



An Examination of the Use of Virtual Reality in Neonatal Resuscitation Learning and Continuing Education

by

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Abstract

Virtual Reality (VR) is an Extended Reality (XR) technology used in many fields, like education and healthcare. One area where VR shows promise is in Neonatal Resuscitation Program (NRP) training. VR provides a lifelike and interactive environment where healthcare providers can practice resuscitation skills, especially if they work in rural or remote areas with limited access to hands-on training. This study aimed to evaluate and compare the impact of two Virtual Reality (VR) technologies, VR simulation and 360° videos, as instructional tools for the Neonatal Resuscitation Program (NRP). There were 15 participants randomly assigned to each condition, with a total of 30 participants. The study focused on assessing participant perceptions, experiences, and satisfaction with each technology, as well as their impact on learning outcomes. The methodology involved a robust data analysis, which entailed descriptive statistics, Chi-Square analysis, and/or T-test for within-group score comparisons. The results indicate that both VR technologies were positively viewed by healthcare professionals for NRP training. However, VR simulation provided a significantly enhanced sense of presence and immersion, leading to improved experiential learning outcomes. Participants using VR simulation reported higher confidence in certain NRP skills, such as proper mask placement and newborn response evaluation. Despite these benefits, no significant improvement was noted in other NRP skills. In conclusion, VR technologies hold significant potential for enhancing healthcare education, including NRP training, and future studies may explore the combined use of VR simulation and 360° video, as well as their application in other areas such as cardiopulmonary resuscitation (CPR) and advanced cardiovascular life support training (ACLS). This research represents a step forward in understanding how VR technologies can contribute to effective and immersive medical education, with potential implications for remote and rural healthcare providers.

To my family and my beloved wife

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List of abbreviations

3D	3 Dimensional
AAP	American Academy of Pediatrics
AHA	American Heart Association
AMA	American Medical Association
AR	Augmented Reality
AV	Augmented Virtuality
bpm	beats per minute
CAVE	Cave Automatic Virtual Environment
CFPC	College of Family Physicians Canada
CME	Continuing Medical Education
CPR	Cardiopulmonary Resuscitation
CPS	Canadian Pediatric Society
HCP	Health Care Practitioners
HMD	Head Mounted Display
HR	Heart Rate
MR	Mixed Reality
NL	Newfoundland and Labrador
NR	Neonatal Resuscitation
NRP	Neonatal Resuscitation Program
PPV	Positive Pressure Ventilation
PQ	Presence Questionnaire
RCPSC	Royal College of Physicians and Surgeons of Canada
SG	Serious Games
TTS	Text-to-Speech
VE	Virtual Environment
VLE	Virtual Learning Environment
VMARs	Virtual, Mixed and Augmented Reality Systems
VPL	Virtual Programming Languages
VR	Virtual Reality
VR-SGs	Virtual Reality Serious Games
VRE	Virtual Reality Environments
WHO	World Health Organization
XR	Extended Reality

Chapter 1

Introduction

Since the development of Virtual Reality, several variations of the technology have emerged. In addition to Virtual Reality, other virtual technologies include Augmented Reality, Mixed Reality, and Augmented Virtuality. These various technologies are encompassed under the umbrella term Extended Reality (XR) and will be discussed below.

1.1 Virtual Reality

The term Virtual Reality (VR) was first coined in 1987 by Jaron Lanier, the founder of Virtual Programming Languages (VPL) Research in the United States. VR was defined as “a computer-generated, interactive, three-dimensional environment in which a person is immersed” [1]. Specifically, computer graphics systems are used in combination with various display and interface devices to provide the effect of immersion in the interactive 3D computer-generated environment, called a virtual environment (VE) [2]. In a virtual environment, users are able to navigate - they are

able to move around and explore the features of a 3D scene. Users are also able to interact, meaning they have the ability to select and manipulate objects in the scene, and receive inputs and produce outputs into the system. For example, users are able to walk through a forest (navigate) and grab and examine a flower found in the forest (interact) [3]. In order to interact with the virtual environment, tools such as Head Mounted Display (HMD), controllers, special glasses, gloves, joysticks, mice and other devices are used [4], [5]. HMDs provide users with an immersive experience with fully realistic images, sounds and other sensations that replicate the actual physical environment [6]. For example, a user may wear an HMD while standing in his/her living room and have a virtual scuba diving experience.

1.2 Virtual Reality Devices

About 20 years ago, the development of devices that surround the user in large 3D viewing areas made it possible for highly-immersive VR. VR technologies include, but are not limited to, Cave Automatic Virtual Environment (CAVE) and Head-Mounted Displays (HMD) [7]. CAVE is a projection-based VR display which uses large, fixed screens more distant from the viewer. CAVE provides a room-sized immersive 3D visualization system that allows users to collaboratively examine and manipulate complex 3D models with natural interaction and a human 1-to-1 scale. The benefit of CAVE is that it is immersive, but at the same time, it doesn't completely isolate the users from the real world, which can be highly intrusive and disorienting to some users. The viewer is still aware of the real world and is able to see his/her own body, which decreases the chances of nausea [8].

HMDs do not allow users to see the outside view of the real world, but rather,

users see the virtual environment instead [9]. There are various brands and models of HMDs that are available. The HMD brands that are most widely used, particularly for training and educational applications, are Oculus Rift (in its three versions) and HTC Vive [7]. While the first-generation HMDs, including Sony HMZ-T1, Nvis nvisir sx111, and Emagin z800 HMDs, are the least used nowadays [7]. Since the development of HMDs, many VR-Environments have been created and applied to educational tasks in specific knowledge areas: mathematics, language, business, health, computer science, and project management [7].

1.3 Increased Usage of Virtual Reality

The VR industry is rapidly growing, with the consumer virtual reality market, divided into hardware and software segments, projected to increase from 6.2 billion U.S. dollars in 2019 to over 16 billion U.S. dollars by 2022 [10]. Similarly, the standalone VR market is expected to reach 98.4 million sales by 2023, generating an installed base of 168 million units with a worldwide population penetration of 2%. This growth is forecasted across all countries, with China taking the lead [11].

Given these projections, many companies are investing in VR. In 2014, Facebook acquired Oculus VR, Inc., one of the leading companies in immersive virtual reality technology, for approximately \$2 billion [12]. Since then, Facebook has released several VR headsets, including Oculus Go — an entry-level headset that runs on a smartphone chip, Rift S — Facebook’s most-powerful headset which connects to a computer, and the most recent, Oculus Quest — mid-range VR headset that doesn’t require a connection to a smartphone or PC [13]. At \$399, Oculus Quest is cheaper than Rift S, and is the company’s first all-in-one “standalone” VR gaming device [14].

Similarly, Apple has been investing in VR technology as well. Apple recently confirmed that it had acquired NextVR, a startup that provides sports and other content for virtual-reality headsets. NextVR supplies content to several existing VR headsets, including Facebook Inc.'s Oculus and devices from Sony Corp., HTC Corp. and Lenovo, and may help Apple's development of VR and AR headsets as well [15].

Overall, the VR industry is rapidly growing, with various companies investing in the technology.

1.4 Current Uses of Virtual Reality

Due to the high cost of VR equipment, the usage of VR environments (VREs) has been restricted to military applications and research institutes over the past 50 years [7]. However, with the development of affordable HMDs, VREs are now used in many different fields, such as for entertainment, architectural design, education, learning and social skills training, simulations of surgical procedures, assistance to the elderly, and psychological treatments [16]. HMDs have also been tested in training for sports, and particularly in industries where new employees are able to receive "risk-free" training using VREs [7].

1.4.1 Virtual Reality Usage in Education

With regard to the educational field, the first VR environments were applied to educational tasks in specific knowledge areas: mathematics, language, business, health, computer science, and project management [7]. VR and Mixed Reality (MR) have been proposed as technological breakthroughs with the power to facilitate learning. One of the reasons for this is that the virtual learning environment (VLE) provides

rich teaching patterns and teaching content. It also helps to improve learners' ability to analyze problems and explore new concepts. It builds a shareable virtual learning space that can be accessed by all kinds of learners by being immersive, interactive and having imaginal advantages [2].

