. As the figure shows, every participant will be asked to finish three VR training sessions individually by using the software we developed with Oculus VR devices. As mentioned before, there are two scenarios that need to be finished. Each participant will finish the first scenario once and have 5-10 minutes break as a safety consideration, and then repeat the first scenario. The training session for the second scenario will be conducted a few days after the initial scenario session are finished.

We have different observation targets for those training sessions. As described in Section 3.3.3, the first scenario was designed to help participants adapt to the VR training software and learn the major procedures of EHW. Meanwhile, the second scenario was designed to activate their long-term memory and test whether they would recall the knowledge learned from previous training sessions.

The total estimated time for the first scenario training sessions is approximately 45-50 minutes. More specifically, we estimated that the participants might spend around 25 minutes on the first trial, 5-10 minutes on the break and 15 minutes on the second trial. Also, the total estimated time for the second scenario training session is approximately 20 minutes. Those estimations are based on our observation during the integration testing phase of software development.

3.7 Conclusion

In this chapter, we indicated the methods we used to conduct the research project. First, we introduced the emergency healthcare workflow (EHW) which is evaluated from the references. Secondly, we demonstrated how the EHW can be converted to a process diagram. Thirdly, based on the process diagram, we developed the prototype software and the emergency healthcare training software using Unity Engine. Fourthly, we indicated the what data items we plan to collect for analysis. Finally, we introduced the set up for our VR training experiment. .

Chapter 4

Results

4.1 Introduction

10 participants were invited to participate our research. The total duration of the experiments was 1 month as scheduled. The average duration of each participant for the first scenario is 1 hour. The average duration of each participant for the second scenario is 25 minutes. The average duration for both scenarios is slightly different than our initial estimation mentioned in Section 3.6.2. There are a few reasons to cause those differences, and they will be discussed in the following sections.

We analyse the experiment results in both individual and grouped sections. In the individual analysis, we list the analytical result of 5 participants as their performance data contains the most typical cases (e.g. the longest and shortest timespan). In the cross-section analysis, we evaluate the timespan and sensor data among different personal data items.

0	3	25.02737	35.14577	150.0869	2/1/2018 2:11:35 PM	2/1/2018 2:12:05 PM	00:00:29.8343661	6.759705	8.614807	20.97267
1	1	37.17795	55.36142	153.4969	2/1/2018 2:12:05 PM	2/1/2018 2:13:11 PM	00:01:05.9784306	12.15057	20.21565	3.409958
1	2	45.88651	65.08263	156.6387	2/1/2018 2:13:11 PM	2/1/2018 2:13:45 PM	00:00:33.5583418	8.708557	9.721207	3.141785
1	3	47.79631	67.28036	156.6387	2/1/2018 2:13:45 PM	2/1/2018 2:13:59 PM	00:00:14.3975853	1.909805	2.197739	0
1	4	49.26871	68.7664	156.6387	2/1/2018 2:13:59 PM	2/1/2018 2:14:14 PM	00:00:15.0770414	1.472397	1.486038	0
1	5	53.5248	73.76152	156.6387	2/1/2018 2:14:14 PM	2/1/2018 2:14:38 PM	00:00:23.4776344	4.256088	4.995117	0
2	1	89.96184	129.1774	165.9766	2/1/2018 2:14:38 PM	2/1/2018 2:16:46 PM	00:02:08.0432584	36.43704	55.41588	9.337936

Figure 4.1: Raw Data Example

4.2 Individual Analysis

We first analyse the individual results based on the data we collected in the experiments. The analysis results are presented in two parts: Quantified Result and On-experiment Observation. The quantified result is based on the Oculus sensor data. As proposed, those data contains state information of every single task and controller movement states. We give the quantified result in the following aspects:

- Timespans for whole training sessions and individual tasks
- Moving distances of controllers and the avatar

Figure 4.1 shows an example of raw data which was collected by the VR software, including the data items mentioned in Table 3.11. The data items in this figure include the task state data, the duration data and the moving distance data.

The on-experiment observation includes the notable phenomenon we observed in the experiments. Together with the quantified result, the on-experiment observation provides different perspectives of analysing the experiment results and contributes to the final research output.

We shows 5 individual cases in following sections. Those cases covers typical data collections such as the longest and the shortest timespan. To protect participants' privacy, we address them by using an alphabet code starting from A.

Participant A

Participant A is a male who within Age Category I, and he is a non-native English speaker. He has a strong technical background (TechBKG IV), and his education

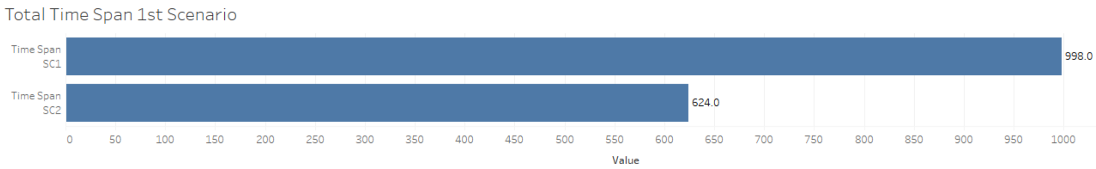


Figure 4.2: Participant A - Total Timespan for 1st Scenario (in Seconds)

background was defined at the top class (Education BKG V). He has a strong understanding of software development such as programming techniques, design patterns and algorithms. He has no prior-experience about emergency healthcare training (HealthcareBKG I) and only a few experiences of VR technology (VRExp Category II).

Quantified Result

Participant A has a significant improvement in overall timespan during the trainings of the first scenario. As indicated in Figure 4.2, he spent 998 seconds (approximately 16.6 minutes) on the first trial and 624 seconds (approximately 10 minutes) on the second trial of the same scenario. This is a 37.5% improvement and may indicate the improved skill after training.

We then look at the timespan of major tasks shown in Figure 4.3. In most of the major tasks, Participant A spent less time in the 2nd trial than the 1st one. The reasons for those exceptions will be discussed in the on-experiment observation part. Within a major task, there are several subtasks. The detailed timespan for each subtask is shown in Figure 4.4.

There are also differences in the controllers and avatar moving distances. We note that some differences are due to the user preferences. Figure 4.5 indicates the moving distances of both controllers for the first and the second training sessions. It can be seen that Participant A's right controller moved 10.9% more than the left controller in the 1st session and 17.3% more in the second session. As the controller movement indicates the hand movement, we can conclude that Participant A prefers to use the right

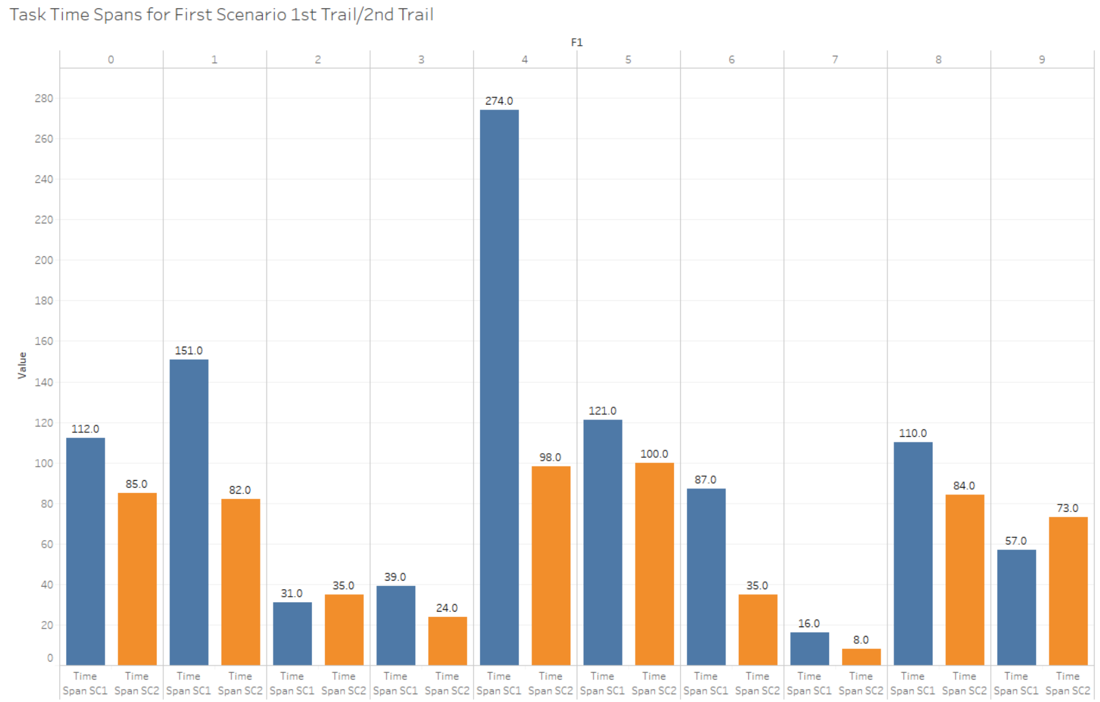


Figure 4.3: Participant A - Timespan for Major Tasks (Blue: 1st trial, Orange: 2nd trial)

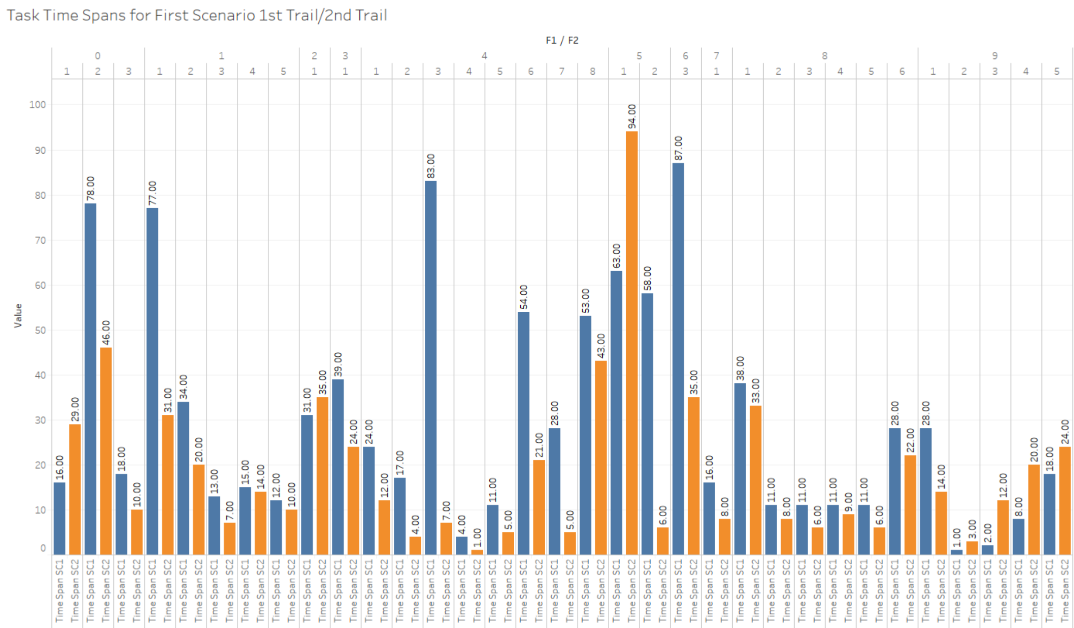


Figure 4.4: Participant A - Timespan for Subtasks (Blue: 1st trial, Orange: 2nd trial)

hand more than the left hand. Through practice, the preference for the right hand gets more notable. Another phenomenon to note is that, although the difference between the left and right controller's movement was increased between the sessions, the total movement for both controllers is decreased.

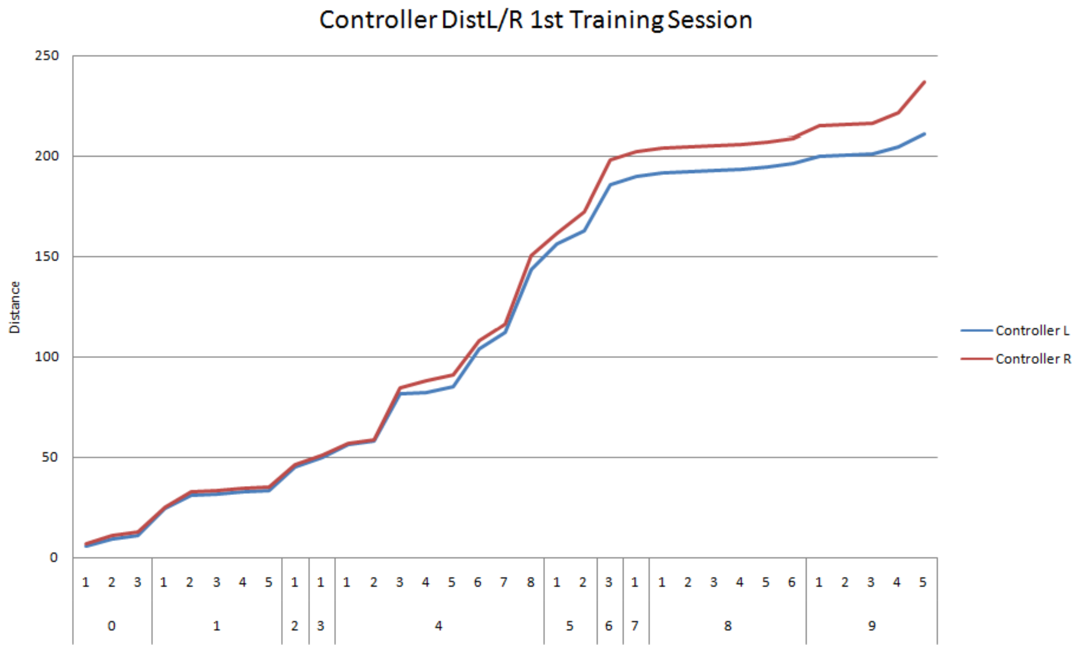
Figure 4.6 shows a significant difference of the avatar's moving distance between two sessions. In the second session, Participant A moved his avatar for a quite longer distance than in the first training session. The reason will be discussed in the on-experiment observation section.

On-experiment Observation

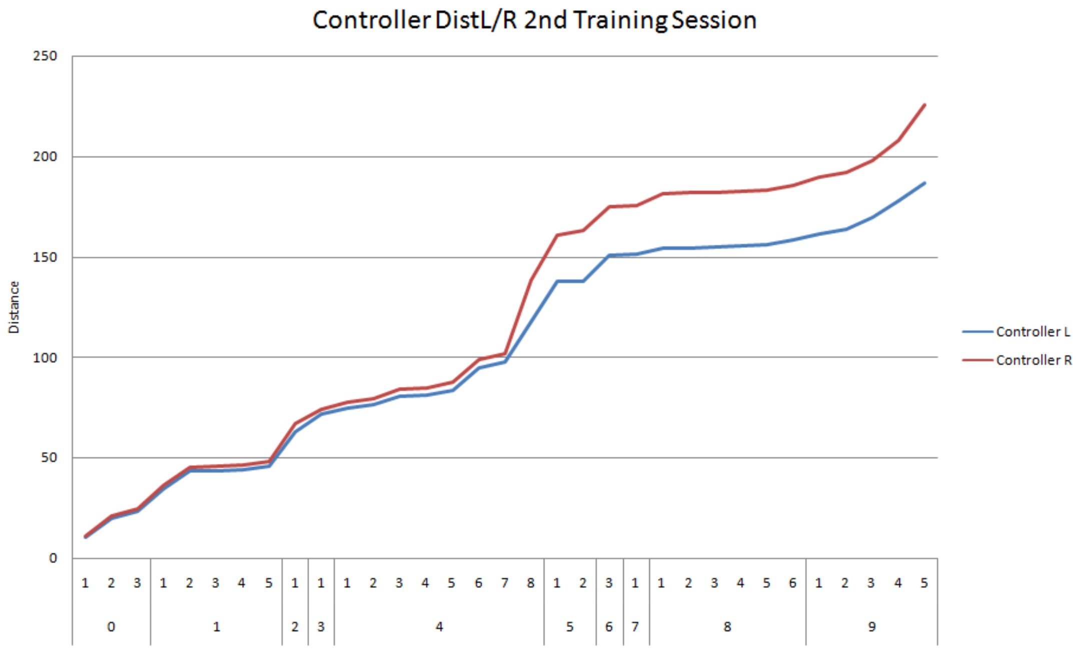
The on-experiment observation of Participant A shows that he adapted to the VR environment in a short time and he tried to explore the VR environment during different sessions. In the first training session, he struggled with subtasks 0-2, which is performing a 'teleporting' action. Therefore, both Figure 4.3 and Figure 4.4 show that he spent more time than expected. A similar problem happened in subtask 1-1, which is performing another 'teleporting' action. Participant A prefers to use the right hand to perform the task, and this behaviour is more exaggerated in training session 2. According to the observation, participant A felt more confident about his 'VR performance' skills in the second session. Therefore, he tried to finish tasks within a shorter timespan.

Another interesting phenomenon observed in his experiment is that he tried to explore the virtual world beyond the tasks given to him. Figure 4.6 provides some evidence to support this observation. In his second training session, he tried to move his avatar to different places of the virtual environment and also tried to interact with game objects in various ways. Figure 4.6 shows that due to his exploration in the virtual environment, the avatar movement distance in the second training session is significantly longer than the distance in the first training session.

Participant A also tried to memorize the full EHW during the experiment. According



(a) Moving distance of L/R controllers for first training session



(b) Moving distance of L/R controllers for secondt training session

Figure 4.5: Participant A - Moving Distance of Controllers

to the observation on each training session and a short interview afterwards, he agreed with that after the first training session he partially memorized the EHW, but he needed

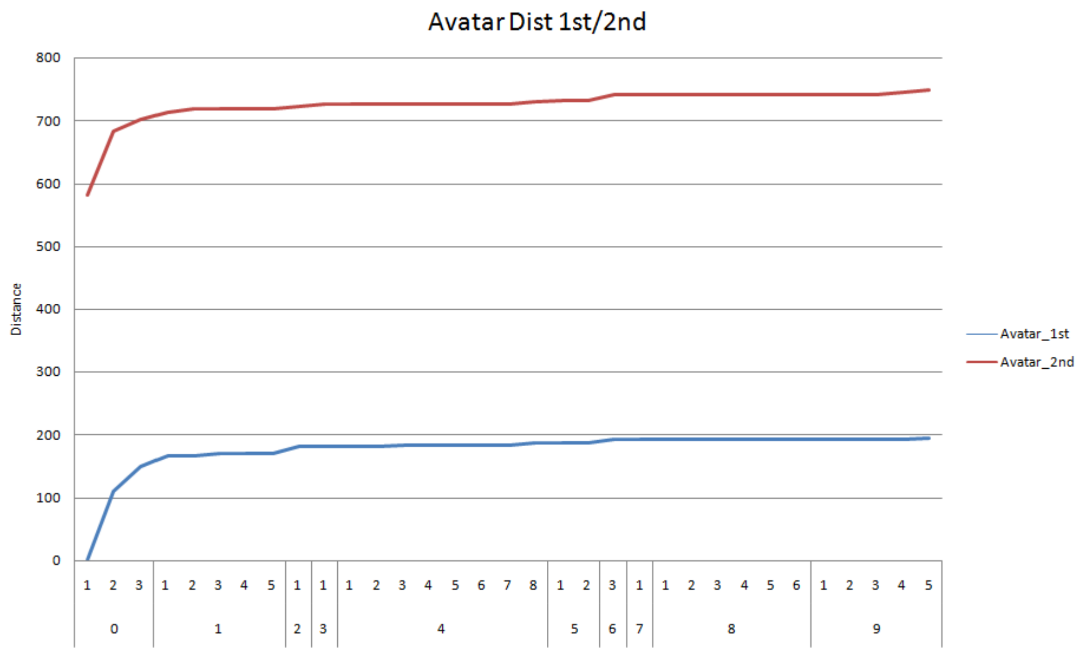


Figure 4.6: Participant A - Total distance of avatar movement

more repeated sessions to remember the full EHW.

Participant B

Participant B is a female and a non-native speaker (Age Category I). She only used smartphone and computer frequently, and she has no further understanding of technical devices beyond that (TechBKG III). She is studying a bachelor degree of foreign language at university (Education BKG III). She has no prior-experiences about healthcare training and VR technology (HealthcareBKG I and VRExp Category I).

Quantified Result

Participant B has a significant timespan improvement during the trainings of the first scenario as shown in Figure 4.7. She spent 1768 seconds (approximately 30 minutes) on the first session and 659 seconds (approximately 11 minutes) on the second session making the improving rate 63%.