Particularly, as shown by studies, immersion in VLE can enhance education in at least three ways: 1) by enabling multiple perspectives, 2) situated learning, and 3) transfer. Being able to change one's perspective helps to understand a complex phenomenon. VR allows this by allowing users to shift between an exocentric and an egocentric frame of reference; the exocentric frame of reference (Figure 1.4.1 A) “provides a view of an object, space, or phenomenon from the outside” ‘66’, while the egocentric frame of reference (Figure 1.4.1 B) “provides a view from within the object, space, or phenomenon” ‘66’. An exocentric perspective enables participants to distance themselves from the context allowing for more abstract and symbolic insights. Whereas the egocentric perspective allows more concrete learning [17].

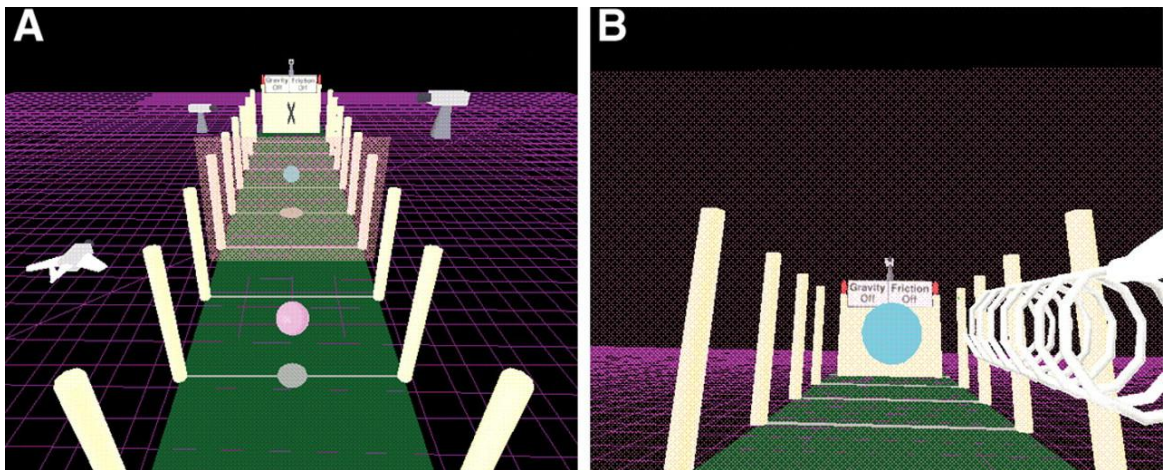


Figure 1.4.1: (A) Exocentric view of NewtonWorld. (B) Egocentric view inside a ball. [17]. Immersive interfaces for engagement and learning.

VLEs enhance and foster education through situated learning [17]. Situated learning theory states effective education requires learning that is embedded in authentic

contexts of practice and activities, coupled with guidance from experts and “legitimate peripheral participation” [17], [18]. VLEs enable situated learning by allowing digital simulations of authentic problem-solving communities in which learners may interact with other participants and/or computer-based agents, who may be at different skill levels [17]. This allows learning to be improved by allowing students/participants to practice real-life scenarios as well as learn from other participants with higher skill levels.

VLEs further improve learning by enhancing transfer through simulation of the real world. Transfer is the ability to transfer knowledge gained in one situation to another situation. One of the issues with traditional presentational style instruction is the low rate of far-transfer. Often, even high-excelling students are unable to apply what they have learned in an educational setting to similar real-world scenarios. The benefit of VLEs is that students are immersed in the simulation of real-world problems and contexts, which means that they only attain near-transfer [17]. This allows students to be then able to apply the knowledge they gained in VLEs in real-world settings. Overall, VLEs improve learning by offering different perspectives, providing situated learning, and enabling transfer to real-world applications.

Furthermore, studies have shown VLEs improve students’ performance significantly. A study by Alhalabi (2016), tested engineering students’ performance using three major VR systems and found that compared to the controlled No-VR group, students performed significantly better when using any VR system than no VR. Additionally, the HMD VR system was found to have superior results than other VR systems [4]. This study showed that the more students are immersed in the environment, the more they learn with better performance.

Research has also shown that knowledge is better retained when the learning

material is delivered in a stimulating manner, which is one of the main advantages of VLEs [19], [20]. One of the ways VR is used in learning in an engaging manner is through “serious games”. Serious games are entertaining activities from which users can also learn and be educated/trained in well-defined areas and tasks [7]. One of the benefits of serious games is that situations which could not otherwise be done in real life, such as ethical dilemmas and/or dangers, can be recreated in serious games, for training purposes. Virtual Reality-Serious Games (VR-SGs) provide the added benefit of an immersive VR environment, which improves user experiences and, therefore, knowledge acquisition. VR-SGs have also been explored in industry and sports for skills training. Other areas that VR-SGs have been used for include training at educational institutions, such as sensitivity to bullying and motivating presentations for teachers and the medical sector, especially skills improvement and knowledge acquisition developed for hospital staff [7].

According to recent research, education which incorporates VR technologies is perceived by learners to be more engaging and enjoyable, with higher levels of satisfaction and perceived usefulness [21], [22]. With regards to VR-SGs for training and education, Checa and Bustillo’s review similarly showed that interactive experience was preferred [7]. This is due to its balance between costs, technological development, the feeling of immersion, and the number of possibilities that users have for learning and improving their skills. The review also concluded that user satisfaction with VR-SG experience was higher than any other learning methodologies [7]. Overall, VR-SGs provide a good learning platform with good user satisfaction and have a vast potential for application in many different areas.

1.4.2 Virtual Reality Usage in Medical Education/Training

One of the major uses of VR is in the medical field, with research showing that about 17.7% of the total VR publications in the last five years are in surgery, rehabilitation and clinical neurology categories [16]. Additionally, about 9% of the recent publications on VR are in the psychology category. VR is widely used in research on new ways of applying psychological treatment or training, such as for treatments and management of phobias [16]. VR is also being utilized in medical education. This is largely because it provides opportunities for users to learn without real-world consequences. For example, medical students can be trained to perform various surgical skills using surgical simulations via robotics and VR systems [23]. This removes the added pressure of learning on real patients while simultaneously providing training for various possible surgical scenarios/settings.

According to a review by Makinen et al. (2020), three types of VR technologies are being used for healthcare learning – haptic simulators, computer-based simulations, and HMD simulations [24]. Of the three, haptic simulators were found to be used the most for healthcare learning, followed by computer-based simulators as the second most used technologies. Haptic simulators are mostly used in surgical training or medical education, as well as in nursing studies and dental studies [24]. The review also showed that different haptic or surgical simulators are used in training for surgery, lumbar punctures [25], intravenous (IV) insertions [26], mandibular fracture reductions [27], and urethral catheterizations [28].

In contrast, computer-based simulators were mostly used in nursing education or in training healthcare faculty such as residents. The most used computer platform for learning on was the Second Life three-dimensional online virtual world. Computer-based SGs such as Virtual Emergency TeleMedicine (VETM), Body Interact and

Home Healthcare Virtual Simulation Training Systems are also used for training purposes [29]–[32]. Lastly, HMDs including HTC Vive, Oculus Rift and Cave98, are also used for training healthcare faculty and nursing students or both. Some medical areas that HMDs were used in included imaging training [33], teaching surgical procedures [34], training on urinary catheterizations [35], [36] and teaching about medication withdrawal [37]. Overall, VR has been increasingly used in the medical field for skills training and education, with haptic simulators, computer-based simulations, and HMD simulations being the three most used VR technologies.

Chapter 2

Motivation

According to the World Health Organization (WHO), in 2016, an estimated 2.6 million newborns died in the first 28 days of life – 1 million of them died on the first day [38]. One of the leading causes of neonatal death is birth asphyxia; as such, performing high-quality newborn resuscitation is crucial for decreasing neonatal mortality [38]. Basic neonatal resuscitation is required in 1/10 newborns, sometimes requiring positive pressure ventilation (PPV), chest compressions, intubation, and administration of volume/cardiac medications [39]. Such events are highly stressful, and even for experienced healthcare professionals, medical errors or deviations from the resuscitation procedures may occur [39]. Therefore, neonatal resuscitation training is crucial for enhancing the quality of care and positive patient outcomes [40].

Knowledge and skill retention of neonatal resuscitation procedures, such as the Neonatal Resuscitation Program (NRP), have been shown to deteriorate as soon as 6 – 8 weeks following training [41]. Booster and refresher sessions involving ‘mock codes’ have been shown to improve knowledge and skill updating [41]. However, access to simulation equipment and organization of timely sessions may be challenging

for health professionals in smaller facilities or more rural locations. Virtual, Mixed and Augmented Reality Systems (VMARs) are an emerging set of technologies being evaluated and adopted across a wide range of medical education disciplines. A more recent trend is to call this family of systems Extended Reality systems (XRs). They typically involve the use of Virtual Reality (VR) and Head-Mounted Displays (HMD) [42]. XRs have been shown to create an enhanced sense of presence and ‘immersion’ amongst learners in clinical sciences training [42]. The recent proliferation of these technologies has created new learning opportunities to improve knowledge and skill retention, as well as increase access to more engaging, self-regulated refresher activities for health professionals in neonatal resuscitation procedures.

The proposed study will involve the development of a VR platform for neonatal resuscitation training and will evaluate its effectiveness in improving neonatal resuscitation skills and retention. The rationale for the project is that VR technologies may offer a cost-effective and efficient means for providers to undertake regular booster and refresher sessions to maintain confidence, knowledge, and skills in neonatal resuscitation procedures. It may also be beneficial for remote learning in the future, which is of importance, particularly in times such as the COVID-19 pandemic situation. The software developed for neonatal training via VMARs may be easily used without the need to travel and attend simulation-based and/or in-person training sessions. The project will explore XRs as a potential solution for rural healthcare professionals to access appropriate neonatal resuscitation refresher updating at their own sites and on their own time, thereby offering greater flexibility. Even when a healthcare professional is not located rurally, the COVID-19 pandemic situation has made it clear that remote training options are vital, and this research & development project will examine the effectiveness of XRs used for this purpose.

2.1 Neonatal Resuscitation Program

The Neonatal Resuscitation Program (NRP) is a standardized, evidence-based approach for training health care providers on the resuscitation of a newborn. It was developed in 1987 by the American Heart Association(AHA) and the American Academy of Pediatrics(AAP), to identify infants at risk of respiratory depression and provide high-quality resuscitation [43]. It has undergone major updates in 2006 and 2010 [43], with the recent 7th edition released in 2016 [44]. The approach to neonatal resuscitation is outlined in Figure 2.1.1.

Any healthcare provider who is expected to participate in neonatal resuscitation is eligible to complete the neonatal resuscitation program [45]. The prerequisites for NRP include being a licensed or regulated health care professional, or a student of a licensed or regulated health profession. For NRP registration, it is important to understand the Canadian guidelines and recommendations as they pertain to an NRP provider. To be classified as an NRP provider, it is necessary to successfully complete the NRP online exam prior to the in-person workshop and to complete the workshop successfully and the Individual Integrated Skills Station Assessment appropriate to their scope of practice. To remain a qualified NRP provider, the NRP provider course has to be renewed every 2 years. Some professional associations or facilities may require NRP provider courses to be completed more frequently [46].

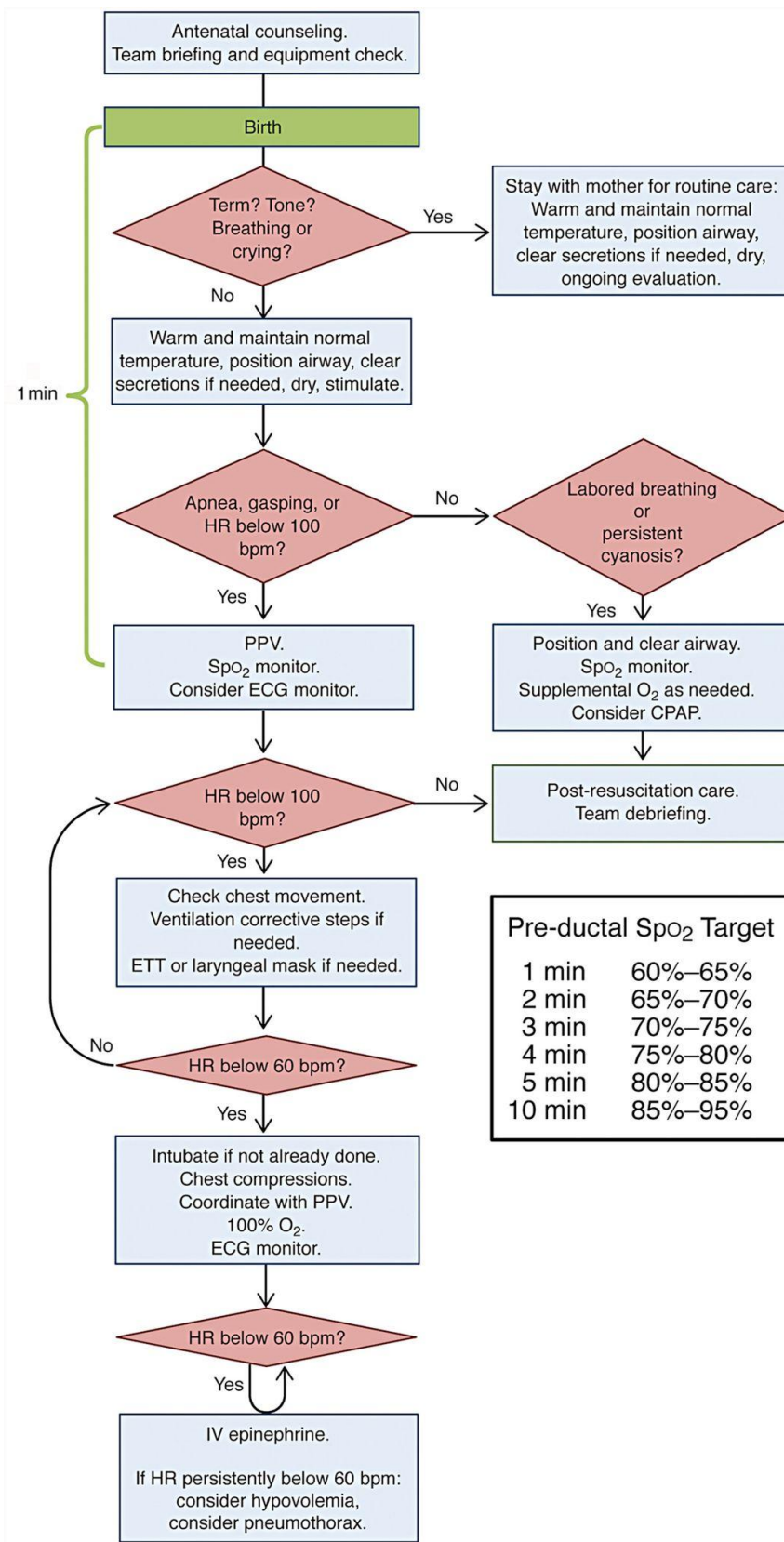


Figure 2.1.1: NRP 7th edition

The NRP provides education and training for healthcare professionals who manage newborns in the hospital setting [47]. In Canada, it is administered by the Canadian Pediatric Society(CPS), and currently, there are about 43,000 active NRP providers with 2,200 active NRP instructors and 110 active NRP instructor-trainers [44]. More than 4 million healthcare professionals have been NRP trained or retrained, across 130 counties, and about 200,000 learners complete the NRP provider course every year [47], [48].

2.2 Continuing Medical Education

Continuing Medical Education (CME) was first initiated in 1947 by the American Academy of General Practice. CME is defined by the American Medical Association (AMA) as “educational activities that serve to maintain, develop, or increase the knowledge, skills, and professional performance and relationships a physician uses to provide services for patients, the public, or the profession”. CME’s content is defined as “body of knowledge and skills generally recognized and accepted by profession as within the basic medical sciences, the discipline of clinical medicine, and the provision of health care to the public”. AMA requires CME credits for re-licensure and is now a common professional pursuit for healthcare practitioners [49].

In Canada, the Royal College of Physicians and Surgeons of Canada (RCPSC) and the College of Family Physicians Canada (CFPC) provide CME certifications [49], [50]. Moreover, Health Care Practitioners (HCP) participate in CME as a crucial component of professional development because it is a practical way to stay on top of changes in the healthcare environment. Through CME, HCPs are able to learn emerging science and apply innovations in clinical settings.