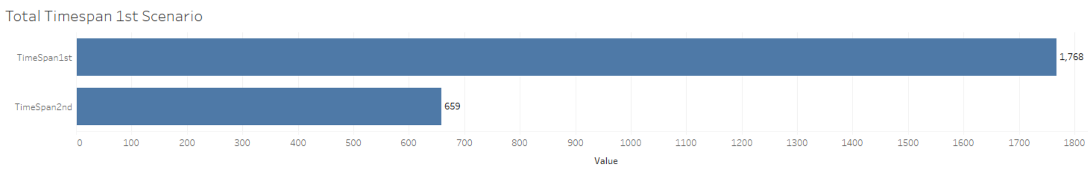


Figure 4.7: Participant B - Total Timespan for 1st Scenario (in Seconds)

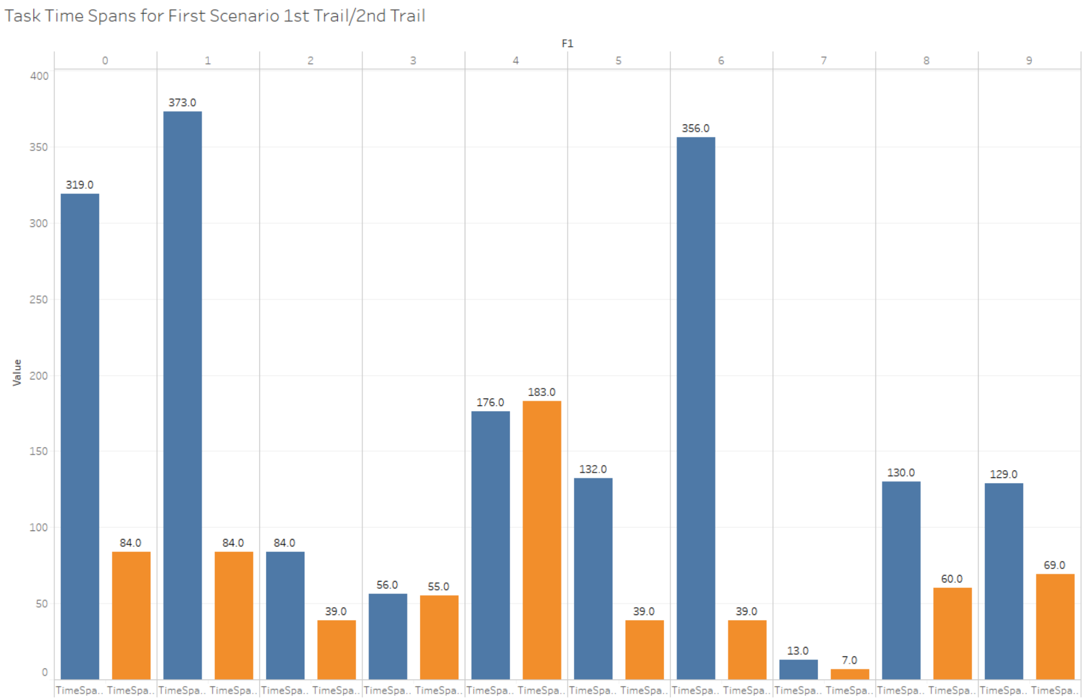


Figure 4.8: Participant B - Timespan for Major Tasks (Blue: 1st trial, Orange: 2nd trial)

Figures 4.8 and 4.9 show that she spent most time on the non-speech interaction tasks (major task 0,1,6). Insufficient technical background made her struggle with those tasks in the first trial. After she getting familiar with the scenario, her performance became fluent, and timespan for each task are reduced as well.

Figure 4.10 shows the controller movement distance results from the first and the second training session. Participant B's controller movements are at average level, which is below 300 moving units. The right controller moved 10.4% more distance than the left controller in the first session and this gap is reduced to 7.1% in the second session. Significant distance reducing in the second training session, especially in major task 2, 4, 8 and 9, can be observed. Based on the above observation, we conclude that

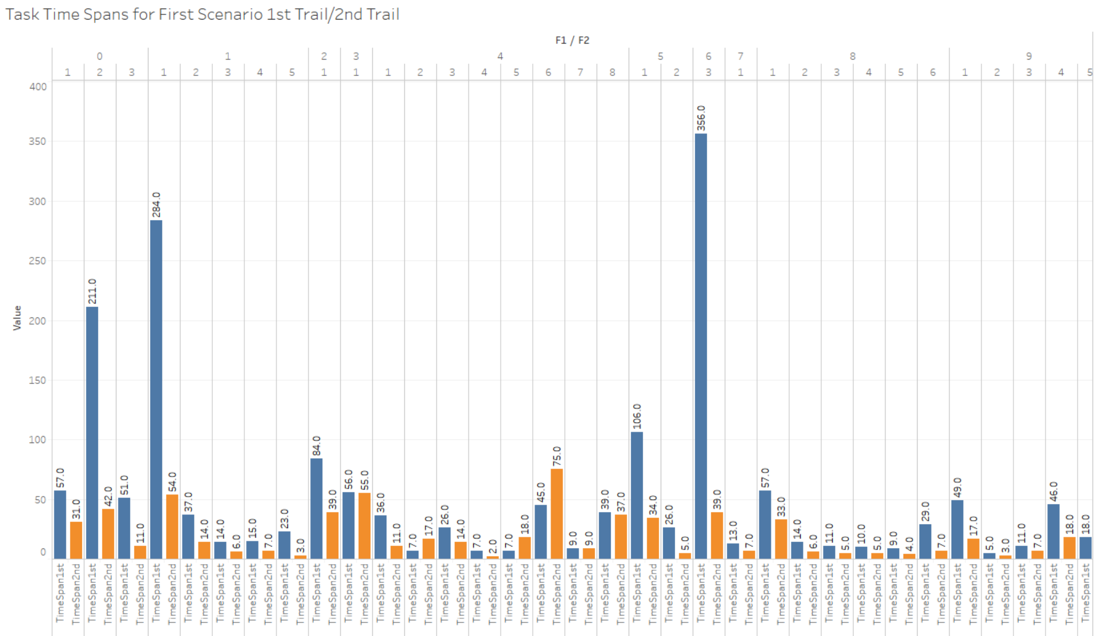


Figure 4.9: Participant B - Timespan for Subtask s (Blue: 1st trial, Orange: 2nd trial)

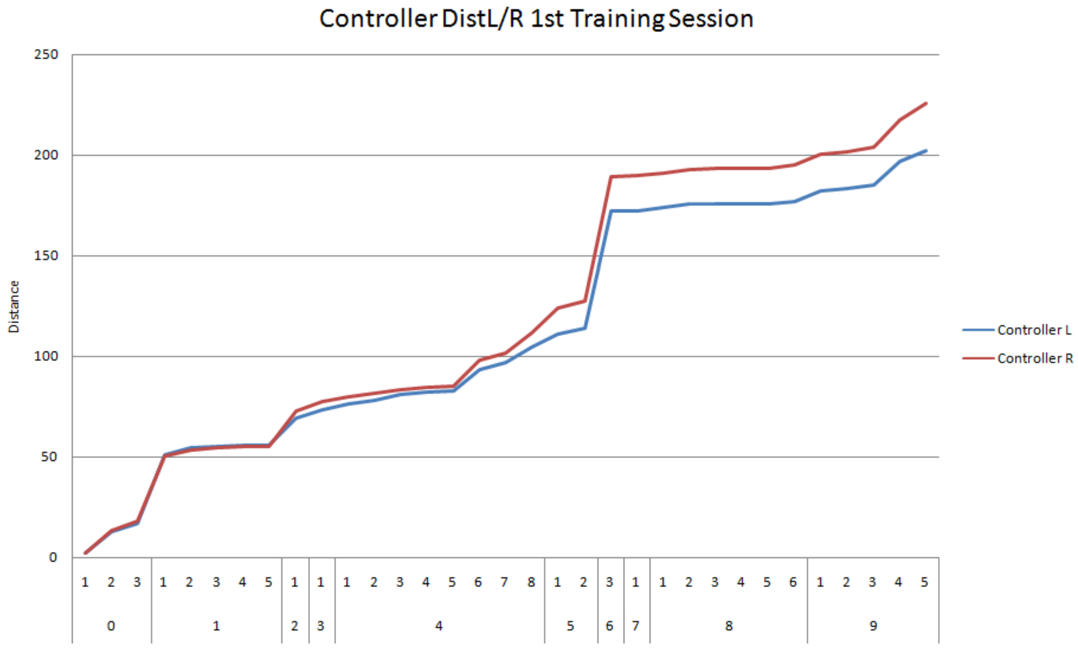
the Participant B prefers to use her right hand more than the left hand.

The avatar movement distances of Participant B is in our expectation. As Figure 4.11 shows, the avatar moving distances are increasing stably in both sessions. The total moving distances in the second session is reduced 65% than the first session, which shows a significant improvement.

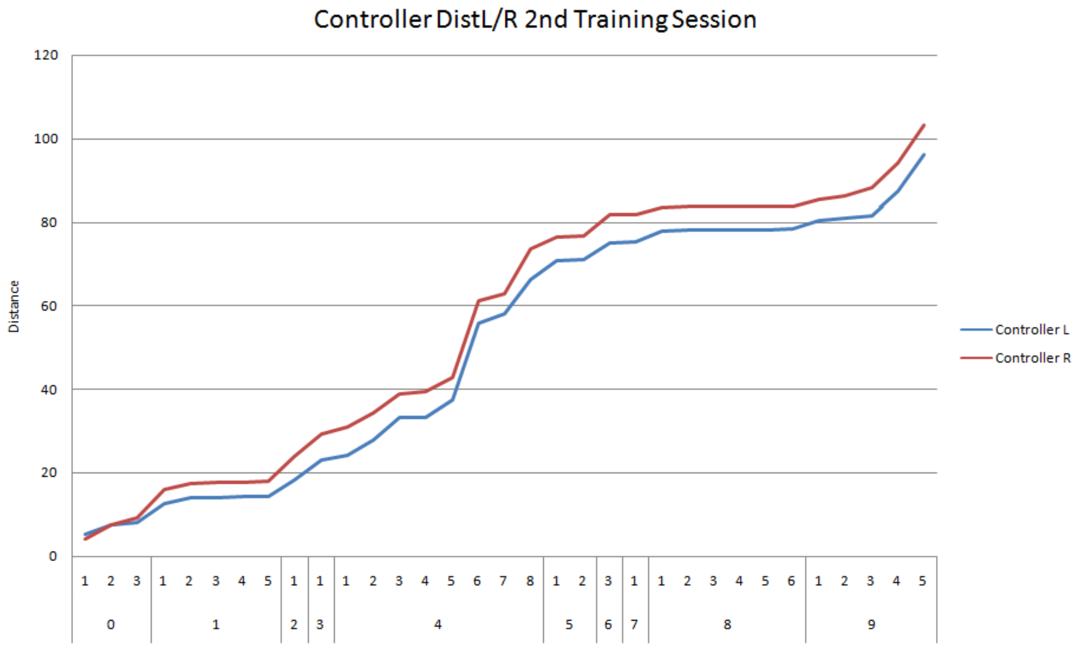
On-experiment Observation

The on-experiment observation shows that her performing preference is different from other participants who have a strong technical background. She struggled in subtask 0-1. This subtask requires the participant to activate the taskhelper.

She also called for assistances during the training sessions; the first assistance was requested in subtask 1-1. In the later subtasks which request teleportation to the target position and to perform a specific action, she has shown her preference of walking rather than using the controller to perform teleportation. When some subtasks require a speech interaction, she tried to say a simpler phrase. For instance, in the pulse assessment task,



(a) Moving distance of L/R controllers for first training session



(b) Moving distance of L/R controllers for secondt training session

Figure 4.10: Participant B - Moving Distance of Controllers

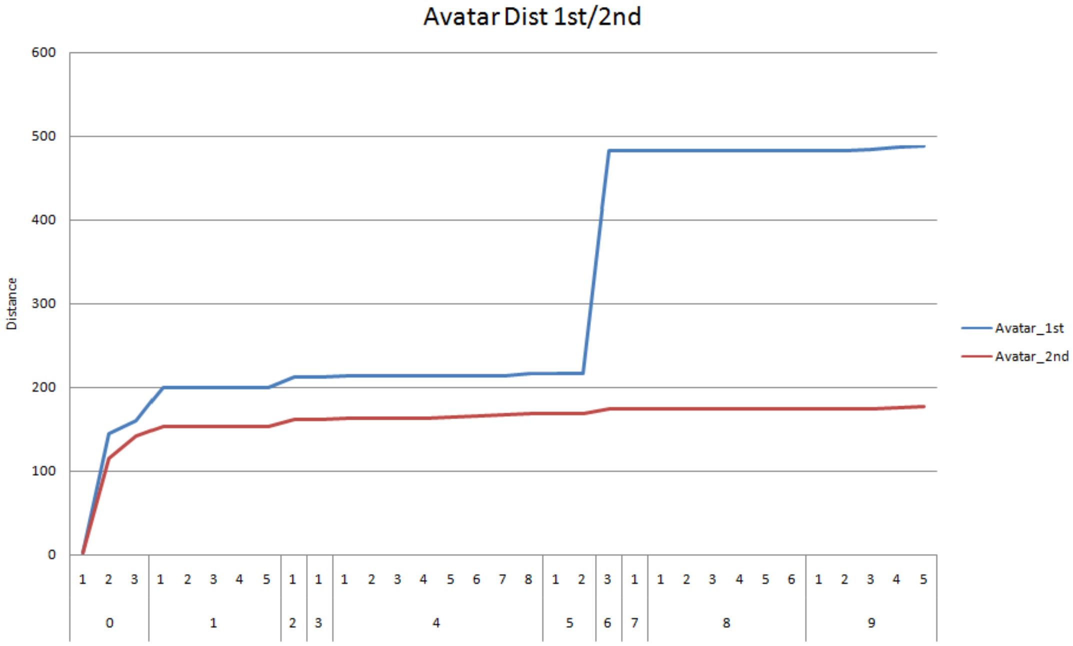


Figure 4.11: Participant B - Total distance of avatar movement

she tried to say "pulse is normal" instead of the full phrase "patient's pulse is strong and normal". Due to the limitation of the speech recognition model, such simplified phrases may not be recognized in the first instance. Thus, the timespan of her first training session was longer than expected.

Also, as observed in the experiment and later confirmed with Participant B, she has trouble with cognitive distance. The researchers found that sometimes she was not able to recognize the distance between her avatar and the virtual objects. For instance, she always missed the position to capture a virtual thermometer. This explained that in Figure 4.11, the avatar moving distance is increasing rapidly in major task 6. In this task, she tried to relocate her position many times to catch the thermometer. The situation was slightly changed in the second session as she adapted better than the first session.

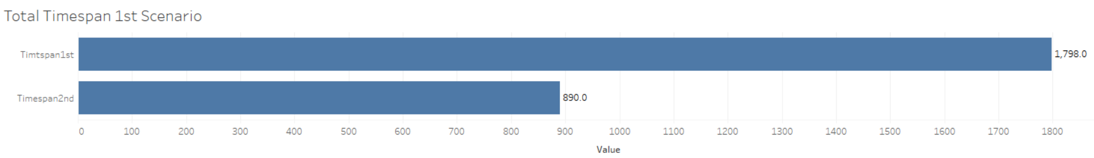


Figure 4.12: Participant C - Total Timespan for 1st Scenario (in Seconds)

Participant C

Participant C is an Age Category IIfemale and an ESI speaker. She is a New Zealand registered nurse and originally from overseas but lived in New Zealand for more than 10 years. She uses smartphone and a computer in daily life (TechBKG II). She just finished her postgraduate study in Auckland University of Technology (Education BKG IV). She is also a member of an emergency response team (HealthcareBKG IV) and participated rescuing people in the Christchurch earthquake 2012. She expressed high interests in applying VR technology to the emergency healthcare field as she never experienced such technology before (VRExp Category I).

Quantified Result

Improvement can be noticed according to her performance. In the first training session, she spent 1798 seconds to finish all the tasks. In the second session, she spent 890 seconds, which is 50% less than the first training session.

As Figure 4.13 shows, in the first training session, participant C spent most times on major task 0, 1, 2, 4 and 6, which covered both speech interaction tasks and non-speech interaction tasks. At the beginning, she had difficulty adapting to the VR environment due to unfamiliarity with the technology. The situation improves in the second session indicating partial adaption to the VR environment.

As shown Figure 4.15, Participant C's right controller moved 16.5% more distance than the left controller in the first session and 14.4% more in the second session. We conclude that Participant C prefers to use her right hand more than left hand. This figure

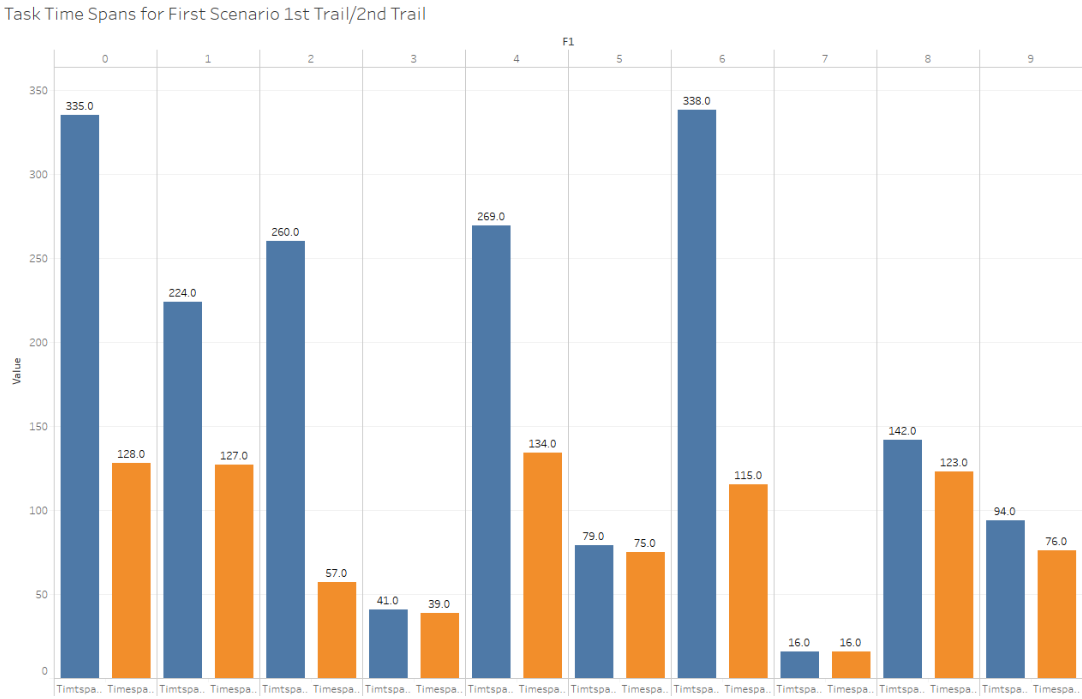


Figure 4.13: Participant C - Timespan for Major Tasks (Blue: 1st trial, Orange: 2nd trial)

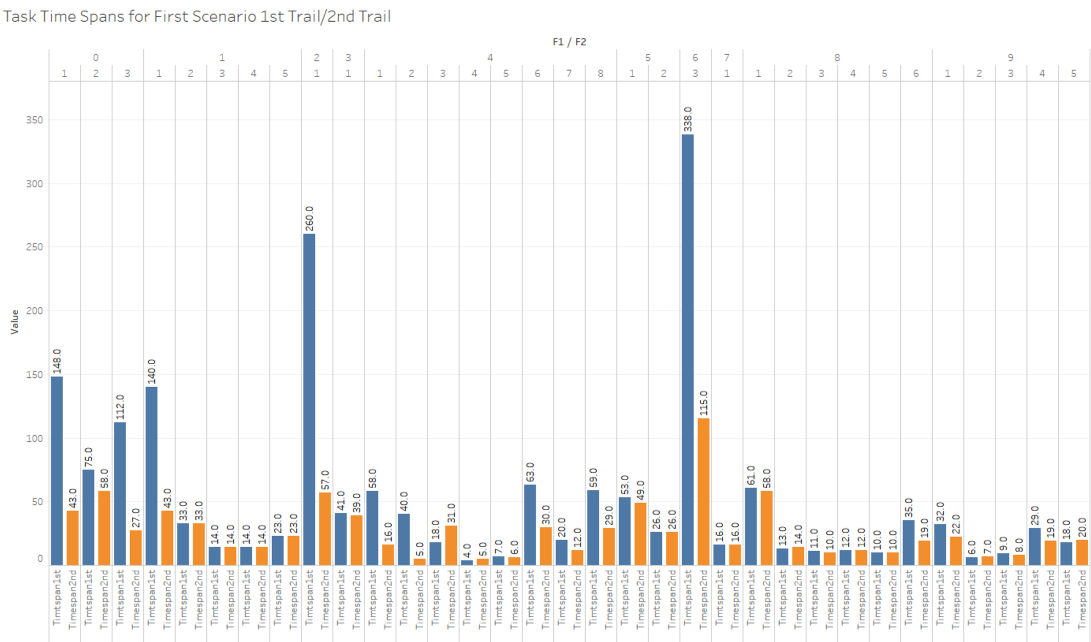
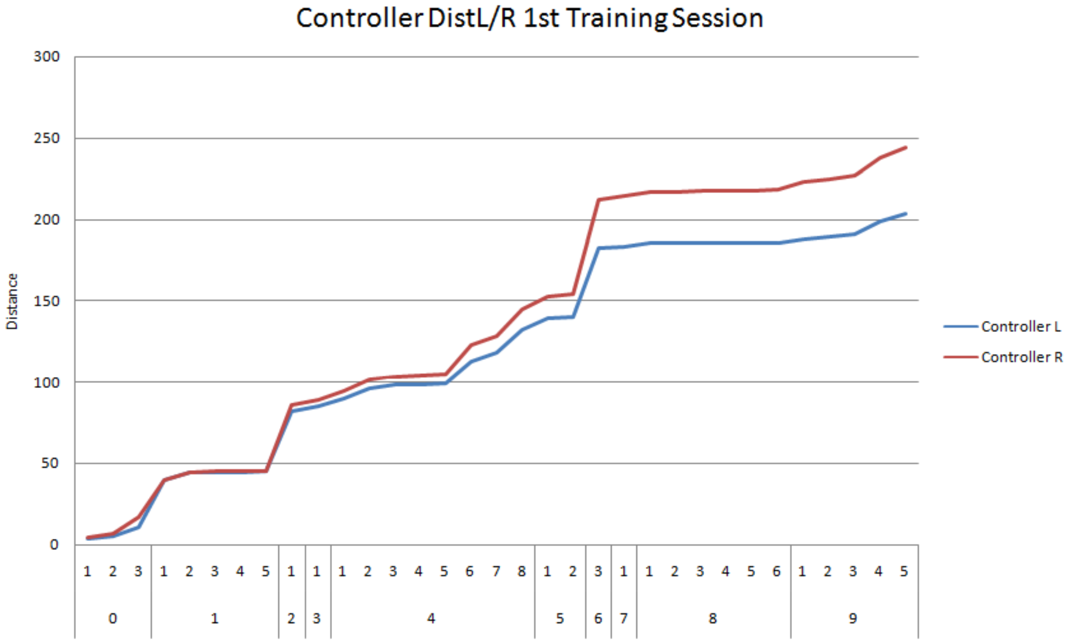
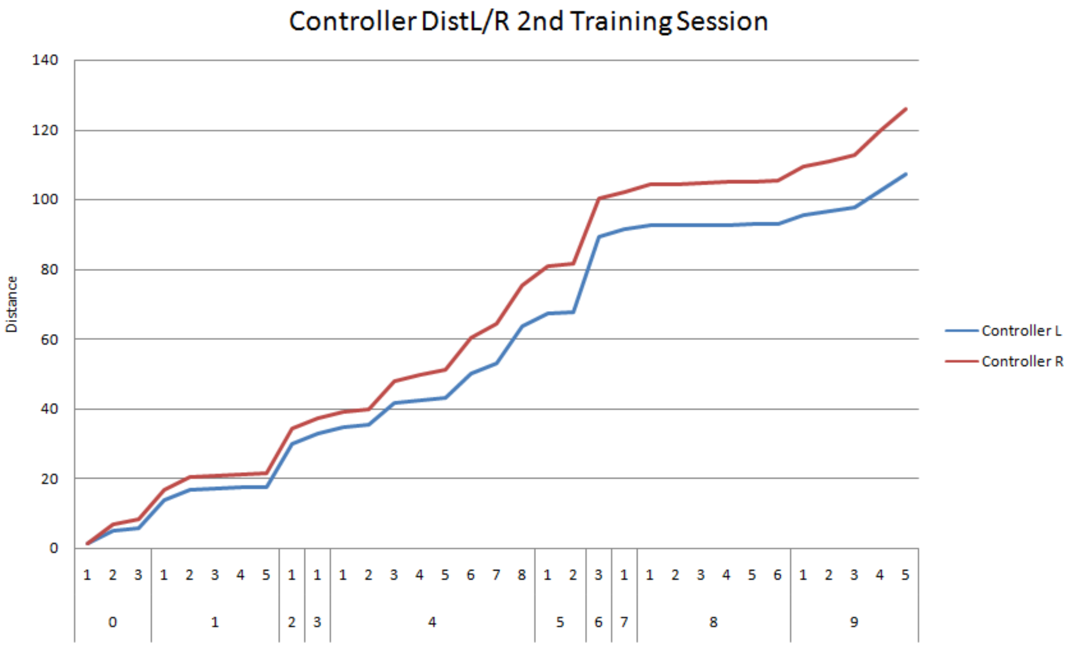