Although HCPs are able to obtain new knowledge and expand their skill sets, research has shown CME to be an effective conduit for positive change in professional practice and patient health outcomes. According to a systematic review by O'Brien et al, on the literature investigating the effect of CME meetings on the clinical practice of healthcare professionals or healthcare outcomes, CME workshops and workshops combined with didactic presentations led from moderate to large changes in professional practice [50], [51].

2.3 Rural Training and Relevance to Newfoundland and Labrador

In 2018, in Newfoundland and Labrador (NL), the neonatal mortality rate for infants between the age of 0 to 27 days was 3.8 per 1,000 live births, and for infants under the age of one was 4.5 per 1,000 live births [52], while in Canada the rates are slightly lower at 3.5 per 1,000 live births, and 4.7 per 1,000 live births, respectively [52]. This means that NL has more neonatal deaths than Canada per capita in the first month of life of a newborn. As previously mentioned, one of the leading causes of neonatal deaths is birth asphyxia, and therefore, being effectively trained in neonatal resuscitation is important for decreasing neonatal mortality [38]. However, studies have shown that knowledge and skill retention of neonatal resuscitation procedures declines as soon as 2 months after training [53].

Rural healthcare providers typically have less exposure to neonatal and pediatric patients, as well as fewer opportunities to access CME and standardized training courses [54]. In many smaller regional health centres and rural communities, access to simulation-based technology is also limited, as are opportunities to access regular

mock codes or booster sessions to maintain knowledge and skills. When faced with life-threatening emergencies, healthcare providers who have not had frequent exposure to performing ventilation, may not be able to recall and apply knowledge and skills rapidly, which may result in delayed or ineffective resuscitation [54]. It has been suggested that improving the professional lives of rural physicians can encourage their retention [55]–[58]. In a province with only one pediatric tertiary care centre, the provision of more cost-effective and accessible options for NRP training could potentially impact the recruitment and retention of pediatricians and other newborn specialists and help improve the quality of care of critically ill neonatal patients in communities around the province. This study, based on the VR research project, has the potential to provide insights for more cost-effective and efficient options for relearning (booster) skills, bridging the gap between the required NRP course format and instruction.

2.4 Research Questions

There are several questions and objectives that this study will explore.

Research questions:

1. Is VR a good learning tool for NRP?
2. Is VR equal to or better as a learning/training tool for NRP when compared to 360° NRP training video?
3. Does VR provide equal or greater user satisfaction than conventional NRP?
4. Is it possible to implement haptic feedback in the VR NRP simulation? If yes, is it a useful feature for the users to learn NRP?

The objectives of this study are to:

- Explore the feasibility and implications of using computer-generated simulations delivered through head-mounted displays (HMDs) to support neonatal resuscitation booster or refresher learning.
- Explore adult learners' perspective on using VR HMDs as a learning modality for neonatal resuscitation training.
- Explore barriers and enablers to integrating VR HMDs as instructional and/or self-learning resources for healthcare providers trained in NRP.
- Examine the effect of VR HMDs usage on learning outcomes in neonatal resuscitation.

Before describing the experimental design and methodology in Chapter 4, we will first review the related work associated with NRP in the next chapter.

Chapter 3

Related Research

Since even the smallest mistake in medicine can have a great impact on the well-being of patients, simulation training is essential. Additionally, studies conducted previously have shown that resuscitation training in simulations is more effective and suitable for teamwork among trainees [59]. Simulations in the neonatal resuscitation area help healthcare personnel to acquire new skills, become familiar with new equipment and technologies, and maintain/refresh current knowledge. In fact, simulation usage in neonatal resuscitation has been increasing day by day [53].

There are various approaches in this area. One of them is serious games, which are used to minimize the mistakes made and help improve and refresh information. In terms of simulation, SGs are divided into three types - board games, video games and VR games. Research shows that a board game in the neonatal resuscitation area called RETAIN improves knowledge retention, communication and teamwork; it increases knowledge retention by 10% [39]. Another study evaluating the same game showed that temperature management increased by 32%, placement of a hat by 33%, plastic wrap by 40% and temperature probe by 23% [60], all of which are essential

parts of neonatal resuscitation.

Other than board games, video games are also promising technology in NRP training. There are several games on NRP training, such as video games, tablet computer games and mobile games. For example, a video game developed by National Health Service Education for Scotland is designed for rural family physicians to practice and maintain their knowledge about neonatal resuscitation. The game focuses on maternal factors, birth locations and prenatal risks [39]. However, no studies have examined any educational or clinical outcomes. There is also a web-based game, developed by Singapore General Hospital, that helps HCPs to retain and assess their knowledge about neonatal resuscitation [61]. This web-based video game focuses on improving teamwork about NRP and time management as users have to finish tasks within a time limit [39]. Another video game called e-Baby, developed by the University of Sao Paulo, focused on nursing students and questioned the ease to use, learning and didactic value [62]. The survey showed that about 93% of the students said it is good for their learning and enjoyed using it [39].

In terms of virtual reality, there are VR serious games about NRP training aimed at improving participants' learning and their abilities. One is called eHBB, developed by the University of Washington, USA and Oxford University, UK [63]. The VR game can be accessible by mobile smartphones and also low-cost VR devices such as Google cardboard. It provides a non-interactive virtual environment and lets users observe the procedures of neonatal resuscitation through their smartphones. It provides a step-by-step guide [39]. The game was developed to supplement the evidence-based in-person global neonatal resuscitation training programme (HBB) for healthcare personnel in low-resource settings (such as in sub-Saharan Africa). Its purpose is to provide an opportunity for continuous learning for new skill development, as well as to help

maintain training fidelity. Overall, eHBB was reported by the National Hospital in Nigeria to be easy to use, educational and enables learning without real-life stress [39].

Another example of a VR serious game aimed at improving neonatal resuscitation is Life-saving Instructions For Emergencies (LIFE) [64], developed by Oxford University, UK. LIFE is both a mobile and VR game. The game allows users to accomplish the VR game procedure while using their own smartphones, and this provides healthcare workers to experience the game even with low-cost settings [65]. The game included a section regarding neonatal resuscitation where users must match the equipment correctly in a virtual rural hospital. Also, users must answer some multiple-choice questions correctly to achieve their targets [39]. However, no educational or clinical study has examined this software's effect on neonatal resuscitation skill improvement [39].

Lastly, Compromised Neonate Program is an immersive VR application developed by University of Newcastle, Australia, for teaching neonatal resuscitation skills to midwifery students [66]. In this VR application, learners must finish given neonatal resuscitation tasks successfully in the virtual hospital environment. There is an ongoing trial to assess the effectiveness of using this VR game, but no research results are available yet [39].

Overall, VR games are divided into two sections - information-based immersive VR applications, and immersive interactive VR applications using hand held controllers. According to various research, information-based VR games about NRP are not very effective [67], while interactive VR games seem promising, but little research is done to evaluate their effectiveness [39]. The research in this thesis aims at filling this gap

in research by developing a new VR neonatal resuscitation application and evaluating potential NRP skill improvement after completing training with the developed application by having a controlled study.

Chapter 4

Experimental Design and Methodology

4.1 Study Design

4.1.1 Part 1: Exposure to First VR Condition

For this study, a purposive sample of NRP providers was recruited through the NRP training course. For a Chi-Square analysis, a minimum total sample of $N=30$ was required, with $N=15$ participants randomly assigned to each of two possible study groups. Participants were randomized into two groups. The first group: 1) watched the NRP scenario via 360° video first, then 2) performed NRP scenario while being recorded for evaluation, and lastly, 3) participated in the NRP scenario as a VR simulation. The second group followed a similar procedure, but instead of watching the 360° video, participants engaged in the VR NRP scenario. The second group: 1) engaged in the NRP scenario via VR, then 2) performed the NRP scenario while

being recorded, and lastly, 3) watched the NRP scenario via 360° video.