Figure 4.14: Participant C - Timespan for Subtasks (Blue: 1st trial, Orange: 2nd trial)



(a) Moving distance of L/R controllers for first training session



(b) Moving distance of L/R controllers for secondt training session

Figure 4.15: Participant C - Moving Distance of Controllers

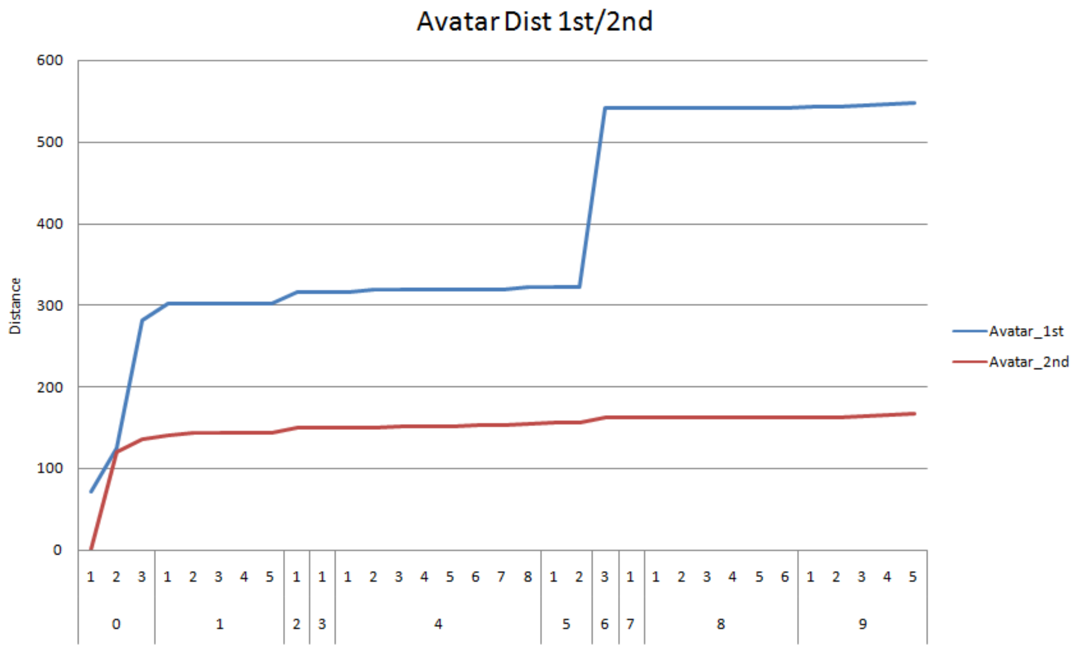


Figure 4.16: Participant C - Total distance of avatar movement

also indicates a significant distances reduction between the first session and the second session. A handed preference can be observed according to her performance as well.

Participant C's avatar moving distance shows a very similar trends as Participant B. An increasing trend in the first training session is observed between major task 5 and 6. Besides this, Participant C also moved quite a far distance between subtask 0-2 and 0-3. This shows that participant C was not good at adapting to VR technology at this stage. In the second session, as she got more adapted in the VR environment, the moving distance of her avatar was more stable than before.

On-Experiment Observation

Participant C spent 30 minutes on the first session. During the session, she almost needed assistances in every major task. The assistances include help teleporting to a target position, correcting the position to a sensor trackable place, performing grabbing and touching object tasks etc. She can finally independently perform teleporting from task 5. She did not struggled with any vocal interaction tasks.

As a New Zealand registered nurse and a certified first responder, she knows all the major steps of the training session, and only struggled with the VR technology itself. For instance, when she performed tasks such as ‘Body Swiping’, she naturally used both hands in the very beginning. Additionally, she can call out the names of the small balls which represent each part of the patient’s body.

She spent approximately 15 minutes on the second training session. After adapting to the VR software, her performance got closer to other participants. Although sometimes she might need help with correcting her position to a sensor trackable place, the request of assistance became rare.

In addition, as English is not her first language, she preferred to get instructions via mixing of reading the contents from the task helper and listening to the vocal instructions. The priority was listening as she had already lived in New Zealand for long time.

Participant C also gives feedback and advice to this research project based on her professional background. That feedback and advice will be mentioned in Chapter 5 of this thesis.

Participant D

Participant D is an Age Category Ifemale and English native speaker. Originally from Australia and currently studying a bachelor of ICT relevant majors in New Zealand (TechBKG III and Education BKG IV). She has no prior-experiences about emergency healthcare training and VR technology (HealthcareBKG I and VRExp Category I).

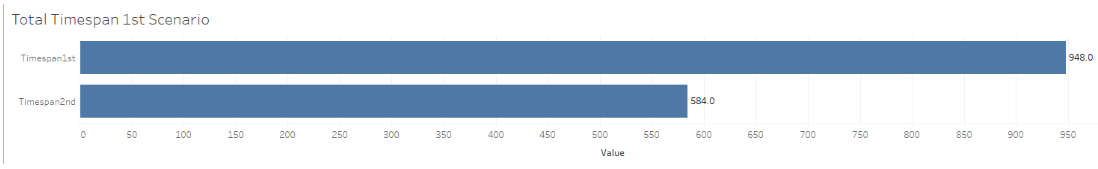


Figure 4.17: Participant D - Total Timespan for 1st Scenario (in Seconds)

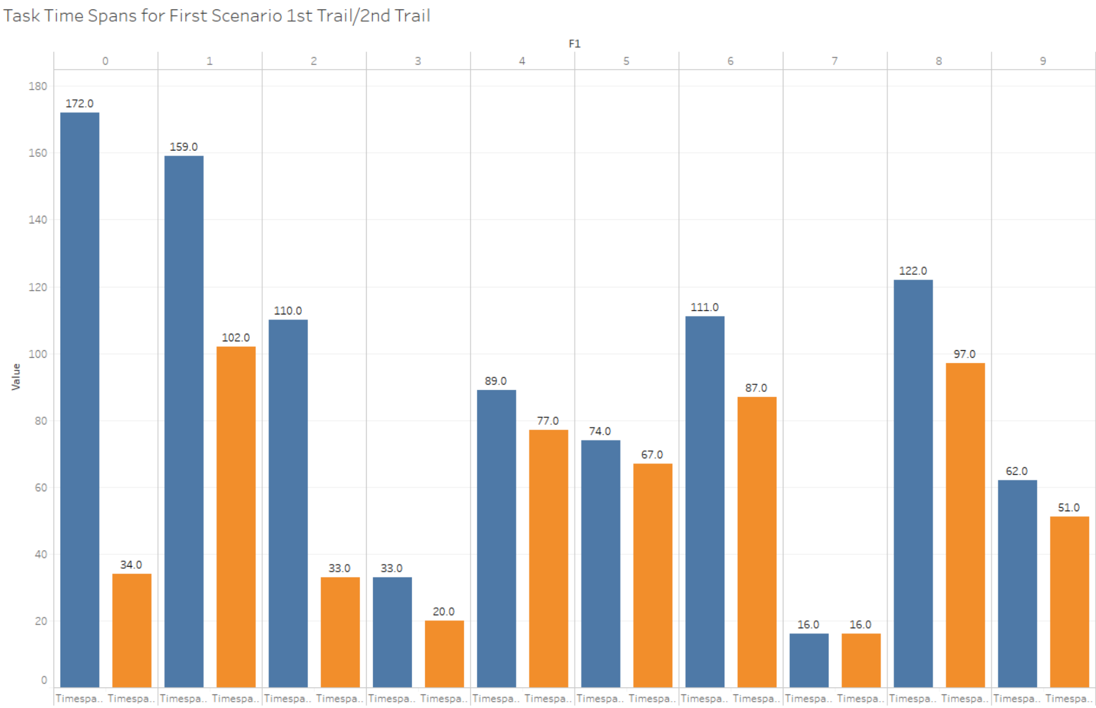


Figure 4.18: Participant D - Timespan for Major Tasks (Blue: 1st trial, Orange: 2nd trial)

Quantified Result

Participant D shows a 39% time reduction between the first training and second training session. She spent 948 seconds on the first training session and 584 seconds on the second training session, which are close to the estimated minimal timespan as designed (the estimated minimal timespan (EMT) means the timespan of finish all tasks without skipping any vocal instructions; this value is between 9 and 10 minutes as designed). It shows that with repeated training, Participant D has better understanding of the EHW as well as the software mechanism.

According to Figure 4.18 and Figure 4.19, it also shows that after spending time

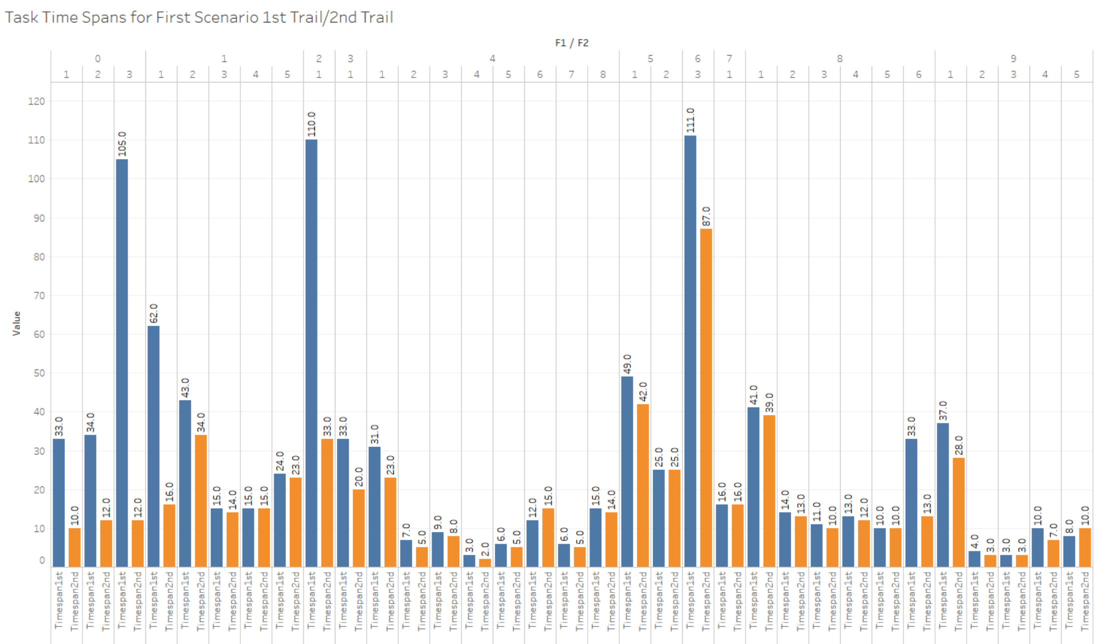
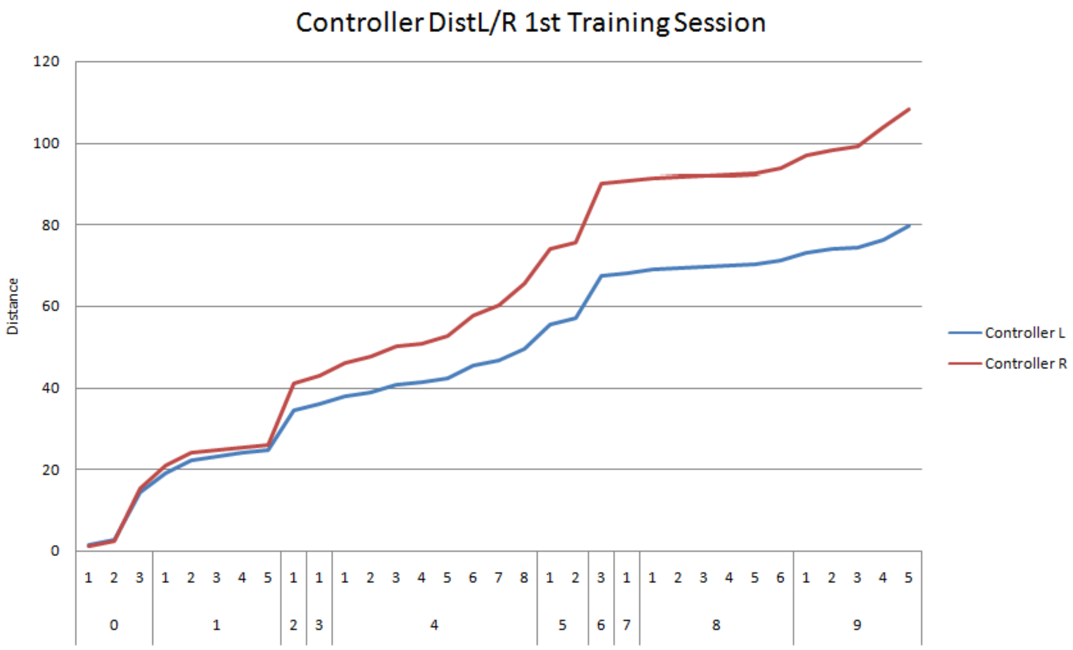


Figure 4.19: Participant D - Timespan for Subtasks (Blue: 1st trial, Orange: 2nd trial)

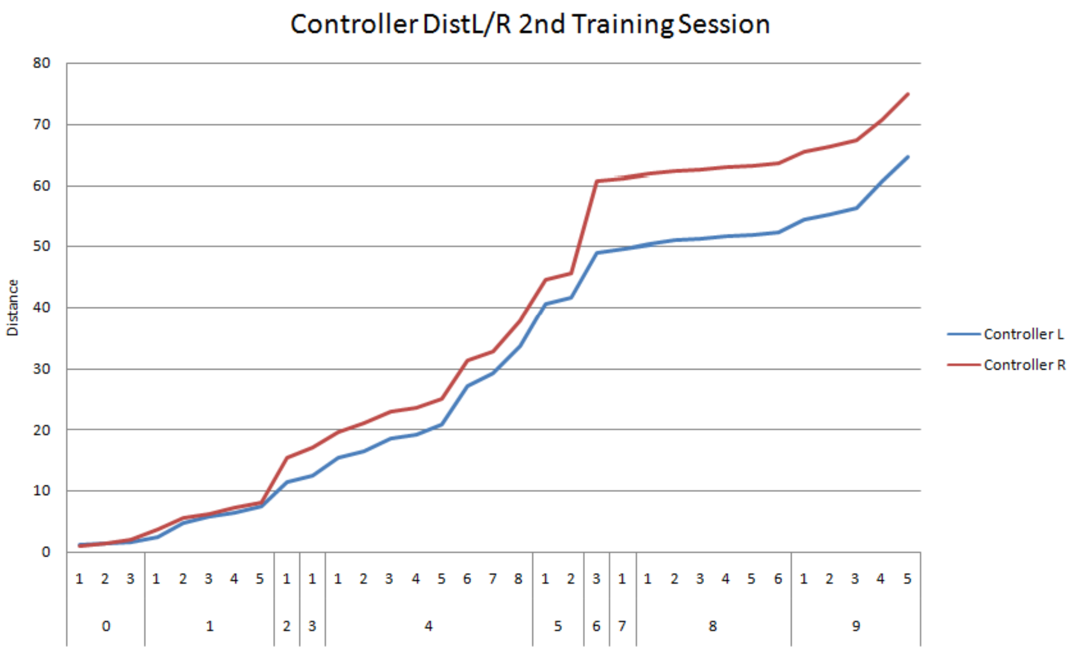
discovering the mechanism of the software, she quickly adapted with the VR environment. The evidence to support this observation is that the gap of timespan on major task 0, 1, 2 between the first and the second training sessions are significantly larger than other major tasks. More specifically, those major tasks contain the first contact of different ways for interaction in the software. Once participant D understood how the interaction mechanism works, she did not struggled with them again. Therefore, the results in the rest of major tasks show less differences than the first three as no more interaction techniques are introduced.

Figure 4.20 indicates that participant D has preference of using the right hand to finish the tasks. She moved the right controller 16.5% more distances than the left controller in the first session and 13.7% more distances in the second session. In the second session, Participant D tried to balance the usage of both hands. As shown in Figure 4.20 that the difference between both hands in second session is reduced. Overall, the moving distance of both controllers are below the average.

The moving distance of her avatar also shows that after she learned how to correctly



(a) Moving distance of L/R controllers for first training session



(b) Moving distance of L/R controllers for secondt training session

Figure 4.20: Participant D - Moving Distance of Controllers

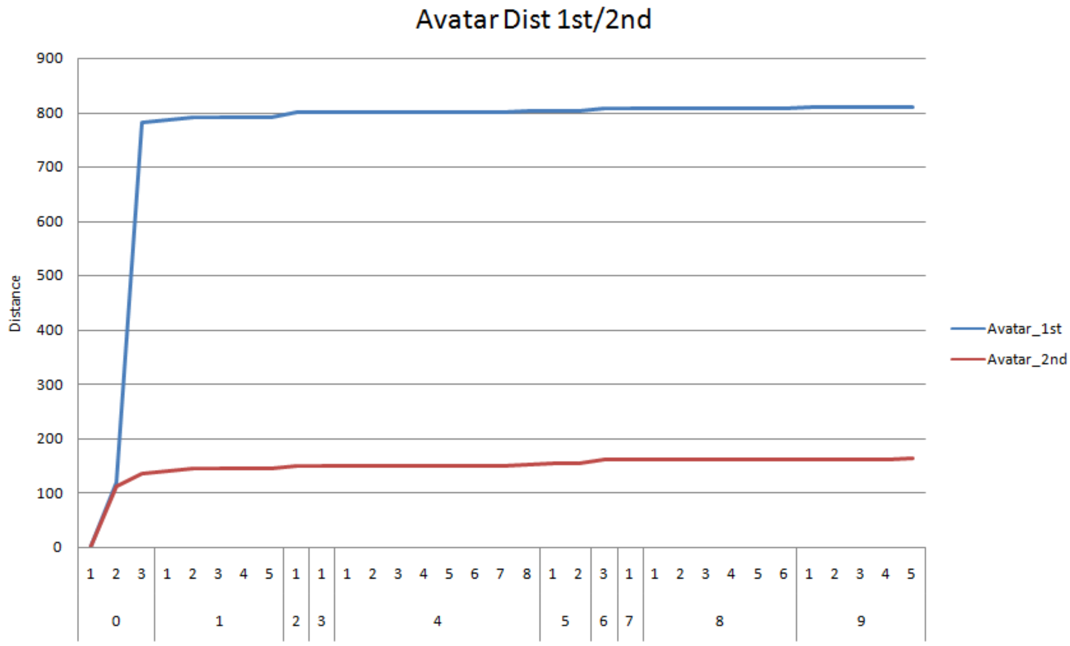


Figure 4.21: Participant D - Total distance of avatar movement

teleprot to a target position in subtask 0-2, she only used this technique when it is necessary. She did not like to explore the environment.

On-Experiment Observation

According to the on-experiment observation, linguistic bias can be found. Participant D preferred to listen the vocal instructions rather than read the information from the task helper. At the beginning of the first session, she was not sure that whether she should interact with the virtual patient by speaking out particular phrases. After a few explorations, she understood the mechanisms of speech recognition and did well in the rest of the speech interaction tasks.

Although major assistance was not needed during scenario 1, participant D was stuck in some subtasks. She quickly called out the task helper and read the instructions from it when she felt struggled.

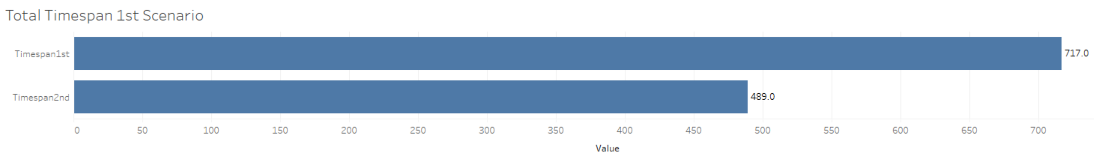


Figure 4.22: Participant E - Total Timespan for 1st Scenario (in Seconds)

Participant E

Participant E is an Age Category Imale and English native speaker. He was schooling in New Zealand and granted his master degree (Education BKG IV). He has relevant experiences about programming but no prior experience with VR technology (TechBKG IIIand VRExp Category I). He was a certified first responder but his certification is expired (HealthcareBKG III).

Quantified Result

Participant E shows a similar improvement trend to Participant D. He spent 717 seconds on the training session and 489 seconds on the second session, making the improvement 31.7%. The timespan on the second training session is lower than the estimated minimal timespan as he skipped some vocal instructions and immediately started to perform the tasks.

Participant E spent the least average time among other participants to finish both sessions. Even so, he also spent times on major task 0 and 1 to adapt into the VR environment. In the rest of the major tasks, he spent less time than the average.

The controller moving distance shows that Participant E prefers to use the right hand rather than left hand. He moved the right controller 10% more distances than the left controller in the first session and 13% more distances in the second session. It is interesting that in real life his dominant hand is the left hand. A similar situation happened for some of the other left-handed participants. Participant E's avatar moving distance shows that he did a short discovery at the beginning of the second session, and

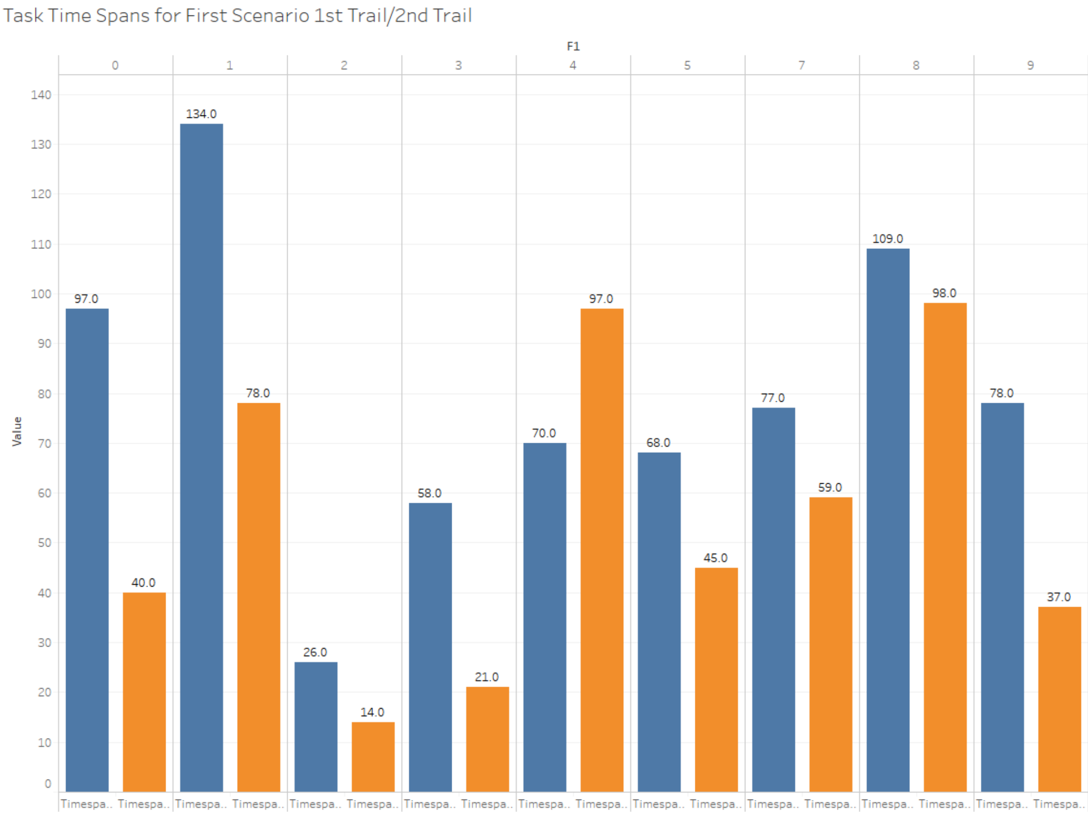


Figure 4.23: Participant E - Timespan for Major Tasks (Blue: 1st trial, Orange: 2nd trial)

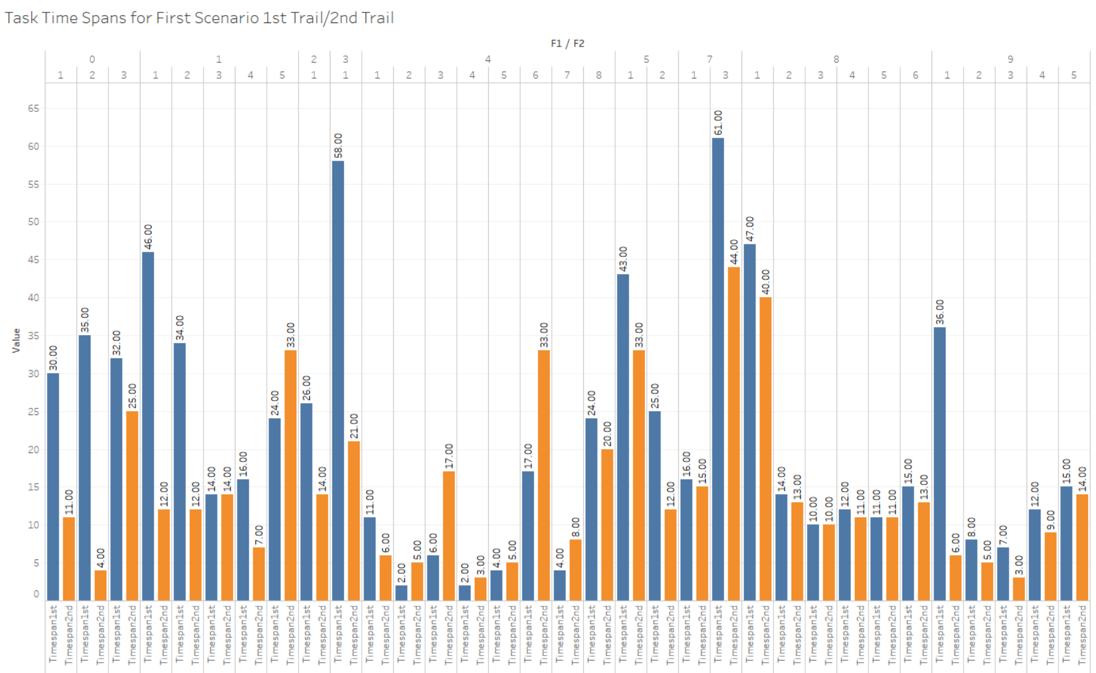
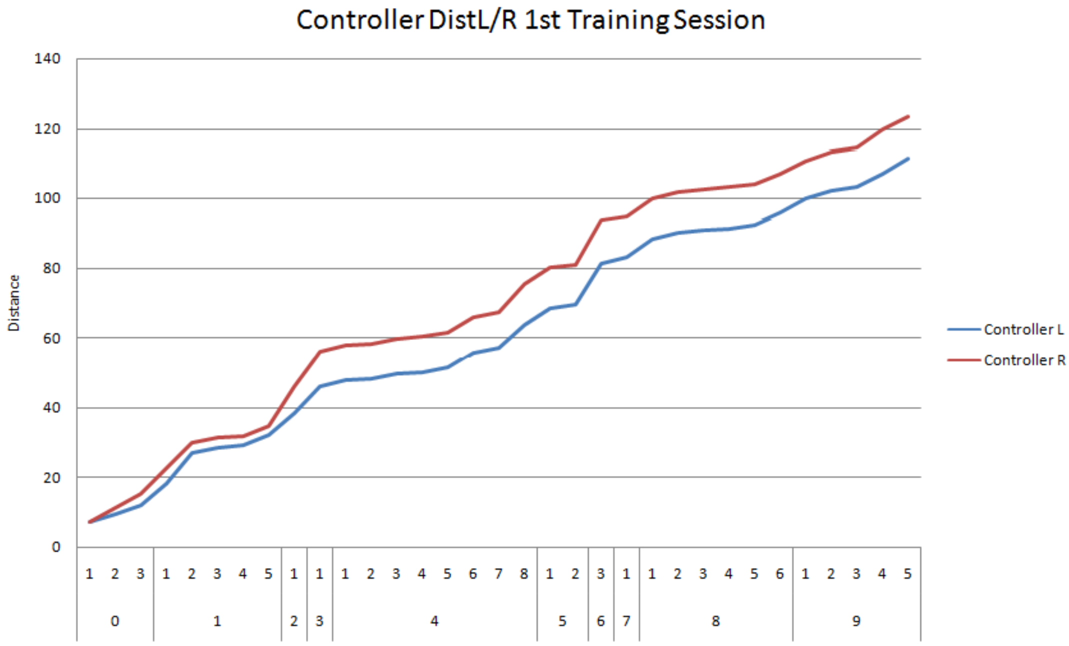
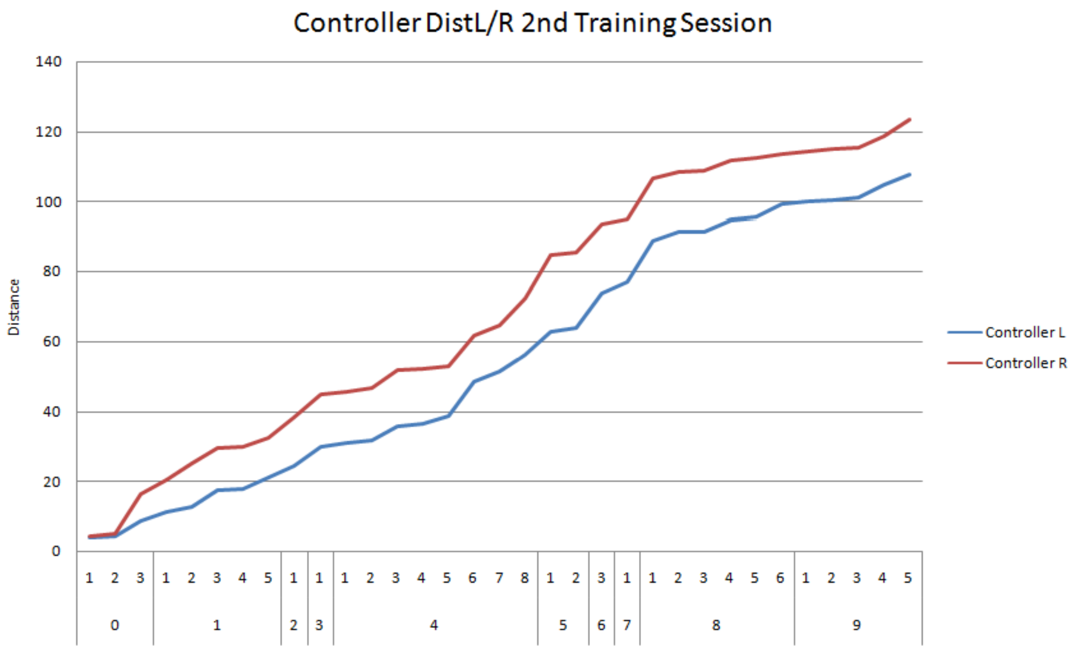


Figure 4.24: Participant E - Timespan for Subtasks (Blue: 1st trial, Orange: 2nd trial)



(a) Moving distance of L/R controllers for first training session



(b) Moving distance of L/R controllers for secondt training session

Figure 4.25: Participant E - Moving Distance of Controllers

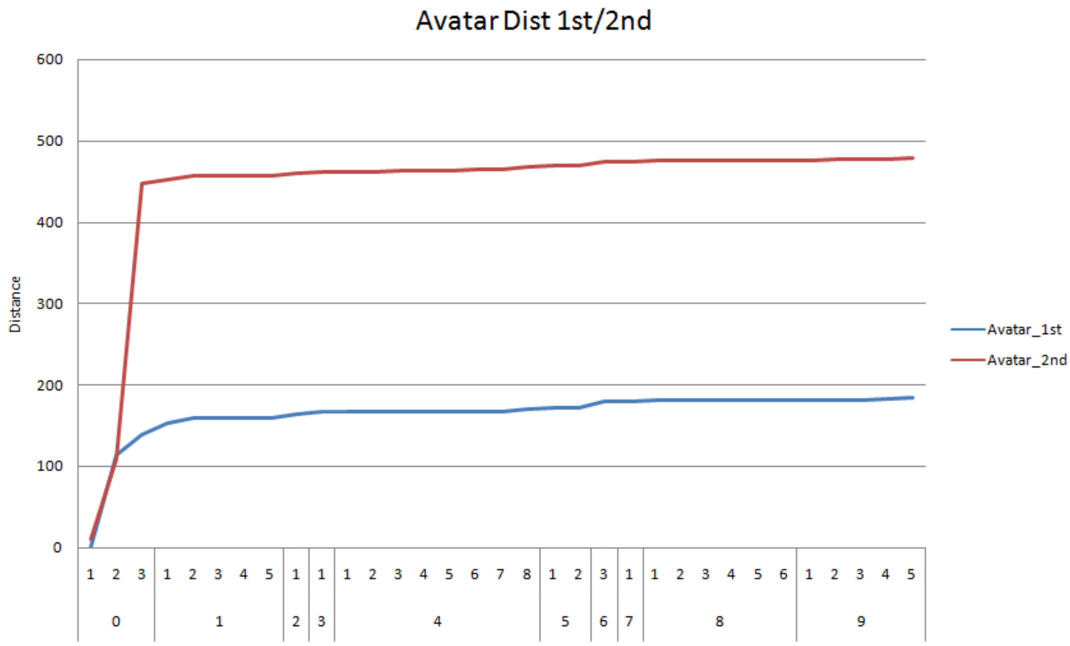


Figure 4.26: Participant E - Total distance of avatar movement

then his performance is similar to the first session.

On-Experiment Observation

The on-experiment observation shows that Participant E preferred to explore the VR technology. For instance, he tried different combinations of keywords in the speech interaction tasks. Also, as a first responder, he knows the major steps of the EHW and he can repeat every detail of the major tasks after the first training session.

In the second session, he discovered a potential bug of the software based on his programming background. (We fixed this potential bug immediately after this training session. The bug does not affects the training results, but has potential to interrupt the training session in a special circumstance)

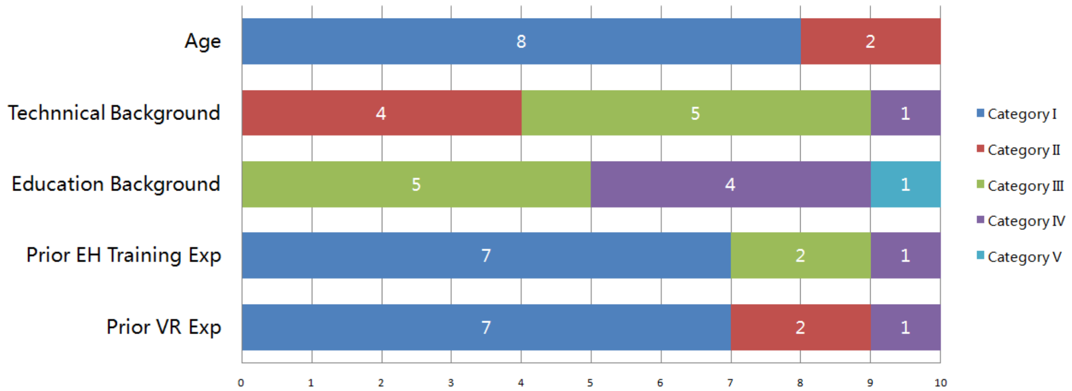


Figure 4.27: Sample distributions (Age, TechBGKs, EducationBKGs, Prior-EHTs and Prior-VRExps)

4.3 Cross section Analysis

After analysing individuals' performance, we did cross section analysis across the data. In this part of the thesis, we will first introduce the sample distributions, then demonstrate the analysis result based on the timespan of each training session as well as the controller and avatar moving distance.

Sample Distributions

We collected the personal data as mentioned in Chapter 3 from the participants. Although only 10 participants were allowed to recruit, we still attempted to balance biological features such as gender, and keep variation of background features, such as level of technical background. The gender ratio over all participants is 1:1, which is purely equal.

Figure 4.27 indicates distributions of different personal features including Age group, TechBGKs, EducationBKGs, Prior-Emergency Healthcare Training Exps and Prior-VRExps. There are 5 categories to classify the participants in each feature.

- Age Group

8 out of 10 participants are categorised in Age Category I (Age ≤ 29) and 2 out of 10 participants are categorised in Age Category II (Age ≤ 39). The reason that the majority of the participants are in Age Category I is due to the recruitment location. As proposed in the ethics approval application, the recruitments were advertised and conducted based on AUT city campus, therefore the potential participants in this area has high probability of belonging to either Age Category I or II.

- Technical Background

  Among 10 participants, half of them were categorised in TechBKG III, 4 of them in TechBKG IIand 1 in TechBKG IV. It is noticeable that there is no positive correlations between Technical Background and Prior-VR Experience. For instance, a person in TechBKG IV group might not be in VRExp Category IV. But, on the contrary, participants in higher VRExp group normally have higher technical background (Equal or above TechBKG III).

- Educational Background

  Similar to the age group distribution, the participants recruited from AUT city campus mostly hold or are in progress of studying at least a undergraduate degree. More specifically, 5 participants hold or are in progress of studying a recognized undergraduate diploma or degree. 4 participants hold or are in progress of studying a postgraduate diploma or a master degree. 1 participant is in progress of studying a Ph.D degree.

- Prior-Emergency Healthcare Training Experience

  7 participants have no prior experience about emergency healthcare training. 2 participants were certified first responders before, but their certification has expired. 1 participant is a New Zealand registered nurse as mentioned in individual

analysis section, and she is still a valid first responder.

- Prior-VR Experience

  7 participants have no VR experience before the experiment. 2 participants have a few experiences (less than or equal 5 according to the interview). 1 participant has relevant experience of developing a VR application. This figure shows that although VR has become a hot topic in recent years, still only a few people have experienced this technology in their daily life.

During the experiments, we observed significant differences in task performance based on participants' native language. Based on this observation, we decided to add 'Native Speaker' as a new dimension of personal data. Among 10 participants, 3 of them are native English speakers and they were born and raised in either New Zealand or Australia. 7 of them are non-native English speakers, but they have living in areas where English is an official language for a long period.

4.3.1 Timespan

The average timespan over 10 participants in the three training sessions are 1352.4 seconds, 737 seconds and 502.3 seconds respectively as shown in Figure 4.28.

For each session, we calculate the average of each subgroups (e.g., grouping in terms of ages, or technical background), and its distance to the overall average (i.e., on all participants). Suppose the overall average is v, and the average of each subgroup is: $s_1, s_2, ..., s_n$, then the relative deviation for each training session t is given as

$$rd_t = \sqrt{\frac{\sum_{i=1}^{n}(\frac{s_i}{v} - 1)^2}{n}} \tag{4.1}$$

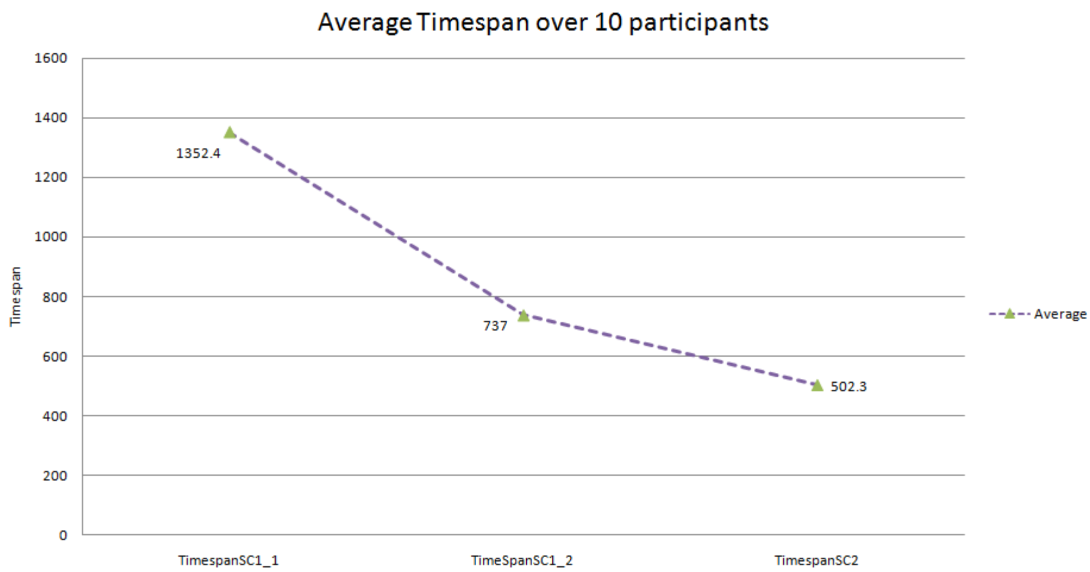


Figure 4.28: Average Timespan over 10 participants

Evaluation on Age group

Figure 4.29 shows average timespan by different age groups among all training sessions. As shown in the figure, a decreasing trend can be observed on both age groups. In the first training session, the average timespan of Age Category II is 1268 seconds, which is 25.1% less than the Age Category I group (1692 seconds). Both groups spent similar time in the second session (Age Category I = 772 seconds, Age Category II = 728 seconds). In the recall session, Age Category I spent 472 seconds on average, which is 24.3% less than Age Category II(623 seconds).

We use Formula 4.1 to calculate the relative deviations rd_t over all training sessions. According to the calculation, the rd_{t_1} = 0.18, the rd_{t_2} = 0.03 and rd_{t_3} = 0.17. It shows that the first training session has the largest relative deviation, and then the gap is reduced greatly in the second session. The smaller rd_t value means the timespan of majorities are closer to the overall average timespan, which also means their performances are improved. In the recall session, as some tasks are slightly changed, the relative deviation is increased again.