In order to ensure a balanced sample for statistical analysis, it was essential to have equal numbers of participants in both the 360° video and VR groups. To achieve this, a random allocation process was used. Specifically, the researchers utilized the Research Randomizer website (<https://www.randomizer.org/>) to simulate a digitalized environment. This process involved randomly assigning 15 participants to the 360° video group and 15 participants to the VR group. The allocation process was designed to minimize the potential for bias and ensure that the sample accurately reflected the studied population.

Similarly, a randomized technique was used in the videos distributed to 3 NRP instructors who would review the recorded videos. In total, 30 participants were randomly distributed to 3 NRP instructors, 10 each. Each NRP instructor graded the videos of the participants who were exposed to 5 VR and 5 360° video conditions.

The NRP “Mock Codes” include 1) Airway, Breathing, and Circulation: Keep neck in a neutral or slightly extended position; 2) Suction out the nose and mouth with a bulb.; 3) Check heart rate (umbilical cord will pulsate, the easiest place to check heart rate) and 4) if apnea or Heart Rate (HR) <100, give positive pressure ventilation (PPV) with a bag and mask (watch for chest rise).

All participants completed a “pre-test” questionnaire at the beginning of the study. The “pre-test” questionnaires are adapted from Curran, Fleet, and Greene (2012), indicating characteristics such as gender, health profession, years in practice, years as NRP provider and experience with NRP [68]. This information enabled comparison and analysis of potential influences these characteristics had on study outcomes. Study design table is shown in Table 4.1.1.

Questions assessing confidence with resuscitation are also included in the pre-test

questionnaire. There were 15 questions in total and values in the range of 0-100 for each option. These questions were used to compare the participants' confidence towards resuscitation before and after completing the simulation using the assigned VR technology.

They also completed a "post-test 1" questionnaire after watching the NRP scenario via 360° video or VR system, prior to being evaluated. These questions were used to compare participant learning outcomes between the two study groups to determine if viewing the scenario through VMARs enhances the self-perceived confidence in resuscitation.

The "post-test 1" questionnaire includes an adapted version of the Presence Questionnaire (PQ), developed by Witmer and Singer (1998). The PQ includes 32 items, rated using a 7-point scale format, which addresses four main conceptual factors that influence involvement and affect immersion in the learning experience, and which has demonstrated high internal consistency and reliability [69].

The questions asked in PQ are different for the two technologies. Some questions have been removed because they are not applicable to 360° video technology. For example, since there is no interaction with objects in the virtual environment in 360° video, object interaction questions were removed. Also, in 360° video, users could move their heads, but since they could not change their position in the plane, movement questions were removed. All of the PQ questions were included in the VRP environment since they were all applicable.

There were also two open comment fields in this questionnaire for the participants to add comments apart from the multiple-choice questions. The first of these comment areas was for them to write what they liked about the VR technology used, and the other area was for them to write what they didn't like.

The questionnaire also included a brief user satisfaction survey adapted from Curran et al. (2000) and validated to reflect the relevant resuscitation scenario [70]. These questions assessed user satisfaction and ease of use of VMARs.

Overall, the “post-test 1” questionnaire assesses 1) satisfaction, 2) ease of use, 3) comments about technology usage, 4) confidence, 5) presence, and 6) motion sickness.

4.1.2 Part 2: First VR Condition Evaluation

As mentioned above, upon completing the first NRP simulation delivered through VR technology, participants performed the resuscitation procedure on an infant’s mannequin while being video-recorded. The videos were assessed by NRP instructors, who gave participants a score based on their performance in the video. The video recorded only the participants’ hands and the infant in the infant warmer. It does not contain any images identifying the participants. Thus, anonymity was preserved. Later, these recorded videos were evaluated by NRP instructors. A score-based scoring system was used according to the performances of the participants in the recorded video. The recorded sample image can be seen in Figure 4.1.1.

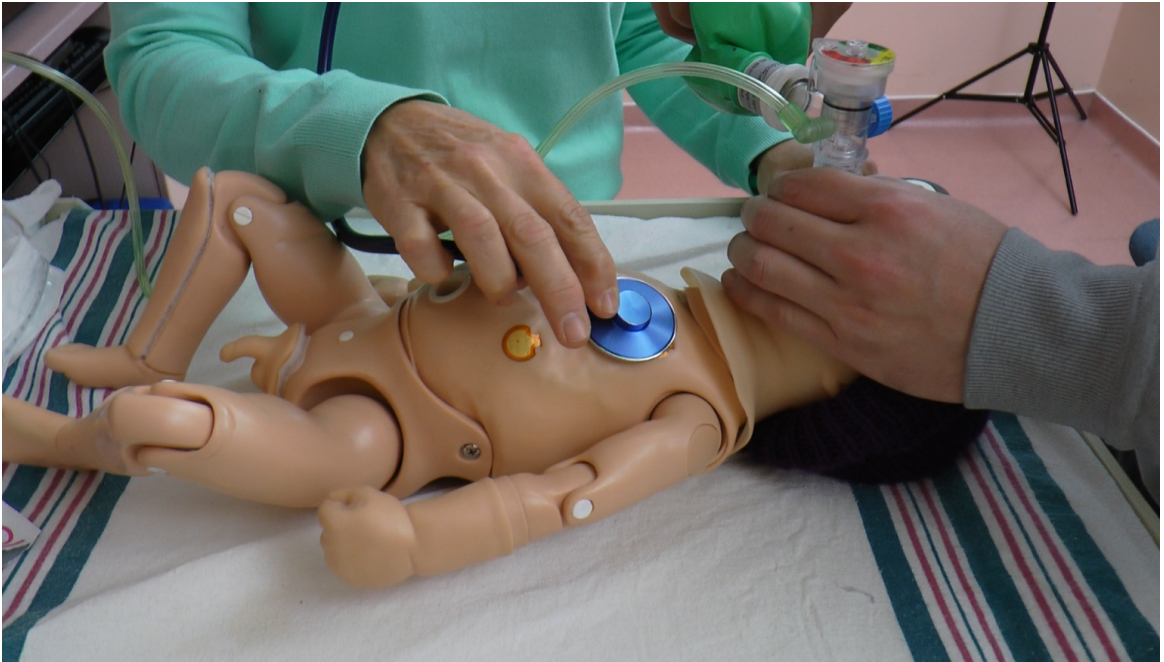


Figure 4.1.1: A sample image from video recordings recorded for evaluation.

4.1.3 Part 3: Exposure to Second VR Condition

After the neonatal resuscitation scenario exhibited by the participants was videotaped, the participants were exposed to the other VR technology. For example, a user who watched a 360° video in the first condition completed the VR simulation this time. Thus, the participants' exposure to both VMAR technologies and their opinions about both technologies were collected with the "post-test 2" questionnaire.

An important element here is the participants' confidence data on neonatal resuscitation, collected only before and after exposure to the first condition. Confidence data after exposure to the second technology were not collected as learned bias would be produced. For the same reason, NRP instructors scored participants' performance only after being exposed to the first technology.

After evaluating and completing the neonatal resuscitation scenario via the other

modality, the participants completed a “post-test 2” questionnaire. This questionnaire was similar to “post-test 1” but only assessed 1) satisfaction, 2) presence and 3) motion-sickness. It did not assess confidence.

4.1.4 Part 4: Data Analysis

The data collected were analyzed using R, with methods of data analysis including 1. descriptive statistics (i.e. frequencies); 2. Chi-Square analysis and/or T-test to compare within-group scores. The results of this study will be disseminated to a broad audience of researchers, knowledge brokers, and knowledge users at each stage of the project.