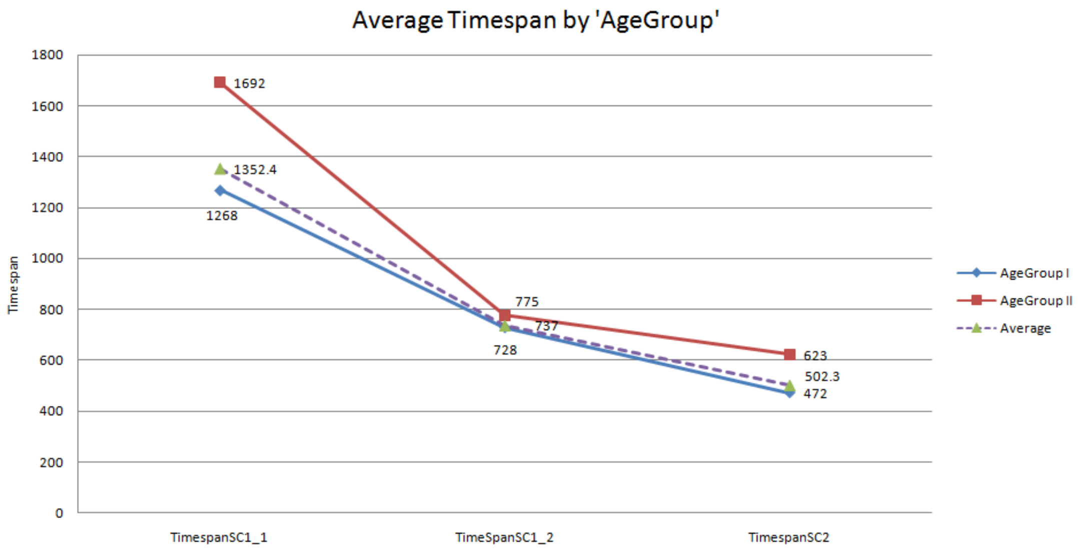


Figure 4.29: Average Timespan by Age Groups Among all Sessions

We have the following observations based on the results:

Observation 1. *With repeated trainings, all participants with different age group improved their performance with reduced timespan in VR emergency healthcare training sessions. The participants in the younger age group spent less time than the older group to finish the session.*

Evaluation on Technical Background

Figure 4.30 shows the average timespan among 3 technical BKGs in the first training session. A significant gap is shown between TechBKG II, TechBKG III, and TechBKG IV. In the first training session, the average timespan of TechBKG II is 1799 seconds. By contrast, the average timespan of TechBKG III and TechBKG IV are 1066 seconds and 998 seconds respectively, which is 40% and 45% less than the TechBKG II group.

In the second training session, participants in all TechBKG groups show obvious improvement on their average timespan. This figure also indicates the decreasing trend of the timespan over all training sessions. According to the figure, the TechBKG II group shows a large improvement between the first and the second training session. In second session, participants in the TechBKG II group spent 50% less time (788 seconds) than the first session. The TechBKG III group spent 30% less time (719 seconds) and the TechBKG IV group spent 38% less time (512 seconds) than the first session. In the third training session, although it was designed as an recall session, the same decreasing trends hold among the three TechBKG groups. The average timespan of TechBKG II is 529 seconds and the TechBKG III is 512 seconds, which shows that the gap between TechBKG II group and TechBKG II group is reduced consistently. The average timespan of TechBKG IV is 351 seconds. Compared with the performance of the first training session, the TechBKG II group has improvement of 70.6%, TechBKG III spent and TechBKG IV spent 64.8% and 52.0% less time respectively.

Similar to the evaluation in age groups, we use Formula 4.1 to calculate relative deviations between the group-based timespan and the overall average timespan and set the value as rd_t. The relative deviations are: rd_{t_1} = 0.27, rd_{t_2} = 0.09, and rd_{t_3} = 0.17. The first training session has large relative deviation in the bias of technical background, which means participants from different TechBKGs have various and large range of timespan results based on their performances. The value is reduced in the second training session and eventually increased again in the recall session.

We have two observations based on the combined results from Figure 4.30 and the results from individual analysis:

Observation 2. *Different technical backgrounds have notable affect on the timespan of participants' first trials, as technical backgrounds influence the VR adaptation time that each participant spent on. Negative correlation existed between technical background and adaptive time, which means in general, a participant who has strong technical background spent less time adapting the VR environment.*

Observation 3. *With repeated trainings, the differences of timespan between the participants with different technical background could be reduced as they gain more*

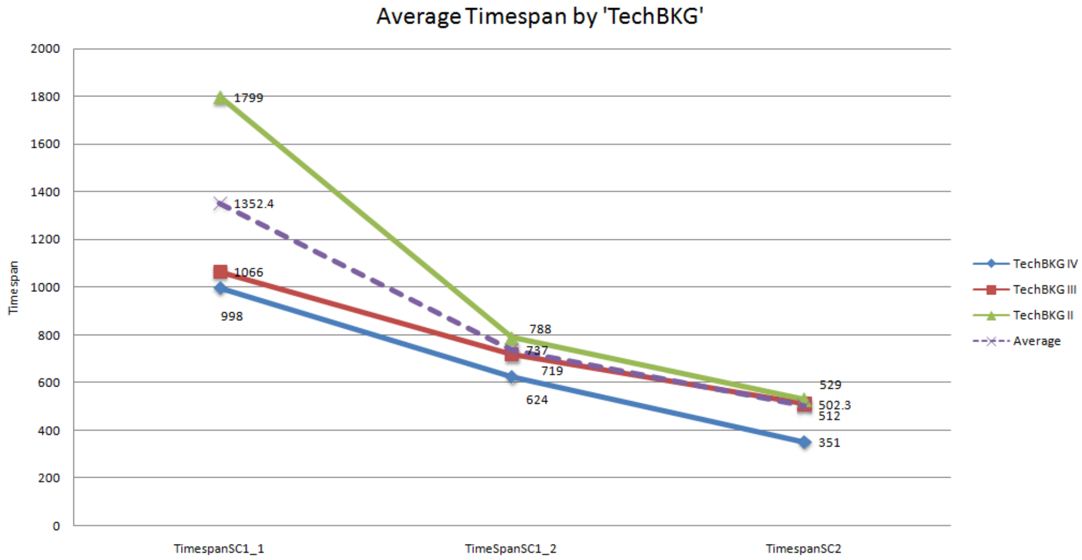


Figure 4.30: Average Timespan by TechBKG among all sessions

experience.

Evaluation on Educational Background

Figure 4.31 indicates the average timespan of different educational background groups among all sessions. The Education BKG V group spent the least time in the first session (998 seconds). The Education BKG IV group spent 17% more time (1536 seconds) than the Education BKG III group (1276 seconds) in the first session. In the second session, both the Education BKG IV group and Education BKG III have similar timespans, which are the 746 seconds and 752 seconds respectively. In the recall session, the Education BKG IV group spent more time (557 seconds) than Education BKG III again (489 seconds). According to the personal data, participants in Education BKG III group were mostly in TechBKG III as well, while other participants in Education BKG IV group have various technical backgrounds.

Formula 4.1 is applied to evaluate the relative deviations between the background based timespan and the overall average. The deviations are: rd_{t_1} = 0.17, the rd_{t_2} = 0.08, and rd_{t_3} = 0.18. The results indicate that participants in different educational

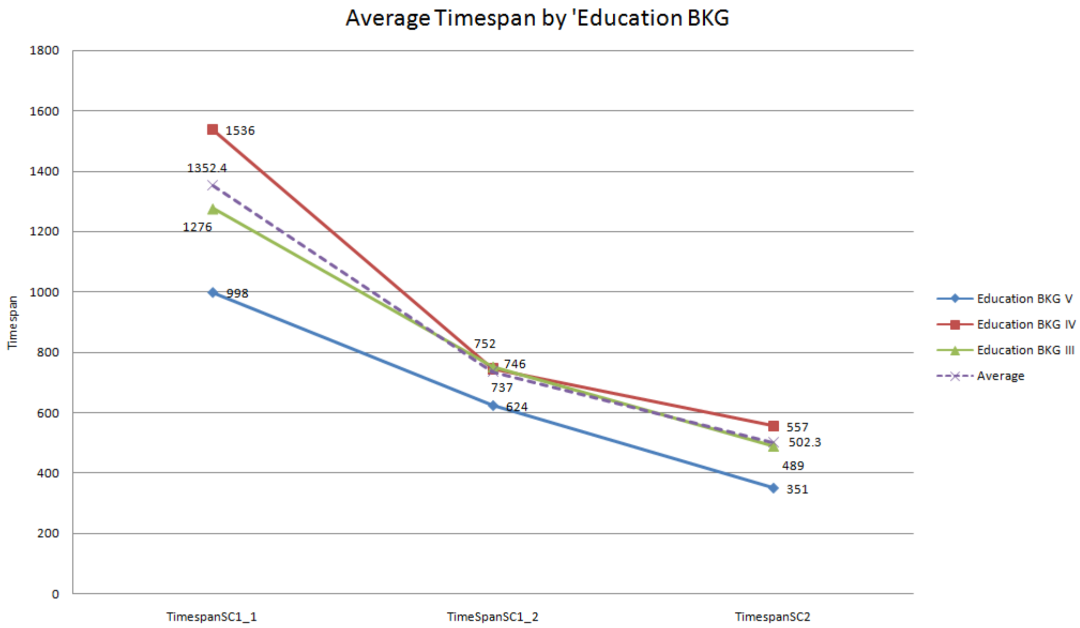


Figure 4.31: Average Timespan by Educational Backgrounds among all Sessions

background have a wide range of deviation when they start trying new tasks. With repeated training, the distributions of their timespan will be limited and the deviation is reduced.

Based on the result of analysing average timespan by educational backgrounds, we have Observations 4:

Observation 4. *With repeated trainings, all participants with different education backgrounds improved their performance with reduced timespan in VR emergency healthcare training sessions.*

We also refined Observation 2 by verifying that educational background shows less influence than technical background while assessing participants' performances in VR emergency healthcare training software.

Evaluation on Prior-Emergency Healthcare Background

Figure 4.32 indicates the average timespan of participant groups with different prior-emergency healthcare experiences among all sessions. According to the figure, it may seems counter-intuitive that the HealthcareBKG IV group spent the longest time on the first training session (1798 seconds). Combining with the results of the individual analysis in previous section, we find that although the participants in the HealthcareBKG IV group spent most of their time getting used to the VR environment and interactions.

In the second training session, the HealthcareBKG I group spent 46.7% less time (731 seconds) than the first session (1371 seconds). The HealthcareBKG III group spent 31.3% less time (680 seconds) than the first session (1064 seconds). Similarly, the HealthcareBKG IV group spent 50.2% less time (680 seconds) than the first session (1798 seconds).

The decreasing trend of the HealthcareBKG I group and the HealthcareBKG IV group can be found in the recall session as well. In the third session, the HealthcareBKG I group spent 68.5% less time (433 seconds) than the first session. The HealthcareBKG IV group spent 66.8% less time (598 seconds) than the first session.

The timespan of the HealthcareBKG III group originally shows a slightly increasing trend on the recall session (696 seconds). We find this is unexpected. By combining the results of individual analysis, we found that one of the two participants in this group spent notable amount time exploring the VR environment in the third session. After reviewing the data, we found a timespan of 57 seconds is related to the exploration, which does not contribute to the task accomplishment. We remove this timespan from the total duration, then the HealthcareBKG III group still shows a decreasing trend in the recall session.

Based on Formula 4.1, the relative deviations can be calculated, which are: rd_{t_1} = 0.22, rd_{t_2} = 0.13, and rd_{t_3} = 0.26. The reasons for such large deviation values in this

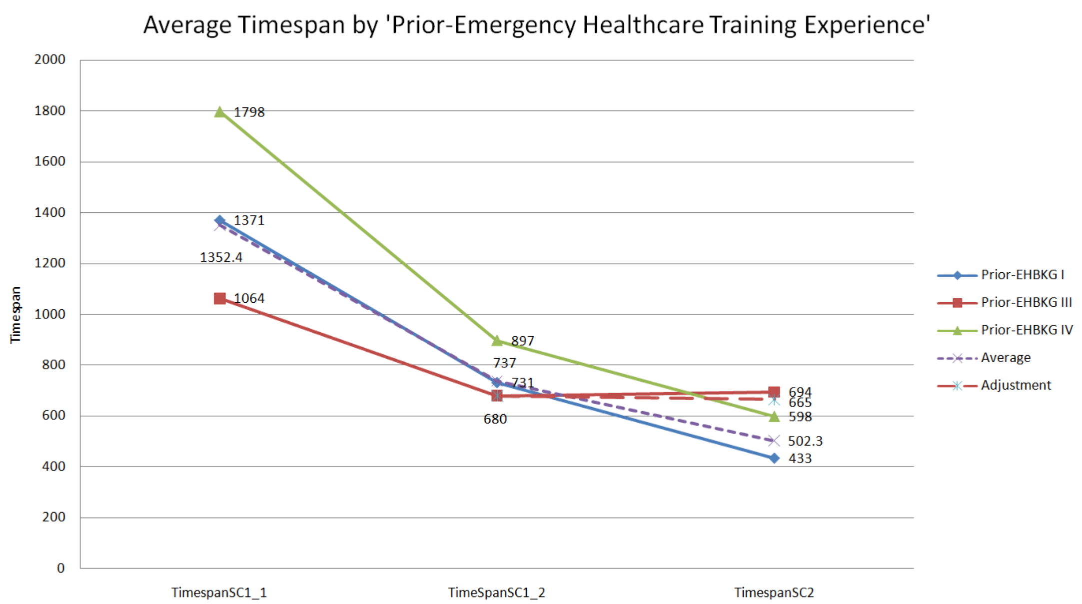


Figure 4.32: Average Timespan by Prior-emergency Healthcare Training Experience among all Sessions

dimension are complicated. One of the major reasons is due to various combinations of different personal features based on those prior-emergency healthcare BKGs, thus created uncertainty in the results. The result shows that the deviation between the first training session and second training session is reduced. But similar to other dimensions, the deviation is increased in the recall session.

Based on the results above, we have Observations 5 and 6 :

Observation 5. *With repeated trainings, all participants with different prior-emergency healthcare training experiences improved their performance with reduced timespan in VR emergency healthcare training sessions.*

Observation 6. *There is no strong evidence that shows a correlation exists between prior-emergency healthcare training experience and timespan of the training sessions.*

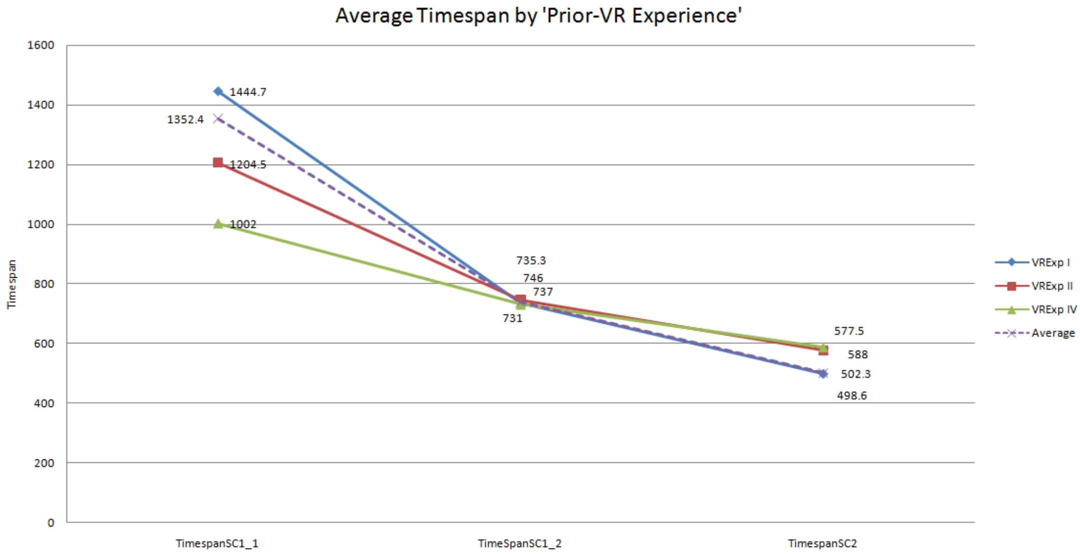


Figure 4.33: Average Timespan by prior-VR experience among all sessions

Evaluation on Prior-VR Background

Figure 4.33 shows the average timespan of different prior-VR experience groups among all sessions. Significant difference can be observed among three groups in the first training session. The VRExp Category IV group spent the least average time (1002 seconds) on the first session. The VRExp Category I group spent the most average time (1444.7 seconds) by contrast, which is 44.1% longer than VRExp Category IV group.

The decreasing trend can be observed among all groups in the second session. In the second session, the VRExp Category I group spent 49.1% less time (735 seconds) than the first session. The VRExp Category II group spent 30.1% (737 seconds) less time and the VRExp Category IV group spent 42.5% less time (731 seconds). This trend holds in the recall session as well.

As calculated by the Fomular 4.1, the deviations are: rd_{t_1} = 0.16, the rd_{t_2} = 0.008, and the rd_{t_3} = 0.13. It shows that the relative deviation in the second training session is the smallest among all evaluation results. The relative deviation in the recall session is also smaller than the results from other dimensions.

According to result from Figure 4.33, we have Observations 7 and 8:

Observation 7. *With repeated trainings, all participants with different prior-VR experiences improved their performance with reduced timespan in VR emergency healthcare training sessions.*

Observation 8. *Prior-VR experience affects the performance at beginning of the training. However, with improved skills and VR adaptation of participants, the effects could be reduced and minimized eventually.*

Evaluation on Linguistic Background

Figure 4.34 indicates the average timespan by different linguistic groups among all sessions. It shows that the native English speakers spent less average time (973 seconds) than the non-native English speakers (1515 seconds) on the first training session. In the second session, the native English speaker group spent 31.7% less time (665 seconds) and the non-native English speaker group spent 49.4% less time (768 seconds) than the first session. In the third session, the native English speaker group spent 60.1% less time than the first session. The non-native English speaker group spent 63.7% less time. A significant decreasing trend can be observed over those two groups.

Also, we found an interesting phenomenon according to the on-experiment observation. The native English speaker preferred to use vocal instructions to acquire task information, while the non-native English speaker preferred to read the texts from the Task Helper. This phenomenon happened among all participants in their first training session. By listening the vocal instructions and performing the tasks, the native English speakers spent 36% less time than the non-native English speakers in the first session. In the second session the difference of timespan between two groups are reduced to 13.5%, as participants in both groups have partially memorised the training content and they do not fully rely on the instructions. In the recall session, as slight changes were made in a few subtask, the gap of timespan between two the groups is increased

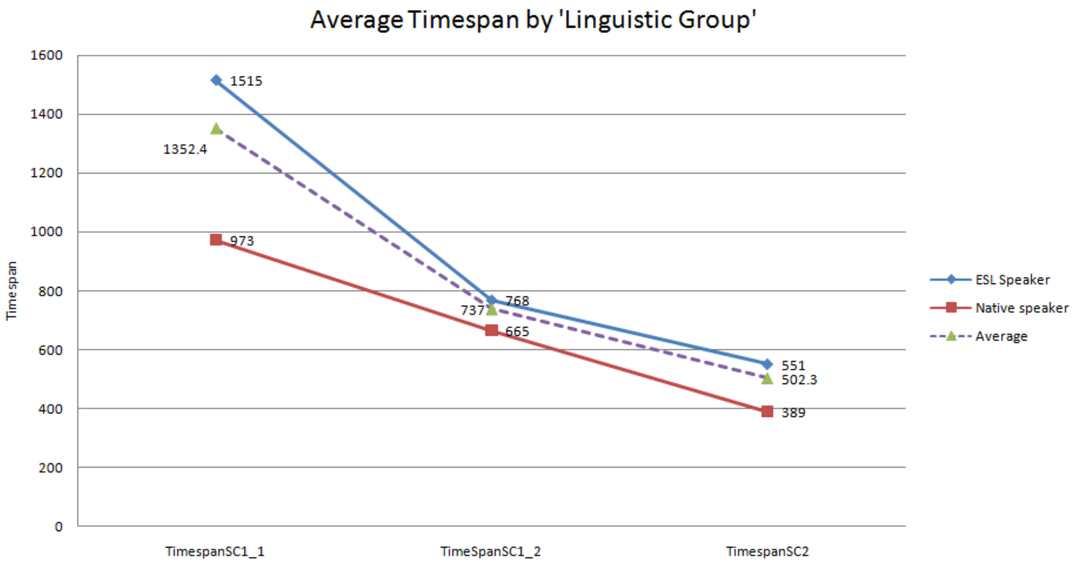


Figure 4.34: Average Timespan by Linguistic Groups among all Sessions

to 29.5%. The relative deviations are: rd_{t_1} = 0.21, the rd_{t_2} = 0.07 and the rd_{t_3} = 0.17, which shows a similar trend to the deviation result of technical background.