4.1.5 Study Design Table

Table 4.1.1: Study Design

<u>GROUP A</u> Randomization N=15 VR first	<u>GROUP B</u> Randomization N=15 360° video first
Pre-test <ul style="list-style-type: none"> • Demographics • Confidence 	Pre-test <ul style="list-style-type: none"> • Demographics • Confidence
NRP Simulation (VR)	NRP 360° Video
Post-test 1 <ul style="list-style-type: none"> • Satisfaction • Confidence • Presence Scale • Motion Sickness Scale 	Post-test 1 <ul style="list-style-type: none"> • Satisfaction • Confidence • Presence Scale • Motion Sickness Scale
PPV Simulation Demonstration <ul style="list-style-type: none"> • Manikin + equipment • Video recorded • Observation checklist 	PPV Simulation Demonstration <ul style="list-style-type: none"> • Manikin + equipment • Video recorded • Observation checklist
NRP 360° Video	NRP Simulation (VR)
Post-test 2 <ul style="list-style-type: none"> • Satisfaction • Presence Scale • Motion Sickness Scale 	Post-test 2 <ul style="list-style-type: none"> • Satisfaction • Presence Scale • Motion Sickness Scale

4.2 Recruitment

Participants for this study were selected from healthcare providers, including physicians, nurses, and medical, nursing, and respiratory therapy students, who have completed the NRP training. Therefore, the participants were found through the NRP Training course. At the same time, posters created for the experiment were hung in various parts of the Eastern Health building and in the corridors of the Neonatal Intensive Care Unit (NICU). The poster includes information about the research related to VR and NRP, the incentive (participation gift) to be given to the participants, and

contact information, provided that the participants have completed the NRP training. Finally, e-mails containing the recruitment letter and poster were sent to the NRP participants. The recruitment email included the title of the research, information about the research, information about the expectations from the participants, monetary compensation to be given for participation, and contact information. These emails were sent by people who will not have an influence on the participants, with the approval of the ethics committee. Susan White, a Nurse Educator with the Provincial Perinatal Program in Newfoundland and Labrador, assisted in the recruitment process.

All participants in the research received a \$25 Tim Horton's gift card. Before the experiment, the participants signed a consent form and were informed. In the consent form, the content of the experiment, its purpose, what it was aimed at, what the participants were asked to do, the questionnaires to be filled, location, length of time, withdrawal from the study information, possible benefits, possible risks, confidentiality, anonymity, data preservation and communication information was included. The consent form, recruitment letter, poster and other related items have all been approved by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) at Memorial University.

4.3 Questionnaires

4.3.1 Demographics

In the pre-test questionnaire, participants were first asked for their demographic information. This included information such as participants' health professional roles,

years in practice, years as a Neonatal Resuscitation Program (NRP) provider and gender. In addition, if the participants did not want to answer some questions, they had the option of selecting “prefer not to answer”. Health professional roles included registered nurse, licensed practical nurse, pediatrician, clinical associate, family medicine resident, pediatric resident, obstetric resident, paramedic, respiratory therapist, medical student, nursing student, and respiratory therapy student. For roles not included in the list, there was the “other” comment section. “Years in practice” refers to the time spent as a healthcare professional, regardless of being an NRP provider or not. This information was obtained as a time interval. The options for this question were 0-5 years, 6-10 years, 11-15 years, 16-20 years and more than 20 years. Years of experience range options as NRP Provider were: 0-5 years, 6-10 years, 11-15 years, 16-20 years and more than 20 years. Lastly, the categorical data analysis question, the gender question, contains male and female options. If participants identified themselves as a different gender from these options, they were asked to select the “another” option and fill in a description. Demographics Questionnaire is shown in Table 4.3.1.

4.3.2 Confidence

The pre-test questionnaire included questions assessing user confidence in NRP. This was done before they were exposed to the first technology to which they were randomly assigned. Participants were asked to fill in each criterion by giving a score between 0 and 100; 0: cannot do; 50: moderately can do, and 100: highly certain can do. The criteria included initiating, establishing and performing effective positive pressure ventilation on a newborn, as shown in table 4.3.2.

In addition, after completing the simulation using the VR technology they were first assigned to, the participants completed the confidence questionnaire once again.

Table 4.3.1: Demographics Questionnaire

Health professional role:	
	Registered Nurse
	Licensed Practical Nurse
	Pediatrician
	Clinical Associate
	Family Medicine Resident
	Pediatric Resident
	Obstetric Resident
	Paramedic
	Respiratory Therapist
	Medical student
	Nursing student
	Respiratory therapy student
	Prefer not to answer
	Other – please specify:
Years in practice:	
	0-5 years
	6-10 years
	11-15 years
	16-20 years
	20 years
	Prefer not to answer
	N/A
Years as NRP provider:	
	0-5 years
	6-10 years
	11-15 years
	16-20 years
	20 years
	Prefer not to answer
	N/A – I have not completed NRP.
When did you last participate in NRP?	
Gender:	
	Male
	Female
	Prefer not to answer
	Another Gender Identity (optional to specify):

The purpose of this was to compare the confidence answers they filled in on the pre-test questionnaire (pre-confidence) with the answers they filled in post-test 1 (post-confidence) to determine whether there was an increase in the participants' confidence in their neonatal resuscitation knowledge.

4.3.3 User Satisfaction

Another factor that was assessed in this study was user satisfaction. The study design included a post-test 1 questionnaire assessing user satisfaction after the VR technology, in which the participants were first exposed, and a post-test 2 questionnaire after the second technology. In other words, after being exposed to both technologies, they were asked to fill in the questionnaire separately based on the technology they were exposed to. There were two likert-scale survey question sets with 6 questions and two open-ended questions in the satisfaction question sets. The first likert-scale question set was asked to measure usefulness. In this question set, there are questions such as the effect of VR technology on participant learning and its quickness and development. This question set was adapted from Lopez Chavez and Rodriguez's question set [71].

The second set of questions was asked to analyze the ease of use of the exposed VR technology. These items included questions about the ease of using the VR technology that the participants were exposed to. It assessed whether participants could do what they wanted to do, that it was clear and understandable, flexible to interact with and whether user skillfulness increased thanks to this technology. Likewise, this question set was adapted from the study of Lopez Chavez and Rodriguez [71].

In both sets of questions, the participants were expected to rate between 1 and 7: 1 = extremely unlikely, 2 = quite unlikely, 3 = slightly unlikely, 4 = neither, 5 =

Table 4.3.2: Confidence Questionnaire

Abilities	Confidence (0 - 100)
1. Identify the indications for bag-and-mask ventilation/ Positive Pressure Ventilation (PPV) in the newborn.	
2. Initiate bag-and-mask ventilation/ PPV	
3. Demonstrate correct mask placement.	
4. Evaluate the effectiveness of bag-and-mask ventilation/PPV.	
5. Recognize ineffective ventilation.	
6. Identify and demonstrate the corrective actions to establish effective PPV (MRSOPA) as indicated by infant response.	
7. Evaluate effectiveness of interventions (MRSOPA) as indicated.	
8. Identify the indications for pulse oximetry and demonstrate correct placement and interpretation of reading.	
9. Demonstrate effective PPV for 30 seconds.	
10. Re-evaluate newborn response after 30 seconds of effective PPV. (HR and spontaneous respirations).	
11. Identify next steps based on infant response	
12. Identify the implications for supplemental oxygen and demonstrate application of supplemental oxygen to meet targeted oxygen saturations.	
13. Monitor my own and other team member's efforts to ensure that proper procedures and tasks occur as expected.	
14. Adapt my performance to accommodate changes that may occur.	
15. Facilitate quality and continuous improvements (i.e. encourage others, and speak up when concerns arise).	

Adapted from Curran, V., Fleet, L. J., White, S., Bessell, C., Deshpandey, A., & Drover, A. (2012). Examination of the Effect of Low versus High-Fidelity Simulation on Neonatal Resuscitation Program (NRP) Learning Outcomes: Final Report of Study Findings. Memorial University of Newfoundland [68].

slightly likely, 6 = quite likely and 7 = extremely likely. The two sets of questions are shown in Table 4.3.3 and Table 4.3.4.

In addition to the usefulness and ease of use of question sets, there was an open-ended comment section not included in these question sets, which allowed for comments from users about the VR technology they were exposed to. These comment sections were included in the post-test 1 and post-test 2 questionnaires. In the first comment section, users were asked to write down what they liked about the VR technology and the neonatal resuscitation training they were exposed to. In the second comment section, they were asked to write down the things they didn't like about it. There are no restrictions on the participants in this comment area.

Table 4.3.3: Usefulness Questionnaire

Items	
1.	Using virtual reality in my learning would enable me to accomplish learning goals more quickly.
2.	Using virtual reality in my learning would improve my learning performance.
3.	Using virtual reality in my learning could increase my learning efficiency.
4.	Using virtual reality in my learning would enhance my learning effect.
5.	Using virtual reality would make it easier to learn.
6.	I would find virtual reality useful in my learning.