We have Observations 9 and 10 based on the results:

Observation 9. *With repeated trainings, all participants with different English language backgrounds improved their performance with reduced timespan in the VR emergency healthcare training sessions.*

Observation 10. *While performing emergency healthcare training tasks, native English speakers prefer to acquire information by listening to vocal instructions, and non-native English speakers prefer to acquire information by reading the written instructions.*

Evaluation on Gender

Finally, we evaluated the average timespan over different genders. Figure 4.35 indicates the average timespan of male and female participants. As the figure shows, both male and female participants reduced their timespan among three training sessions, and a decreased trend of difference is shown between genders. In the first session, female

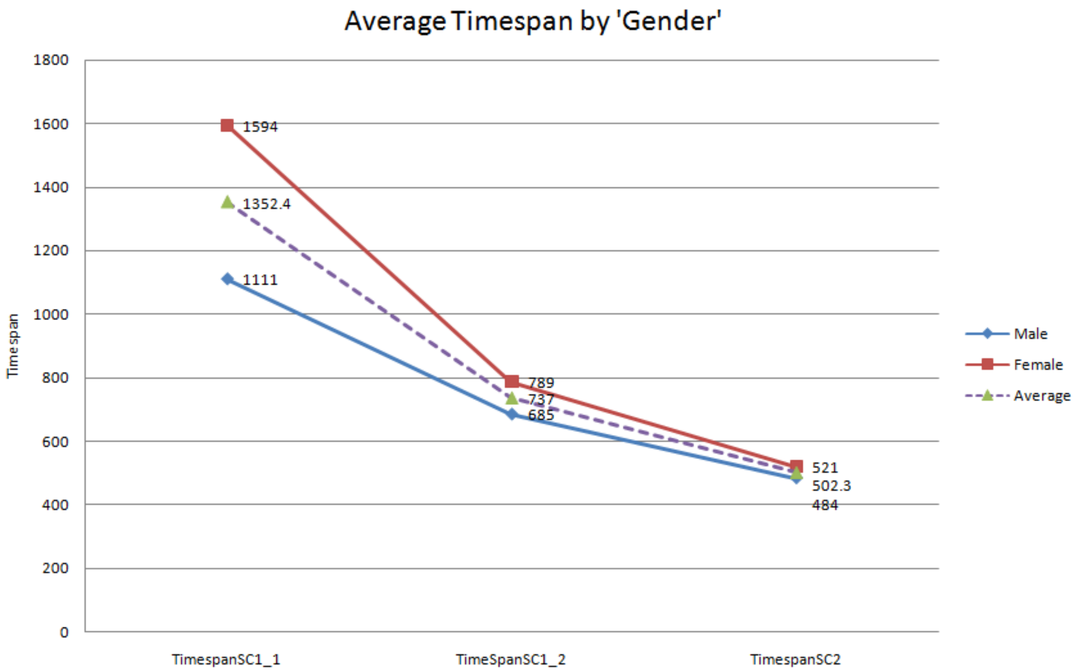


Figure 4.35: Average Timespan by Gender among all sessions

participants spent 1594 seconds on average and the male participants spent 1111 seconds. In the second session, the male participants spent 39.4% less time (685 seconds) and the female participants spent 50.6% less time (789 seconds) than the first session. In the recall session, improvement rate of the male participants and the female participants is 56.5% (484 seconds) and 67.4% (521 seconds) respectively.

The timespan difference between groups in the first session is 30.4%. However, the gap keeps reducing until the third session. In the third session, the male participants only spent 7.2% less time than the female participants. The relative deviations are: rd_{t_1} = 0.17, the rd_{t_2} = 0.07 and the rd_{t_3} = 0.03. The rd is reduces over three sessions.

Based on the results from Figure 4.35, we have Observations 11 and 12:

Observation 11. *With repeated trainings, all participants with different genders improved their performance with reduced timespan in VR emergency healthcare training sessions.*

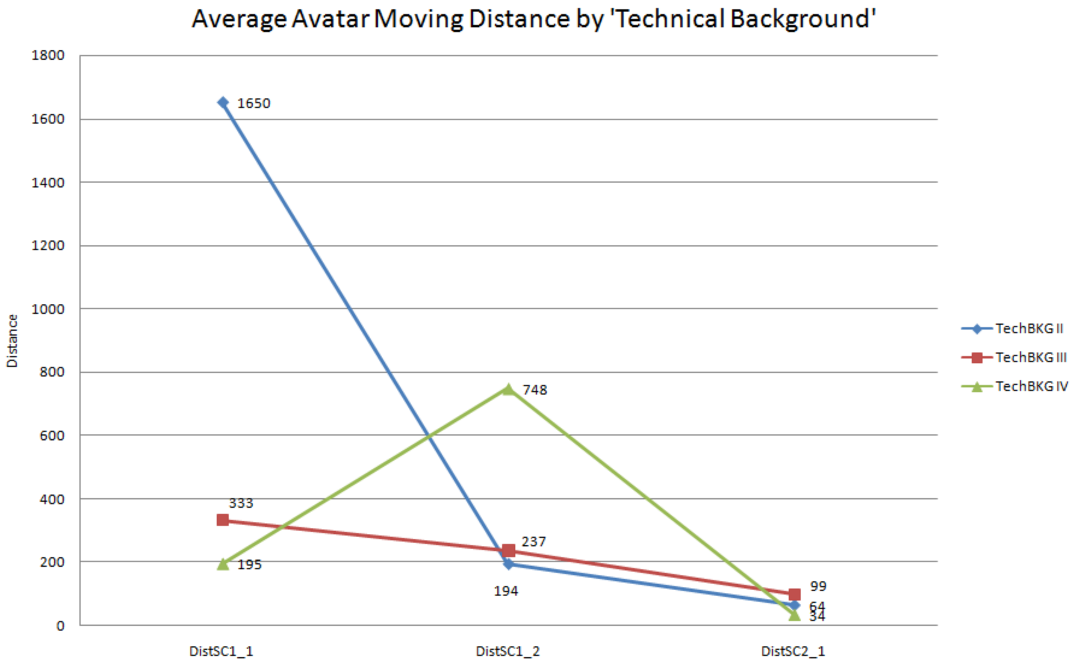


Figure 4.36: Average moving distance of Avatar by technical background among all sessions

Observation 12. *Although gender difference existed initially, with repeated trainings, such differences will be reduced and eventually their timespan will be closer to equal.*

4.3.2 Controller and Avatar Moving Distance

Figure 4.36 indicates the average moving distance of avatars by different technical backgrounds (TechBKGs) among all sessions. Both the TechBKG III group and TechBKG IV group increased the moving distances of their avatars during the second training session, while the TechBKG II group kept a decreasing trend among three sessions. Combined with the on-experiment observation, that shows participants who have higher technical backgrounds prefer to explore the interesting things (e.g. buildings, street-views, training mechanisms etc.) in the virtual world after they got familiar with some training scenes. The participants who have lower technical backgrounds prefer to keep their current status and concentrate on finishing tasks.

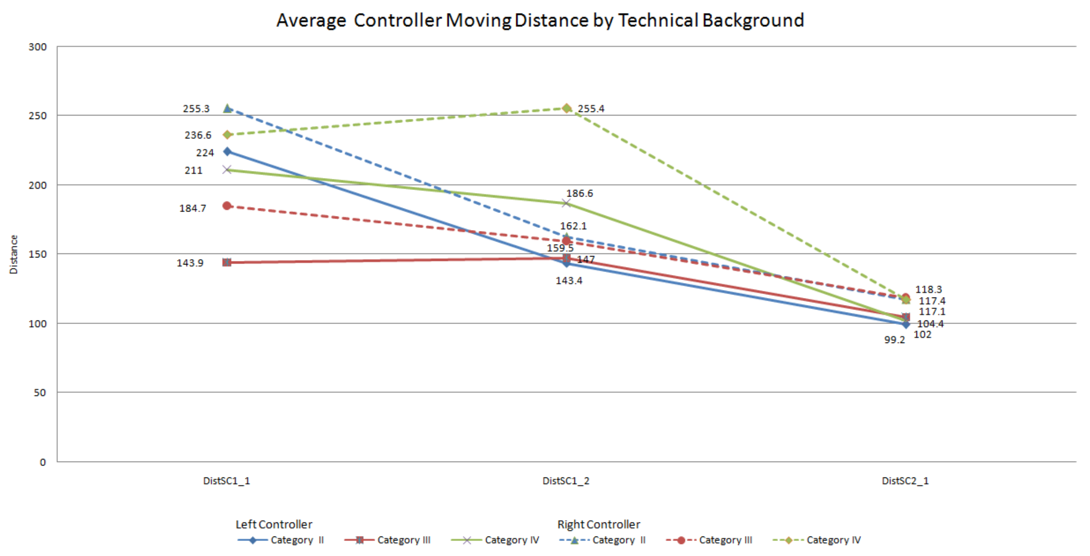


Figure 4.37: Average moving distance of Avatar by technical background among all sessions

Figures in 4.37 indicate the average moving distances of L/R controllers by different TechBKGs among all sessions. Decreasing trends similar in 4.36 can be observed. The average controller moving distances of TechBKG III group and TechBKG IV group were shorter than TechBKG II group at the first training session. In the second session, the TechBKG IV group and TechBKG II group decreased moving distance of their left controller. The decreasing ratio of TechBKG IV groups was 11.6%. By contrast, the TechBKG II group reduced their left controller moving distance by 36%. The TechBKG III group increased the left controller moving distances a little bit (2%). For the recall session, all TechBKGs reduced the moving distances of the left controller at a similar level (ranging from 99.2 to 104.4 units).

Also according to the figure, the TechBKG II group and TechBKG III group reduced moving distances of the right controller at similar level in the second session. The TechBKG IV group shows an increasing trend by contrast. Based on the on-experiment observation, the TechBKG IV group preferred to explore the virtual world (e.g. buildings, street-views etc.) after they got familiar with the VR technology. In the recall session, similar to the left controller, all the three groups' right controller moving distances were reduced within a short range of each other.

Based on the results, we have Observations 13 and 14:

Observation 13. *With repeated trainings, all participants with different backgrounds improved their performance in the VR emergency healthcare training sessions. The improvements can be quantified by the moving distances of their avatars and controllers.*

Observation 14. *People with higher technical background have more interesting on discovering the virtual world, while the participants with lower technical background prefer to concentrate on finishing the tasks themselves.*

4.4 Conclusion

In this chapter, we analysed the data collected from the VR training sessions. Combined with the individual analysis results and observations from cross-section analysis, we concluded our major conclusions as follows:

Conclusion 1. Technical background plays the most significant role compared to other features while assessing people's performance in VR emergency healthcare training sessions. People with higher technical backgrounds more easily adapt to the VR environment and have higher interests to explore the VR environment. People with less technical background are slower to adapt to the VR environment and they prefer to concentrate on finishing the tasks and partially ignore other elements in VR environment.

This major conclusion is made based on the individual analysis and Observations 2, 6, 8, 13 and 14.

Conclusion 2. With repeated trainings, people despite different personal background, eventually can gain knowledge and improve their performance with reduced total timespan.

This major conclusion is made based on the individual analysis and Observations 1, 3, 4, 5, 7, 9 11 and 12.

Conclusion 3. During the training, the native English speakers prefer to acquire information by listening vocal instructions, and the non-native English speakers prefer to acquire information by reading texts instead.

This major conclusion is made based on the individual analysis and Observation 10.

Chapter 5

Discussion

In this chapter, We discuss the problems we had in our experiment regarding the hardware and software, and the possible solutions. Finally, we point out the directions of future research.

5.1 Hardware Problems and Solutions

The problems in hardware can be split into two categories: VR headset related and motion sensor related.

5.1.1 VR Headset Related

Firstly, according to the feedback from participants and developers, we found that the current version of the Oculus VR headset is not quite user friendly to those who have vision impairments. In the recruitment stage, many potential participants showed their interest in joining this research project. Unfortunately, most of them have vision impairments from very mild to severe levels. We set up some testing scenes such as Google Earth VR and Oculus Home for them. The test results show that those who have vision impairments may be able to see virtual objects and interact with them, but they cannot see small and medium text sizes. Most of them reported that they could not read texts with font size of 18 or smaller from a distance of 5-20 units in the VR environment. Also, they reported blurry vision when trying to rotate the VR headset. For the reasons mentioned above, we had to reject potential participants who wished to join this research project.

Possible solutions to solve this problem are to increase the resolution of the headset screens or improve the optical imaging mechanism for the VR headset. A temporary solution includes adding a small amount of space in the VR headset that allows the user to attach their glasses in front of the screen.

Secondly, the weight of the Oculus VR headset is too heavy (470g). This may cause fatigue for some users after a long use time (more than 30 minutes). In our experiment, few participants spent more than 30 minutes on their first training session. Although we asked and confirmed with them that they do not need a break or stop, we still can observed they felt tired after the session. Most of them reported that weight is the major reason that making them feel tired.

A possible solution to solve this problem is to reduce the weight of the VR headset with lighter, more efficient gear. A temporary solution is that the software developer should build in break mechanisms in their products. For instance, in our case, we could split the major Tasks into different scenes, ensuring each task can be completed within 15 minutes. We believe that with such solutions, users can concentrate on their performance without any additional fatigue setting in.

Finally, we want to discuss the capability of the Oculus VR headset. As we investigated before, current VR headsets are mostly limited by data transmitting broadband. Most commercial level products are connected to the computer by wire. Such connection type can provide stable data transmission between the computer and VR headsets. However, it is obvious that the available space for activities is limited by the length of the wires as well as posing a tripping hazard. Some experimental modifications based on current commercial productions have been conducted, such as wireless extensibility modification for Oculus headset, done by Stefan from AUT, New Zealand. However, the VR headset companies still have not announced tools or APIs to support such modifications.

We believed that with the improvement of VR headsets, especially the stability and wireless-access ability, VR technology could be used in more application scenarios.

5.1.2 Motion Sensor Related

Hardware Configuration

One of the biggest challenges we had during the experiment was with the motion sensor. Firstly, the configuration processes provided by Oculus are redundant and not flexible enough. For every participant, we had to configure the sensors from the very beginning of the processes and those configuration processes are linear and compulsory. Although Oculus provides a 'skip' function in some processes; however, due to the restricted sensor configuration mechanism, the 'skip' function is essentially useless. The sensor configuration processes include a tutorial and testing scenario, which takes approximately 15-20 minutes meaning every participant is required spend an extra 15-20 minutes to configure the sensors for each session.

We recommend that the hardware producer split the configuration for headset and controllers, and also provide 'in-application' adjustment options for the user, which allows them to configure the hardware while running the software.

Tracking Range

The second, and the most important problem, is the available tracking range of the Oculus sensor. From our testing and observations, the motion capturing of Oculus sensors works as expected within a height range from 0 meters to 1.5 meters, which means the sensors can track motions for all the upper body and most parts of the lower body. For the height range approximately from 1.2 meters to 1.9 meters, the sensors have a chance of losing tracking signal from the controllers. Out of this tracking range, both controllers and headset cannot be tracked by the sensors. Employing a third sensor can change the tracking range and qualities on 2D space (width range), but the range and quality of tracking signal on 3D space (the height dimension) cannot be improved significantly.

As our experiment is designed, participants were asked to perform tasks in multiple postures, such as ‘standing’, ‘single knee down’, ‘sitting’, etc. However, due to the limited tracking space, we had to reallocate participants’ positioning during the training session to make sure the controllers and headsets can be perfectly tracked. Depending on the how well the participants adapted to the VR environment, the position reallocating (or assistance) could happen a few times in each training session. As our on-experiment observation reported, the minimum position reallocation is one time for a single session (occurring with the Participant E) and maximumly four times for a single session (occurring for Participant C).

Possible solutions are recommended to solve similar problems. Firstly, for similar scale projects that require large motion space, researchers can try different signal sending and receiving devices such as a laser receiver matrix showed in Figure 5.1. Such navigation systems can be used to replace the original motion capturing system from Oculus, providing wireless functionality, larger tracking space, and height-sensitive tracking. However, most of them are still in the experimental stage and it might take time to configure the application.

The second possible solution is recommended for research projects with smaller scales, which involves adding ‘height control’ function to the user avatar when necessary. In general performance, the user does not need to perform actions at a very low height (lower than 0.5 meters). For those actions which need to be performed at very low level,

Figure 5.1: Oculus Headset using Laser Navigation system (Developed by AUT, New Zealand)

developers can add a function on the Oculus controller that allows the user to adjust the height of the eye-view.

The third possible solution is to add an additional sensor, which can collaborate with other motion sensors to capture motion from any height. This solution is lowly recommended due to the extra cost and complication of configurations.

5.2 Software Problems and Solutions

The problem in software can be split into three aspects: training scenarios, tasks, and architectures.

5.2.1 Training Scenarios

In this research project, we built two scenarios by implementing re-usable components. The scenes from the two scenarios are completely different, but the tasks contained are quite similar. In the future, we plan to build more scenarios which contain dedicated tasks. For instance, a cyclone disaster scene should contain a scenario such as 'if someone is pinned under a fallen tree, how would we rescue him/her?'. Dedicated tasks such as 'moving trees' and 'control major bleeding' can be set based on those new scenarios.

Moreover, group co-operation scenarios which involve many participants collaborating in one virtual environment can be explored in the future. In this research project, the participants are performing the tasks in a 'single player' mode. Also, only one virtual patient needs to be treated in each scenario. However, in reality, there will normally be more people on the response team and patients requiring assistance. How to co-operate with other rescuers and how to dispatch the patients with different levels of injuries by using VR technology are possible research topics based on our current work. Work done by Norri-Sederholm et. al (2016) can provide further research support for those topics.

We recommend that future research employ multi-training patterns. We proposed multi-training patterns during the experiment design stage; however, due to the limited development time, we only implemented one pattern. Figure A.12, Figure A.13, and Figure A.14 demonstrate the training patterns we proposed in the early stage, which correspond to a display, simple training, and parallel training models, respectively. In the parallel training model, participants perform physical and vocal interactions at the same time, which is closer to the real-life situations.

5.2.2 Tasks

The Major tasks and Sub-tasks in this research project are designed to focus on the workflow of emergency healthcare training. Details and first aid techniques are not included in the scale of the VR training software. As we mentioned in the chapter 4, suggestions from first responders indicated that future research could focus on specific problem solving goals, such as 'control bleeding'. An appropriate way of implementation would include introducing specific problem occurring in a emergency healthcare circumstance (e.g. major bleeding), different conditions that could caused by this problem (e.g. major bleeding on different parts of the body), and the procedures to prevent or solve such problem (e.g. the techniques to control the major bleeding).

5.2.3 Architecture

The architecture of our current VR training software has features of flexibility and extensibility. However, this architecture is mainly designed for linear scenarios. We plan to develop an improved architecture that supports 'Open-World' style scenarios. 'Open-World' is a video game term defined by Computer & Games. (2008) and Booker (2008), in which a player can roam a virtual world and approach objectives freely, as opposed to a game with more linear gameplay. We believe that an open world style scenario will be better than a linear one to evaluate the participant's training result. To build the open world style scenarios, some components in the current system architecture need to be modified or upgraded. For instance, dynamic objects need to be grouped (e.g. catchable, touchable, etc.) and more interaction functionalities need to be added on to groups to provide different responses to the user. We provide three possible training patterns in the Appendix A.10.

5.3 Threat of Validity

Based on the methodology we used, we listed threats to internal and external validity that may affect the research outcome.

5.3.1 Threats to Internal Validity

History

In this research, as we aware that VR is a new technology for most of the participants, we set up full instructions in both vocal and text format in our training software. We believed this proposed method could minimize the occurrence of unanticipated event which may affect the results. As reflected in the results, most of the co-relations are in our initial expectation (e.g. co-relation between technical background and timespan). However, a small amount of unanticipated event still occurred and eventually caused inconsistency result in specific feature. For instance, a few participants with higher technical background spent longer time than the rest due to their preference of 'discovering the VR world', but not 'struggling by the task'.

Maturation

As mentioned in previous chapters, there is a 'one week interval period' between the second training session and the recall session. The initial consideration of this proposed design is that we want to observe the influence to learning curve by different features. This could be a potential threat of maturation. Although the reflection of results shows that all participants has eventually improved their performance in the recall session. However, the relative deviation of the recall session in specific personal feature is still large.

Statistical regression

In this research, we used timespan and moving distance as two major measurement dimensions. Although the experiment and research protocol are designed to avoid statistical regression. During the analysis process, we still investigated every single extreme data (e.g. extreme long timespan or distance moved) by playback the video which is recorded during the training session. Overall, those extreme data do not affect the objectivity of the final results.

Selection

Selection is a very important consideration of validity while we recruiting the participants. As mentioned in 3.4, we set personal features which can category the participants. We tried to keep the variation in all features when we recruiting the participants. However, due to time and geographical limitation of the recruitment process, we only partially kept the variation in some features such as technical background and education background. Some features such as age and prior-VR experience are not perfect balanced. This could be a potential threat to the validity of the research. We recommend that in the future research, there could be a more balanced participant groups.

Testing

We isolated the outcomes of three training sessions, therefore, the results from previous training session would not affect the following training session. All participants are required to perform three training sessions, there is no dependency of their performance across different sessions.

Design contamination

The design contamination is also a considerable threat while we began to develop our research experiment. To avoid this threat, we kept every participant in anonymous status and there is no communication between them until the entire experiment was finalized. During the training session, the performance area is closed and only the scheduled participant is allowed to enter this area. According to the schedule, there is no possible way that participants can see or talk to each other. The researcher only gave basic assistants when it is needed. The assistants regards to training content would not be given.

Experimental Morality

There is no participant who failed or quit the experiment, as restrictive recruitment principles are set. The recruited participants finished all training sessions.

5.4 Future Research

Based on our current research and conclusions, we recommend future research as follows:

Further analysis based on current data collection

As personal features and high accuracy performance data are collected from our experiments, we suggest that further analysis can be done based this data collection. For instance, researchers can analyse the relationship between performing styles (not only the timespan and distances) and personal features. We believe such analysis can provide conclusions that may improve the next generation of training software.

Experiments with larger participant groups

As limited by the project scale, we only conducted 30 training sessions based on 10 participants. In the future, with few iterations of the current version of VR training software, we highly recommend conducting more experiments with larger participant groups. Larger samples will provide more information between personal features and their performances, which can also support stronger evidence based on larger scales of quantitative research.

Implementation based on AR/MR

In specific tasks such as ‘Body Swiping’ and ‘Airway maintenance’, VR technology shows one of its major drawbacks which is lacking physical feedback from the object. We highly recommend implementing those tasks with AR/MR technology, as it can provide a fully immersive experience to the participants. On the other hand, the participants can gain comprehensive knowledge by physically touching and interacting with the objects. The AR/MR technology may not be applicable to the entire workflow training, but it can show advantages on training for specific tasks.

5.5 Conclusion

In this chapter, we discussed the problems we had during the VR training sessions and considered the direction of future studies. Firstly, we discussed hardware problems with regards to the VR headset and the motion sensors. Secondly, we indicated the possible improvement of VR training software in the perspective of scenario, task and system architecture. Finally, we specified three future research directions.

Chapter 6

Conclusion

In this thesis, we first reviewed the literature regarding VR technology and emergency healthcare training. Then, we identified the emergency healthcare workflow (EHW) from referenced sources (e.g. John (2018) and skills for life ltd. (2013)) and converted the EHW to a process diagram. We used incremental methodology to conduct a software development project based on this process diagram. The main outputs of this project is a VR-based emergency healthcare training software. After the software development, we trained 10 participants with a total of 30 sessions on the emergency healthcare workflow by using the emergency healthcare training software. Their personal and performance data were collected by the training software and stored in a SQL database to be analysed.

Three major conclusions are made based on our evaluation of those data:

1. Technical background plays the most significant role among all other features while assessing participants' performance in our training sessions. People with more technical background adapt to the VR environment quicker and are generally more explorative, while those with less technical background are slower and concentrate more on finishing the tasks without noticing other elements in the VR environment.

2. With repeated training, people despite with different background, can eventually gain knowledge and improve their performance with reduced total timespan.

3. During the training, native English speakers prefer to acquire information by listening to vocal instructions and the non-native English speakers prefer to acquire information by reading text instead.

We found that the current VR headset hardware still has potential for improvement. For instance, the VR headset can be designed with wireless connection, thus giving the user a better experience. Moreover, the motion sensor should incorporate 'full-body' tracking, rather than 'half-body' tracking. We also discussed the possible improvement of our software in the perspective of scenario design, task design, and architecture design.

We list two main limitations of our research as follows:

- This research focuses on the EHW training, therefore, less technical details (e.g., major bleeding control) are presented in the training software.

- Only 10 participants were recruited by the research and each of them only perform 3 training sessions. This is a limitation due to the time limit for this study.

For future research, we have the following directions:

- Further analysis can be conducted based on our current data collection. For instance, the use of machine learning algorithms to evaluate more correlations between personal and performance data.

- More technical details of emergency healthcare training can be added based on the current version of the training software. For instance, techniques of CPR, AED, etc.

- Experiments with larger participant groups can be conducted. In addition, with a higher amount of participants, the evaluation method can be improved.

Overall, this one year research project built a foundation of using VR technology on emergency healthcare training. It indicates a method that can be used to convert EHW, develop the training software, and evaluate experiment results. The final results of evaluation indicated that VR technology has potential to train people the emergency healthcare workflow efficiently and effectively..

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Appendix A

Research Materials

A.1 Functional Requirement Lists for the Prototype Software

We analysed and defined the functional requirements for the prototype software as follow:

- Environment

    1. The prototype should be able to demonstrate a virtual environment.
    2. The virtual environment shall be able to simulate a real-world scene, which contains lighting, shadowing, building object models as well as their materials.
    3. This virtual environment can be a static world, but essential physics such as force, rigid body, collision, material reflection shall be contained.
    4. The objects, components or mechanisms from above-mentioned requirements shall be reusable, adjustable and replaceable. All the procedures shall be finished without replicated or redundant programming.

5. Emergency healthcare scenes can be placed within this virtual environment. The application shall be able to switch between those scenes within very short time (e.g.between 50ms and 3sec).

- Player

1. The prototype should be able to simulate a virtual object that represents real user, so-called 'Avatar' in following paragraphs. The appearance of the Avatar shall be human-like.
2. The Avatar shall be constructed by lighting, shadowing, object models and materials.
3. The design styles of Avatar shall be fitted with the design styles of the virtual environment. The following examples addressed some incorrect matching of design styles:
   (a) An ancient worrier Avatar and modem city. The time and era do not match.
   (b) An Avatar with decent suit and battlefield. The context does not match.
   (c) A 2D Avatar with a 3D environment, vice versa. The model dimension does not match.
4. The Avatar shall be a dynamic object with essential physics such as skeleton, joints, rigid body, collision, material reflection etc..
5. The objects, components or mechanisms of the Avatar must be reusable, adjustable and replaceable. All the procedures shall be finished without replicated or redundant programming.
6. The Avatar can proceed customized interactions by adding scripts.

- Interactions

1. The Avatar shall able to move in the virtual environment. The definitions of 'move' include moving forward, backward, leftward, rightward and turning.
2. (Optional) The Avatar can jump in the virtual environment.
3. The Avatar can interact with objects in different ways in the virtual environment.

- Software Performance and Configuration

1. The prototype must be compatible with at least one Operation System in Windows 8.1, Windows 10, Linux Ubuntu 14.00 or higher version.
2. Visual resolution and display mode of the prototype must compatible with both LED monitor with a different range of screen resolution setting and commercial level of VR hardware.
3. The prototype can play media format files such as audio and video.

A.2 Component Descriptions for Prototype Architecture

A.2.1 Presentation Layer

Five components or objects are identified at this layer and their major functionalities are addressed as follow:

1. Graphic User Interface

   This component generates a GUI framework.It also receives messages from other components or objects via Actions Layer and display them in a re-defined format.

2. Scene Environment

   This component generates a virtual environment and manage the parameters relevant to the environment, such as lighting control or scene control.

3. User Avatar

   This component generates an Avatar and the avatar responses to user control by any designed inputs(Mouse,Keyboard,Controller,etc.).The avatar actions are controlled by logic events management components from Actions Layer.

4. Interact-able Objects

   Those objects are set at the virtual environment and can be interacted with the user avatar. Their properties and logic events are controlled by components from Actions Layer.

5. Static Objects

   Those objects are statical, such as cars, chairs etc.. Their properties and actions are pre-defined and keep static over all the software life-cycle.

A.2.2 Action Layer

Three components are identified and only C-Sharp scripts will be employed at this layer.

1. Avatar Movement

   This component controls avatar's movement action. It builds a connection between User Avatar component in Presentation Layer and hardware inputs such as Mouse input by referencing relevant classes from Unity Engine Library.

2. Avatar Interaction

   This component provide different interactions to the avatar. Some interactions such as bing object can be generalized , and the others such as avatar animations need to be customized to a dedicated methods.

3. Object Interaction

This component provide interactions to the interact-able object, thus they can correctly respond to different actions performed from avatar.

A.3 Compare Unity Engine and Unreal Engine

we compared advantages and disadvantages of them as follow:

Table A.1: Unity Engine and Unreal Engine comparison

Engine	Advantages	Disadvantages
Unity	1. Lightweight client architecture. Easy to install, debug and built the software 2. Convenient to configure VR project 3. Low learning costs and full documentations 4. Low developing costs (The Engine itself is free) 5. Advanced UI design system 6. originally support programming languages include C-sharp, Boo script and Unity script 7. Assert Store 8. Provide some VR project Demo and documentations	1. Less built-in tools 2. Inefficient resource usage for rendering system 3. Lighting system is too simple 4. Sometimes bugs occur for the shadow system 5. Poor support for material editing 6. less support for game controllers than Unreal Engine
Unreal	1. Visual effect satisfy the requirement of a typical 3A game product 2. Better Lighting system and Rendering system than Unity Engine 3. Blueprints visual scripting system allowed user plan the project without coding 4. Provide material editor and other official add-on editors. 5. Provide some game development templates 6. Game controllers are well supported	1. Originally only support the C++ programming language 2. The entire engine itself needs to be recomplied if the target deploy platform is Sony Play-station 4, and that takes up to few hours to be finished. 3. High learning cost. The sub-system or editors are well functional ,but they are too complicated to a beginner 4. Some documentations are missed 5. Extremely high development cost 6. Lacking of VR project samples and documentation

Figure A.1 indicated the difference between Unity and Unreal Engine in various perspectives. They also demonstrated different preferences of 'Art Style' of rendering system over these engines. Those so-called 'Engine Style' can also be found in other commercial games developed by industry in the game market.

A.4 Learning pathways for Unity

There are different development roles in a development team and we recommend the following example learning pathways for those developers. For instance, to satisfy the requirement 'The virtual environment shall be able to simulate a real-world scene, which contains lighting, shadowing, building object models as well as their materials.'. The researcher can focus on learning the knowledge relate to Physics component (In Unity Essential), Environment modelling and texture/materials replacing. We displayed the learning pathway of those knowledge in the mind map at figure A.2.

As the example demonstrated, this design methodology provides flexibilities and extensibility to the project. For a development group, the developers can be assigned to specific roles such as 'Environment Designer' or 'Character Designer', learn relevant knowledge and co-operate with each other. The figure A.3 demonstrated two possible learning pathway for different roles in a development team. For individual developers, they can play different roles in different development stages, and only concern relevant knowledge.

(a) Lighting and Hybrid Rendering

(b) Lighting, Shadowing and Indoor Rendering

(c) Lighting and Shadowing

Figure A.1: Unity Engine (Left) VS Unreal Engine (Right)

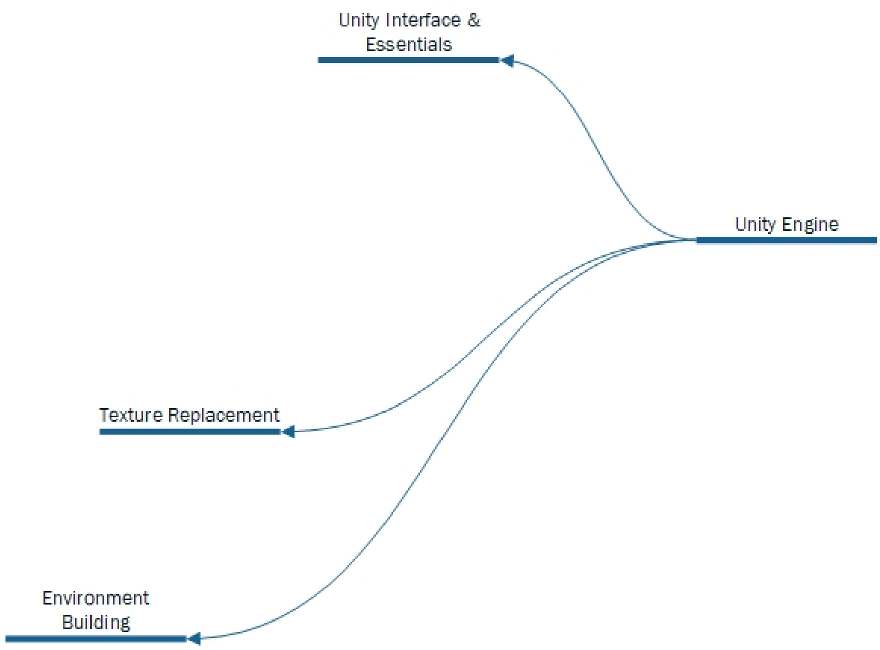


Figure A.2: Learning Pathway for Environment Designer

A.5 Demonstration of building virtual environment

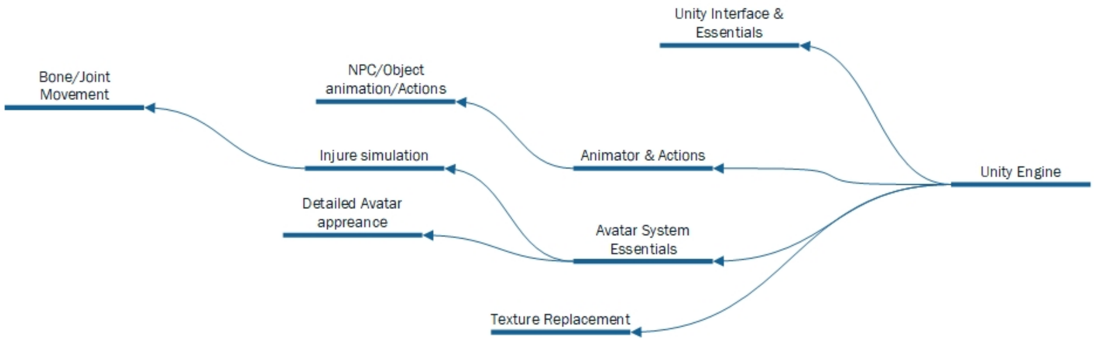
A.6 Trigger Mechanism

As an example, in the prototype software, a virtual patient is designed as an interact-able object. We set a trigger beside this virtual patient object and added the interaction events on it. Radius of the trigger has been set as 2 times larger than attached game object and it will triggering the add-on events when a target object is collided with its conllider. Figure A.5 followed by indicated how this mechanism works:

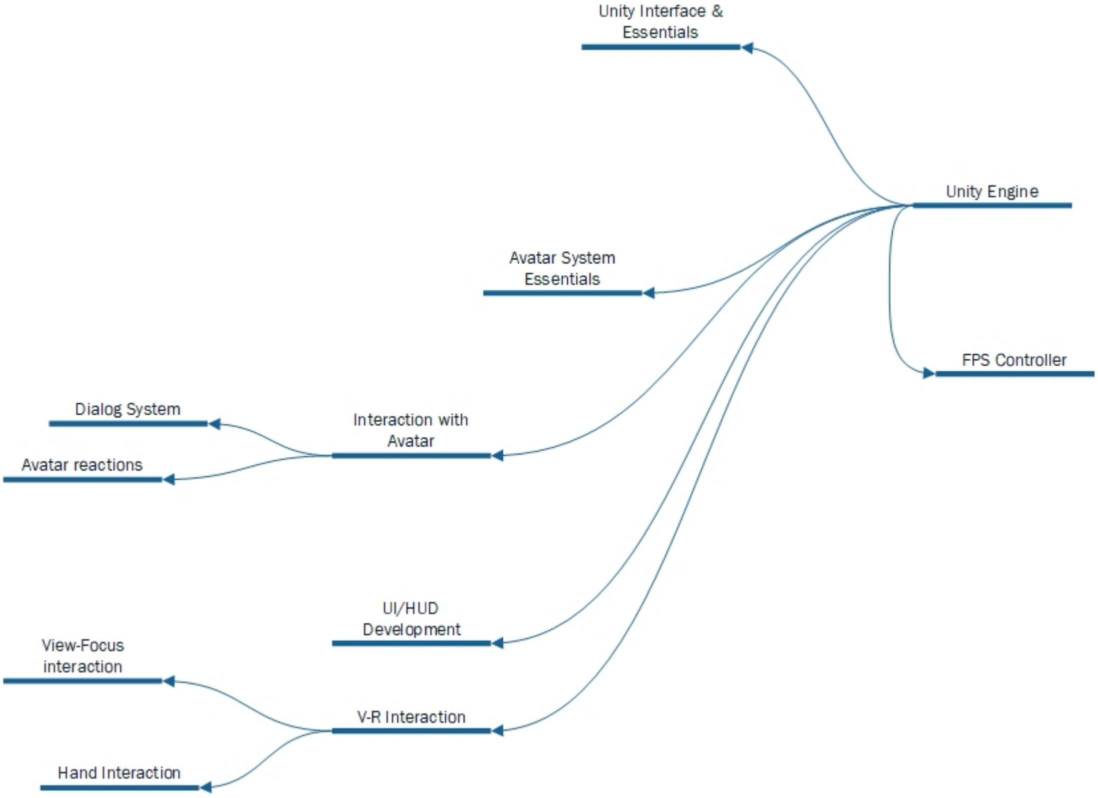
A.7 Possible improvements evaluated from the Prototype Software

- Possible Improvement 1: More flexible software architecture

  Although the software architecture of the prototype software has extensibility

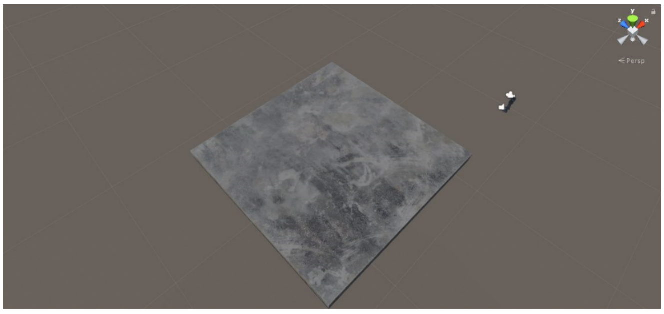


(a) Learning pathway for Script Designer

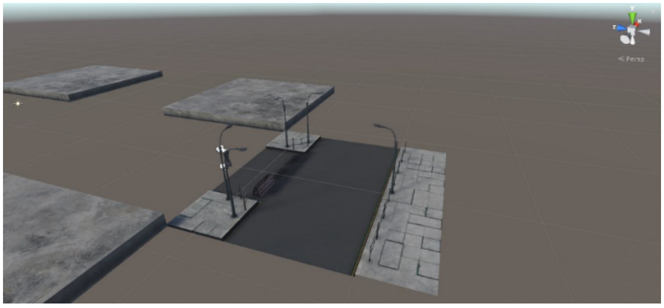


(b) Learning pathway for Character Designer

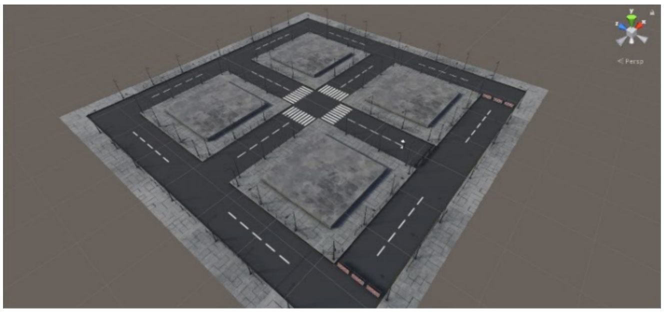
Figure A.3: Learning pathway for different roles in development team



(a) A single profab asset - Floor block



(b) A grouped profab asset - Street block



(c) Virtual environment constructed by different profab assets

(d) Zoom-in view of the virtual environment

Figure A.4: Build virtual environment scene

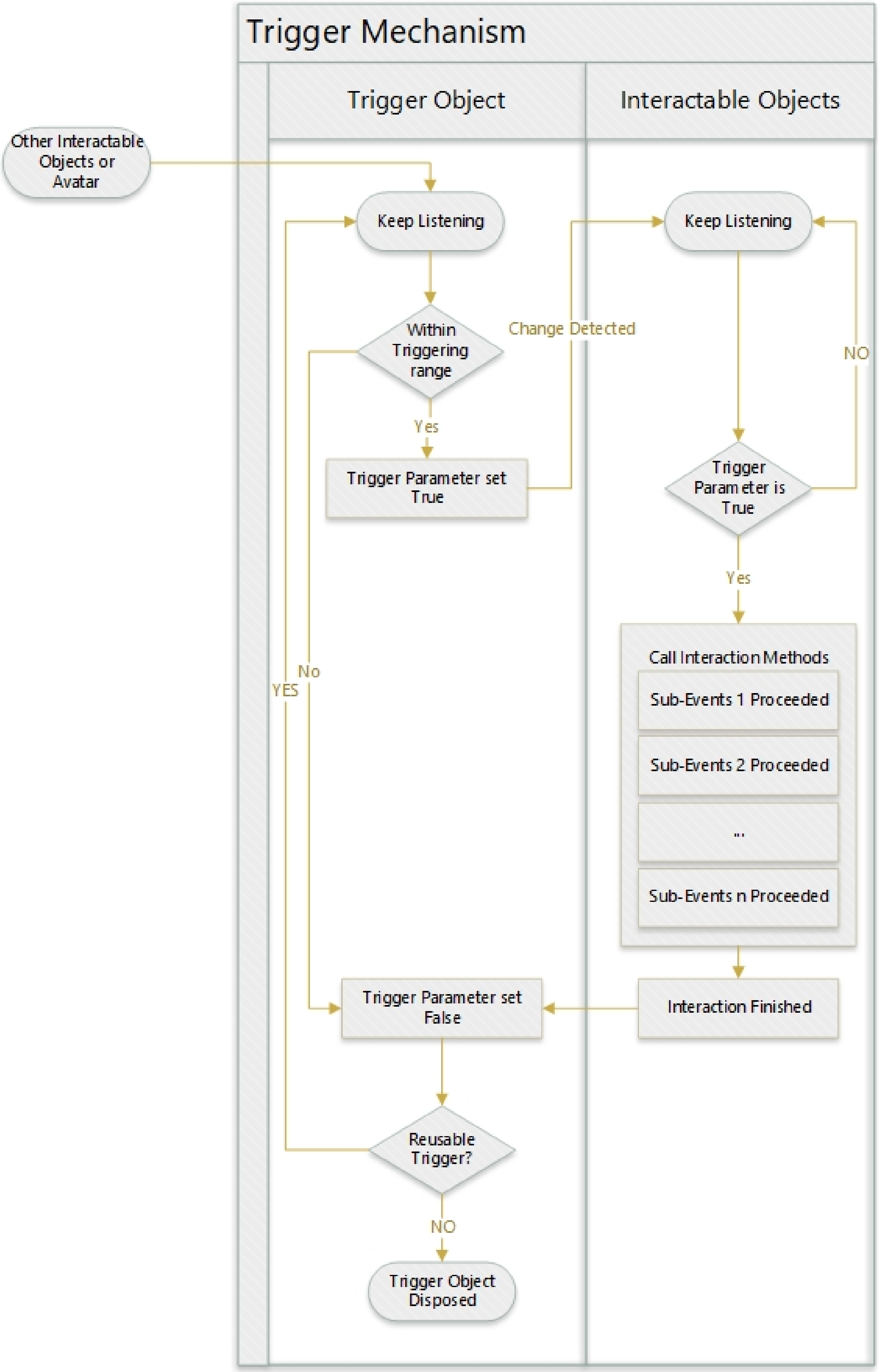


Figure A.5: Trigger Mechanism

and flexibilities, we found that methods or functions in the Actions Layer still not abstracted enough. In the future version of software, we plan to redesign the components in the Actions Layer that makes the software more flexible. There are some design patterns we can use for optimization, for example, the dedicated functions (a specific procedures for a single task) and the general functions (functions that can be shared by multiple tasks) can be defined and implemented separately.