Adapted from: Chávez, OL, Rodríguez, LF, & Gutierrez-Garcia, JO (2020). A comparative case study of 2D, 3D and immersive-virtual-reality applications for healthcare education. International Journal of Medical Informatics, 141, 104226 [71].

4.3.4 Motion Sickness

In XR technologies, it has been observed that users may exhibit motion sickness symptoms when they are exposed to these technologies for a long time. It has been

Table 4.3.4: Ease of Use Questionnaire

Items	
1.	Learning to operate virtual reality was easy for me.
2.	I found it easy to get virtual reality to do what I want it to do.
3.	My interaction with virtual reality was clear and understandable.
4.	I found virtual reality to be flexible to interact with.
5.	It would be easy for me to become skillful at using virtual reality.
6.	I found virtual reality easy to use.

Adapted from: Chávez, OL, Rodríguez, LF, & Gutierrez-Garcia, JO (2020). A comparative case study of 2D, 3D and immersive-virtual-reality applications for healthcare education. International Journal of Medical Informatics, 141, 104226 [71].

determined that the symptoms caused by these technologies on people can occur at mild, moderate and severe levels.

In total, 16 symptoms were identified, and 4-point scales were used. These scales are 1=None, 2=Slight, 3=Moderate and 4=Severe. These symptoms are classified into 3 main categories: Oculomotor (O), Disorientation (D) and Nausea (N). Some symptoms may fall into more than one category. For example, general discomfort falls into categories O and N, while blurred vision falls into categories O and D.

In this project, participants were asked to fill out a motion sickness questionnaire after each VR technology they were exposed to. Since moderate and severe symptoms may affect the experiences of the participants, motion sickness questions were included in both post-test questionnaires. The participants were informed on the consent form that if the participants felt any symptoms at a severe level, they would not continue with the experiment, and it would be terminated. The motion sickness questionnaire assessing symptoms is shown in table 4.3.5.

Table 4.3.5: Motion Sickness Questionnaire

Symptoms	None	Slight	Moderate	Severe
1. General discomfort				
2. Fatigue				
3. Headache				
4. Eye strain				
5. Difficulty focusing				
6. Increased salivation				
7. Sweating				
8. Nausea				
9. Difficulty concentrating				
10. Fullness of head				
11. Blurred vision				
12. Dizzy (eyes open)				
13. Dizzy (eyes closed)				
14. Vertigo				
15. Stomach awareness				
16. Burping				

Adapted from: Kennedy, RS, Lane, NE, Berbaum, KS, & Lilienthal, MG (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The international journal of aviation psychology, 3(3), 203-220 [72].

4.3.5 Presence Scale

Presence in Virtual Reality is the absence of users from their physical environment and feeling themselves present in the virtual environment. In virtual environments, where the presence felt by the users is high, those virtual simulations are considered more effective [69]. As Witmer and Singer pointed out, items are examined in 4 factors in the Presence Questionnaire. These include; 1. Control Factors (CF); degree

of control, immediacy of control, anticipation of events, mode of control and physical environment modifiability; 2. Sensory Factors; sensory modality, environmental richness, multimodal presentation, consistency of multimodal information, degree of movement perception and active search; 3. Distraction Factors; isolation, selective attention and interface awareness; and 4. Realism Factor; scene realism, information consistent with an objective world, the meaningfulness of experience and separation anxiety/disorientation.

In this project, we adapted and used the Presence Questionnaire (PQ) developed by Witmer and Singer. The reason it was modified was the differences between VR and 360° virtual environments. In VR simulation, the user interacts with the virtual environment and virtual objects. On the other hand, in 360° video; the user experiences virtuality, but only watches and does not interact with the environment in any way. Control Factors stated by Witmer and Singer were not valid for 360° video. There was no environment modifiability or event anticipation in any way, nor any control. Therefore, it was requested that the CF items be filled by the user only in the post-test after the VR simulation. Correspondingly, after the 360° video session, the user is requested to leave the CF items in the PQ blank. Therefore, there are 32 items after the VR simulation in the PQs in the post-tests, while there are 17 items after the 360° video session. This difference in both PQ's highlights an inherent reduction in the sense of presence when comparing the VR simulation to the 360° video.

A 1-7 likert-scale was used while answering PQ items. Answers corresponding to 1 point generally have a negative meaning, answers corresponding to 4 points are generally neutral, and answers corresponding to 7 points generally have positive meanings. One of the important elements to be considered is that not all questions

are not asked in a positive sense; there are some questions that need to be taken out of negative meaning. For example, “How much did the visual aspects of the environment involve you?” was a positive question. If the participants felt very involved, they would rate it “completely involved”, 7 points; if they didn’t feel involved at all, then they would select rate it 1, “Not at all”. However, “To what extent did events occur outside the virtual environment distract from your experience in the virtual environment?” is a negative question. The simulation created in the project aims to ensure that environmental factors do not affect the user. Therefore, the fact that the users said, “I was not affected at all” to this question indicates that the simulation is more effective. In this question, if the user selected that they are very uncomfortable, it would be “Very distractive” and 7 points, and if they were not disturbed at all, it would; “Not at all” with 0 points should be selected. Therefore, while performing data analysis, high scores in some questions mean effectiveness, while low scores in some questions mean effectiveness.

During the experiment, users were asked to complete this questionnaire based on the technology they were exposed to Therefore, they were required to fill out the corresponding PQ in each of the post-test 1 and post-test 2 questionnaires. However, while they answered 32 items in one post-test, they answered 17 items in another post-test, or vice versa.

Table 4.3.6: Presence Questionnaire

Item	1	2	3	4	5	6	7
1. How much did the visual aspects of the environment involve you?	not at all		somewhat			completely	
2. How much did the auditory aspects of the environment involve you?	not at all		somewhat			completely	

Continuation of Table 4.3.6							
Item	1	2	3	4	5	6	7
3. How natural was the mechanism which controlled movement through the environment?	ex- tremely artificial		borderline			completely natural	
4. How compelling was your sense of objects moving through space?	not com- pelling		moder- ately com- pelling			very compelling	
5. How much did your experiences in the virtual environment seem consistent with your real world experiences?	not con- sistent		moder- ately consistent			very consistent	
6. How completely were you able to actively survey or search the environment using vision?	not at all		somewhat			completely	
7. How well could you identify sounds?	not at all		somewhat			completely	
8. How well could you localize sounds?	not at all		somewhat			completely	
9. How closely were you able to examine objects?	not at all		pretty close			very closely	
10. How well could you examine objects from multiple viewpoints?	not at all		somewhat			extensively	
11. How involved were you in the virtual environment experience?	not involved		mildly involved			completely engrossed	

Continuation of Table 4.3.6							
Item	1	2	3	4	5	6	7
12. How quickly did you adjust to the virtual environment experience?	not at all		slowly			less than	
13. How completely were your senses engaged in this experience?	not at all		somewhat			completely	
14. To what extent did events occur outside the virtual environment distract from your experience in the virtual environment?	not at all		somewhat			very distractive	
15. Were you involved in the experimental task to the extent that you lost track of time?	not involved		mildly involved			completely engrossed	
16. Were there moments during the virtual environment experience when you felt completely focused on the task environment?	not at all		few			a lot	
17. Was the information provided through different senses in the virtual environment (eg, vision, hearing, touch) consistent?	not at all		somewhat			completely	
18. How much were you able to control events?	not at all		somewhat			completely	

Continuation of Table 4.3.6							
Item	1	2	3	4	5	6	7
19. How responsive was the environment to actions that you initiated (or performed)?	not responsive		moderately responsive			completely responsive	
20. How natural did your interactions with the environment seem?	extremely artificial		borderline			completely natural	
21. Were you able to anticipate what would happen next in response to the actions that you performed?	not at all		somewhat			completely	
22. How well could you actively survey or search the virtual environment using touch?	not at all		somewhat			completely	
23. How compelling was your sense of moving around inside the virtual environment?	not compelling		moderately compelling			very compelling	
24. How well could you move or manipulate objects in the virtual environment?	not at all		somewhat			extensively	
25. How much delay did you experience between your actions and expected outcomes?	no delays		moderate delays			long delays	

Continuation of Table 4.3.6							
Item	1	2	3	4	5	6	7
26. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	not proficient		reasonably proficient			very proficient	
27. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	not at all		interfered somewhat			prevented task performance	
28. How much did the control devices interfere with the performance of assigned tasks or with other activities?	not at all		interfered somewhat			interfered greatly	
29. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	not at all		somewhat			completely	
30. Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?	not at all		somewhat			completely	
31. How easy was it to identify objects through physical interaction, like touching an object, walking over a surface, or bumping into a wall or object?	not at all		somewhat			completely	

Continuation of Table 4.3.6							
Item	1	2	3	4	5	6	7
32. How easily did you adjust to the control devices used to interact with the virtual environment?	easy		moderate			hard	

Adapted from: Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. Presence, 7(3), 225-240. [69].