- Possible Improvement 2: Advanced environment modelling and texturing

  The virtual environment and object modelling in the prototype software are just meet the basic requirements of our initial design. Details of those objects are not well considered as limited development time. We plan to implement objects with detailed model and higher resolution of textures in the future version of software.

- Possible Improvement 3: Implementation based on real VR device

  We found that practices of using VR device APIs are also necessary. As the virtual reality devices were not purchased during the prototype software development stage, the VR based interactions can not be implemented. Although we used the simulator to simulate the VR screens, the actual feedbacks of the interactions are quite different. We plan to involve the VR device at the beginning of the software development, then the developer can implement the functionalities based on the real VR device and we believe that this can bring better user experience to the software.

A.8 Recruitment Protocol

After decided the criteria of experiment invitation, we set up a workflow that guided us how could we recruit the participants as well as satisfy the requirement of the ethics approval. Figure A.6 demonstrated the full workflow of the recruitment process.

There are few steps need to be finished during the recruitment process. To begin with, the primary researcher will deliver the experiment posters to different places in AUT city campus and Northshore campus. Those posters contained simplified but essential information about this research project, such as what is our goal and what time will the experiments be happened. If any potential participants are interested in the experiment, they can contact the primary researcher and make an appointment for first contact meeting.

The first contact meeting is a face to face communication mechanism that we utilized to introduce our research project and recruit participants. Each first contact meeting involved primary researcher and only one potential participants. The duration of this meeting is about 15-20 minutes on average. During each of the first contact meeting, the primary researcher will talk about our research project to the potential participants which include the project background, our aims and goals, and what the experiments need to be done. A participant information sheet will also be delivered to the potential participants as a compulsory requirement of ethics approval. Some simple questions will be asked to make sure the potential participants meet the requirements of the inclusion criteria as described before and do not meet any requirements of the exclusion criteria. Finally, in the contact meeting, a formal invitation will be announced to the potential participants.

Each potential participants have up to 3 weeks of consideration period to consider whether they wish to join the experiment or not. At any time within those 3 weeks they are allowed to send either acceptive respond or rejective respond to the primary researcher. If nothing was sent from a potential participant after 3 weeks, then we assume that the participant is not interested to participate in this research project and his/her response will be set as rejection by default. Personal information of all the rejected potential participants will be deleted due to information security consideration.

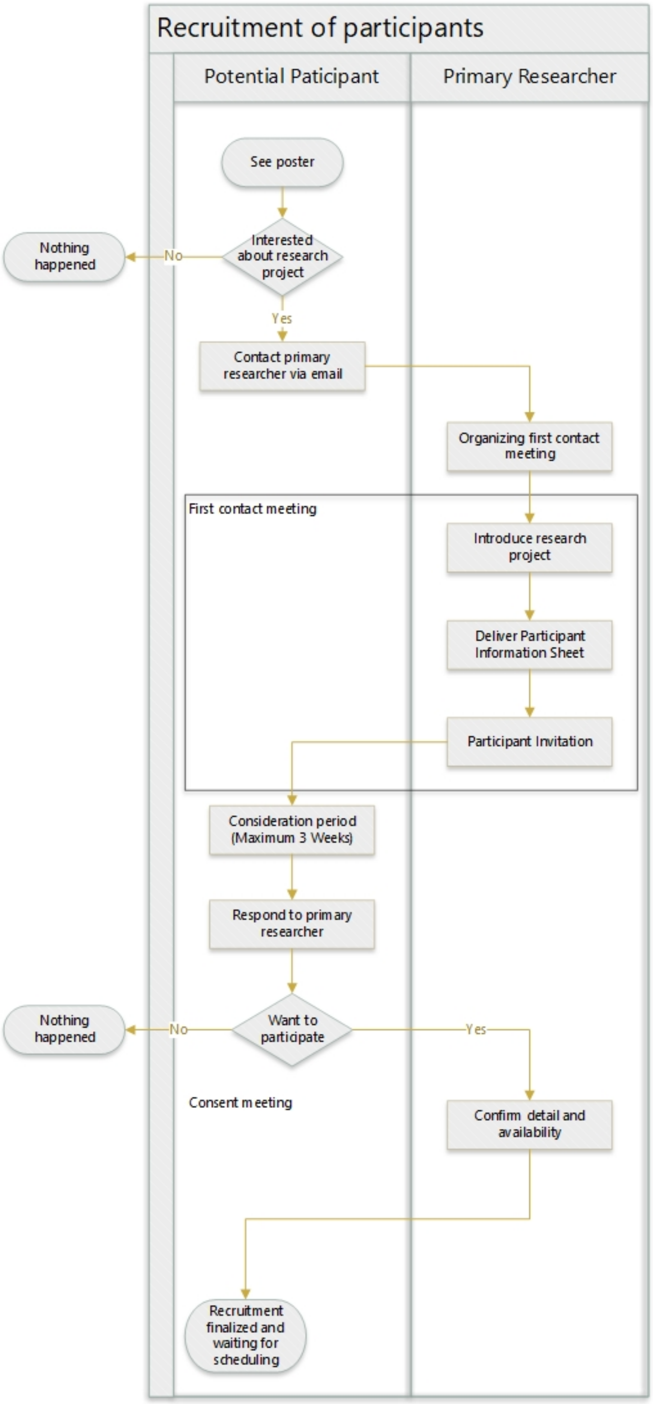


Figure A.6: recruitment

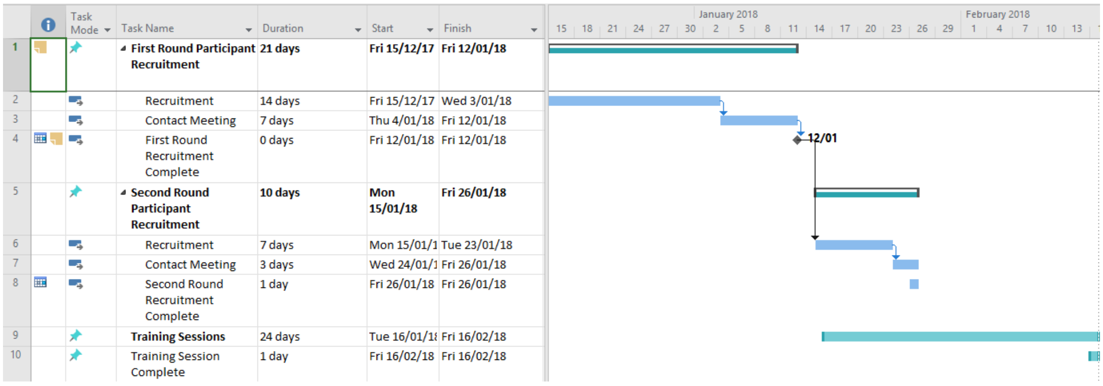


Figure A.7: The schedule of participant recruitment

For those who confirmed that they would participate the experiment, the primary researcher will confirm the detailed information with them. After check time availability with those participants, an experiment time slot will be allocated to each of them. The recruitment process is finalized once all the participants confirmed the schedule.

A.8.1 Time Schedule of Participant Recruitment

Based on our estimation of project progress, we set up 2 round of recruitment. The second round of recruitment is an optional process in case of that the participants recruited from first round did not satisfy the minimal requirement of the experiment. Figure A.7 shows the planned schedule of participant recruitment.

In the initial schedule, the first round of participant recruitment shall start no later than 15th December 2017 and end at 12th January 2018. All the potential participates have 15 working days maximally (3 weeks in general) to consider their availability of participation and make the final decision. Based on the number of confirmed participant, the research team should decide whether the second round of participant recruitment is needed. If the second round of participant recruitment is needed, it would start no later than 17st January, 2018 and end before 30th January, 2018. The Same process as first round participant recruitment, the potential participants have 15 workdays maximally for consideration and decision making.

2 weeks after participant recruitment, the experiments will be arranged to start. As above-mentioned it approximately takes 15-20 working days to finish those training sessions. Optimistic time estimate for finalizing the training session would between 16th January 2018 and 16th February 2018.

However, due to multiple reasons such as overlapped university holiday and Christmas holiday, delayed application integrate testing etc., the recruitment process is finalized at the beginning of the AUT semester 1, 2018, which is the 1st of March and one month behind the scheduled date. The finalization of experiments is also one month behind the estimated schedule.

A.8.2 Information Security policies

By satisfying the requirement of ethics approval, we applied following key principles of privacy protection and information security policies to protect participants' privacies.

There are two key principles of privacy protection we followed with, the first key principle is that any data collected, saved and published must not contain any identifiable information for participants. The second principle is that the data must be stored and accessed in a safe way without any information leaking.

Based on above-mentioned principles, we used following compulsory policies to ensure the participants' privacy is secured:

1. No identifiable images will be made public.
2. The electronic version of contact details will be not allowed to be stored on any public or private network servers. Those data need to be stored at the dedicated computer with strong password policy.
3. Any hard copies of participants' contact details are not allowed to be created before they signed the consent form.

4. For those who already signed the consent form, the hard copies of their contact details will be stored in a locker which is located at Central of Artificial Intelligence Research (CAIR) AUT, WT 411, AUT city campus temporarily. Those hard copies must be destroyed after the completion of data analysis.

5. The researcher can only collect the data which are indicated in section 3.4. Any other un-indicated data will be considered as unauthorized data. The participants keep their rights to ask the researcher to remove any unauthorized data.

6. The researchers must keep the data collections in private. Only the authorized persons have the permission to access the data.

7. If anyone except the currently nominated researcher will be involved in this research project (e.g. Research assistant), a Confidential Agreement (CA) need to be signed.

Beside those compulsory policies, we also defined data storing and destroy policies to satisfy the requirement of ethics approval. According to the storing and destroy policies, we defined that once the analysis is completed, electronic data and consent forms will be stored respectively in two different office located at AUT city campus. More specifically The electronic data will be downloaded to an external hard drive and be locked in a steel cabin and the cabin will be installed at WT134, AUT city campus. While, The consent forms will be locked in a cabin as well. This cabin will be installed at Central of Artificial Intelligence Research (CAIR) AUT, which is located at WT 411, AUT city campus. After six years, the electronic data stored in the external hard drive will be destroyed by formatting the external hard drive and the consent forms will be destroyed by a shredder.

The access permissions are also defined to protect participants' privacy. In this research, only the primary researcher and his supervisors have authority to access to both of the above-mentioned data.

A.9 Experiment Hardware Demonstration

A.9.1 Oculus Devices

1. Oculus Rift Virtual Reality Headset

   Oculus Rift is a set of virtual-reality goggles that will work with desktop or laptop. The Oculus Rift using a pair of screens that displays two images side by side, one for each eye. A set of lenses is placed on top of the panels, focusing and reshaping the picture for each eye, and creating a stereoscopic 3D image. The goggles have embedded sensors that monitor the wearer's head motions and adjust the image accordingly. The end result is the sensation that users are able to look around an immersive 3D world.

2. Oculus Sensor

   In Oculus sensor, the Constellation system has been designed as an extendible single-camera solution. This gives users the option to play with various sensor configurations and extend the tracking ability of the system for use with Oculus Touch controllers. In this research project, 3 sensors are required due to its room-scale VR training sessions.

3. Oculus Touch Controller

   Oculus Touch is a new VR input device that Oculus VR unveiled alongside the consumer model Oculus Rift. It's actually a pair of tracked controllers designed to deliver a "hand presence", which provide more nature-style interaction options for user as well as developers.

Figure A.8: Oculus Rift Virtual Reality Headset

Figure A.9: Oculus Sensor

Figure A.10: Oculus Touch Controller

Figure A.11: GoPro action camera

A.9.2 Motion Cameras

1. Gopro Action Camera

   GoPro is the action camera of choice as it is lightweight, compact, and mountable. The GoPro camera can capture still photos and video in high-definition through wide-angle lens while being remotely controlled or configured to work automatically. In this research, we plan to use GoPro as a front-top motion capture camera. The reason to choose GoPro due to its wide-angle lens camera and high-definition motion capturing features as above mentioned. It is easier to monitoring the whole experiment environment with acceptable motion details.

2. DSLR Camera

   A digital single-lens reflex camera (also called a digital SLR or DSLR) is a digital camera that combines the optics and the mechanisms of a single-lens reflex camera with a digital imaging sensor DSLR camera will be used as a side camera that co-operate with front-top camera.

A.9.3 Desktop Configuration

The configuration of the desktop is shown below:

Table A.2: Experiment Desktop Configuration

Components	Model/Specifications
CPU	Intel Core i7-2600 CPU @3.40GHz (8 Cores)
RAM	32GB
Storage Device	256GB SSD and 320GB Hard drive
Graphical Card	NVIDIA GeForce GTX 1070
Operation System	Windows 10
Monitor	24 inch wide LED monitor

A.10 Training Pattern

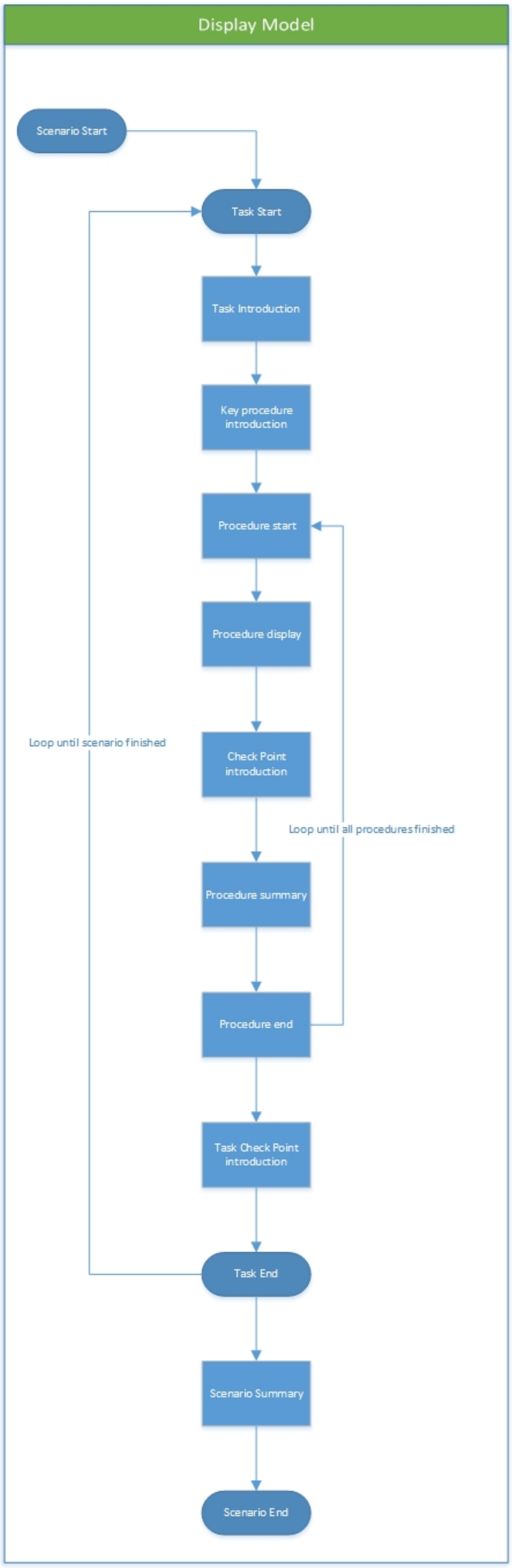


Figure A.12: Training Patten 1: Display Model

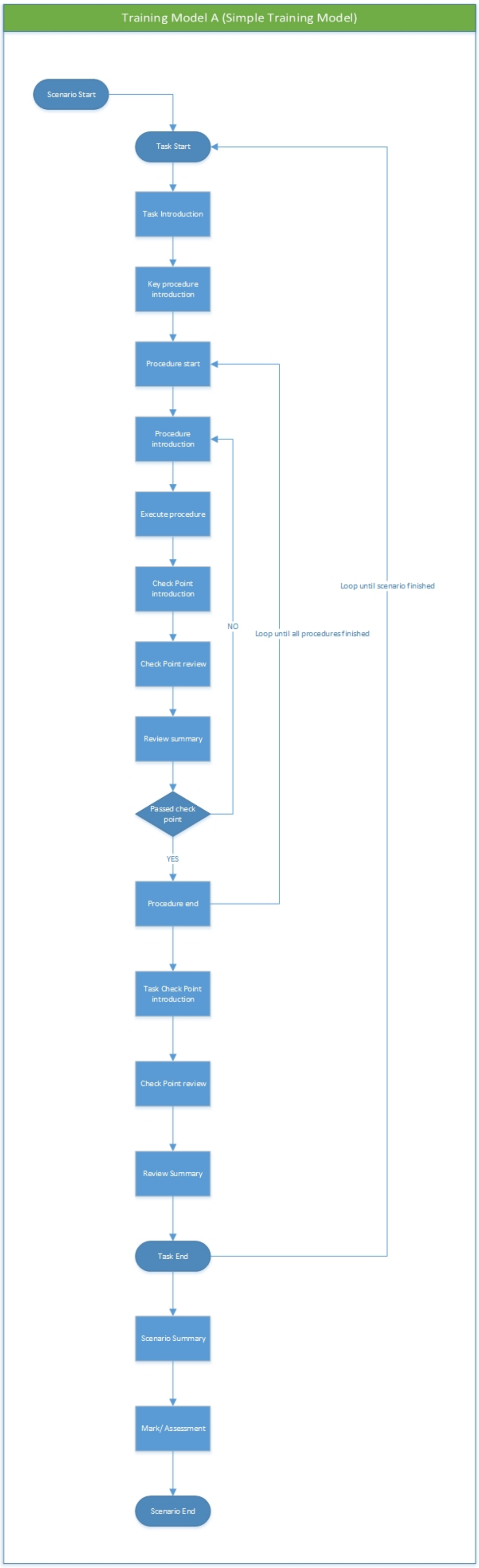


Figure A.13: Training Patten 2: Simple Training Model

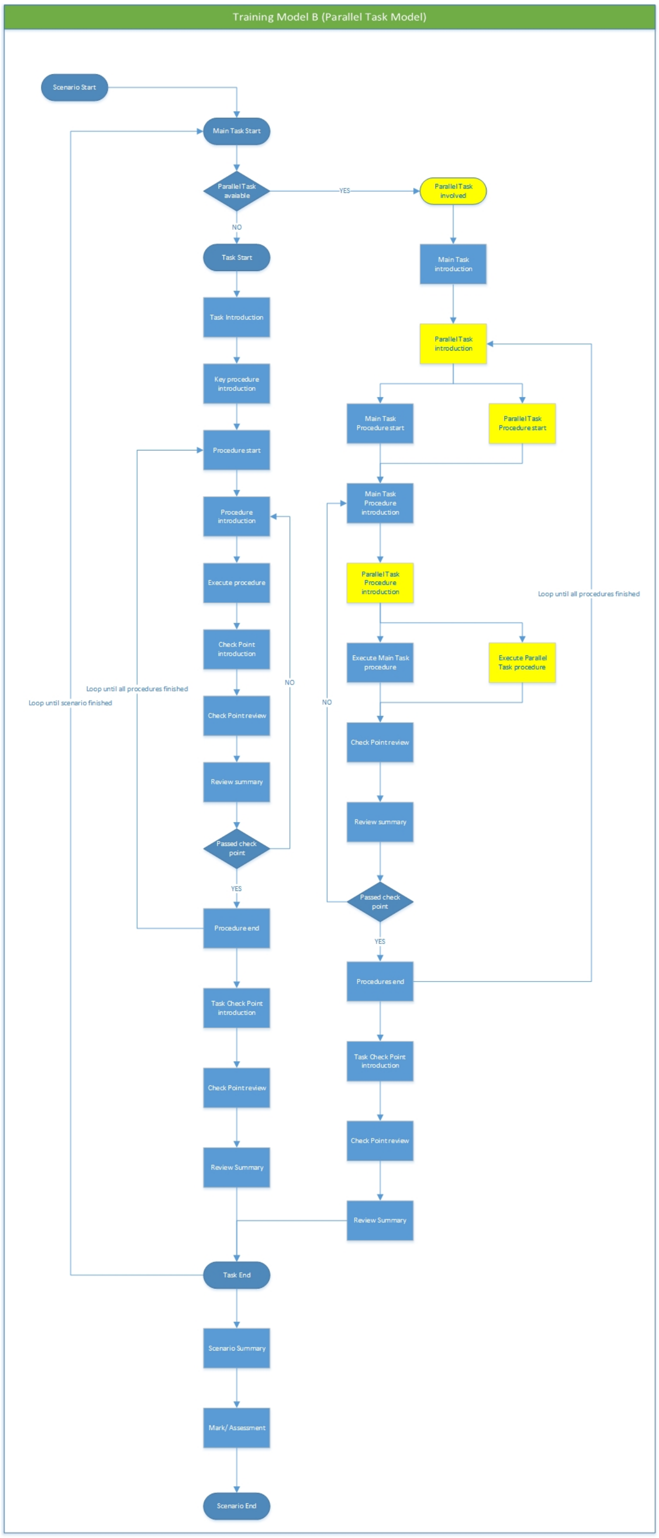


Figure A.14: Training Patten 3: Parallel Task Model

Appendix B

Ethics Approval

The ethics approval application was submitted to the AUT ethics committee on November, 2017. Full ethics approval was issued on 1st December, 2017. The Issue number is 17/428, Enhancing healthcare with virtual reality. Figure B.1 shows electronic copy of the full approval.

AUTEC Secretariat

Auckland University of Technology
D-88, WU406 Level 4WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

1 December 2017

JiRuan
Faculty of Design and Creative Technologies

Dear Ji

Re Ethics Application: **17/428Enhancing healthcare with virtual reality**

Thank you for providing evidence as requested, which satisfies the points raised the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 1 December 2020.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form:http://www.aut.ac.nz/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtainingit. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries,please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: peng.xia@aut.ac.nz; Dave Parry

Figure B.1: The Ethics Approval