4.4 VR System and Objects

For this project, I used Unity 3D as the visual design program and also the game engine [73]. Unity's 2020.02f version was used for the development of the project because this version was the most stable version while the requirements of the project were completed, and it did not have any problems with haptic feedback.

HTC VIVE Pro was used as the HMD in the project [74]. The pieces of equipment of VIVE Pro used in the project are: One head-mount device where you can see the virtual environment, one VIVE Tracker to be used as a bag valve mask in the left hand, one HTC Controller for the right hand to take action on the bag part of the mask, and base stations. Base stations are placed on two opposite corners sides of the room to detect the headset and controllers. To evoke a realistic sense of engaging in Neonatal Resuscitation, the VIVE Tracker incorporates wrist straps and a ball, strategically positioned in the area intended for the user's grasp of the bag valve mask. This design allows the user to simulate the physical actions involved in the resuscitation process effectively. To illustrate the implementation of the wrist straps and ball on the VIVE Tracker, a visual depiction can be observed in Figure 4.4.1



Figure 4.4.1: HTC Vive tracker used for VR simulation in the project

4.4.1 Objects

Since the project was about medical education, medical 3D objects and environment were preferred to be used in the simulation. Since the use of VR is mostly focused on computer video games, it is more difficult to find objects (also known as Unity assets) in the medical field than in other fields. This is why the Unity Asset Store remains limited in its variety [75]. Another source are free 3D objects from the internet. From the free 3D object websites on the internet, it is necessary to use objects in a way that the Unity program can recognize. If Unity can not recognize them, it is necessary to bring them to a format with a compatible file extension that Unity can understand with the help of various converter programs (Blender, SketchUp, etc.).

In this project, many such objects were found from free websites and used in the VR simulation.

We can divide the objects in the project into those that interact with the simulation and those that do not. Those interacting with the simulation are sometimes triggered by the action of the user and sometimes by successive events, depending on the flow of the workflow. Objects that are not affected by the simulation, that is, static, remain stationary. For example, the walls of the room are not affected by simulation or user interaction in any way.



Figure 4.4.2: A sample view of the simulation room from the User's perspective.

4.4.2 Interactive Objects

Baby

The 3D infant object was used as the model on which the participants would perform the operation and monitor their vitals at the same time. These human-like objects are called humanoid avatars in Unity. While choosing the infant avatar, the

important thing was to select an object with a so-called bone structure to ensure breathing and head movement during the simulation. This bone structure allows the joints to be moved easily with the help of C# scripting.

Doctor Avatar

Teamwork is very important in the neonatal resuscitation procedure performed on newborns. As such, a human avatar was selected to be a doctor teammate to assist the VR user during the training in the project. This human avatar helps the user with animations in important places in the flow of the training and gives voice commands when necessary to provide the necessary actions. For animations to be provided, the joints of this human avatar must also be movable.



Figure 4.4.3: Sample image of Doctor Avatar. He stands on the right side of the user's view and helps the user during the simulation

Infant Warmer

The infant warmer in which the infant in the simulation will be positioned was requested to be the same model as the infant warmer used at the Eastern Health building. This was done in an effort to provide an environment that the participants were familiar with. By the infant warmer, there is also the area of the wall where the NRP algorithm posters are hung. It is positioned right in front of the user when the user starts the simulation.

Blanket

Initial steps in neonatal resuscitation are very crucial in managing the baby. One of the initial steps includes wiping the baby with a blanket and making it suitable for resuscitation, and then keeping the baby under it to keep him/her warm. To provide virtual reality immersion, the blanket 3D object was added to the simulation as cloth. This object can be affected by objects that collide with it and gravity, adding realism to the simulation.

Bag Valve Mask

In the event that a baby develops difficulty breathing and develops hypoxia, a bag valve mask is used to provide the baby oxygen during neonatal resuscitation. In the project, the bag valve mask is designed to be held with the user's left hand, and oxygen can be provided by squeezing the bag with the right hand. Therefore, this object consists of two parts; the left part held over the infant's mouth with the left hand and the right part with the right hand to simulate providing oxygen via bag valve mask. In the project, a VIVE Tracker was used for the left part, and a VIVE

Controller was used for the right part, which would hold the bag. When the user squeezes the bag, that is, giving oxygen to the infant, the bag should animate the contraction and expansion. The user does this with the help of the button on the controller while holding the VIVE controller in their right hand. The longer the user holds the button, the more the bag is squeezed.

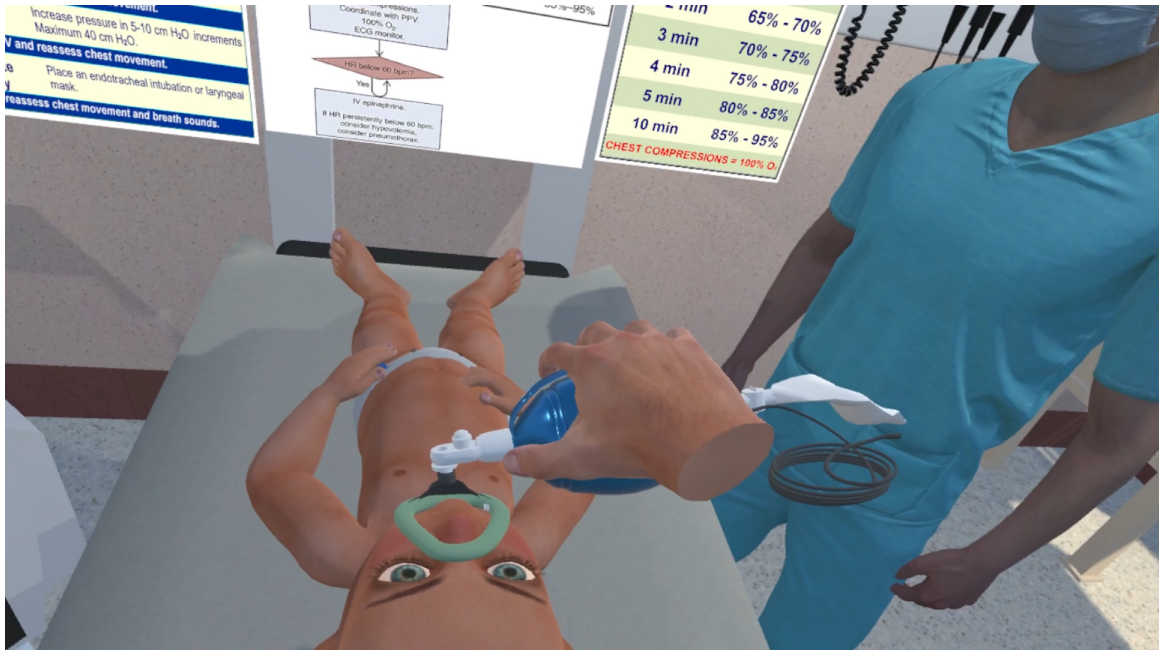


Figure 4.4.4: A sample image from the simulation. The user holds the mask to the baby's face, holds the bag valve mask with right hand and does PPV

Pulse Monitor

Another object that is interactive in the simulation is the Pulse Monitor. The pulse monitor is essential in neonatal resuscitation as it provides information on the vital signs (heart rate, oxygen saturation, heart rhythm). This object group consists of 4 objects; 1) Pulse oximeter, attached to the wrist of the infant; 2) ECG probes, attached to fit the infant's breast; 3) ECG cables, designed to connect the probes with the pulse monitor and can be affected by gravity, and lastly; 4) the pulse monitor, a

monitor that displays the vital signs.

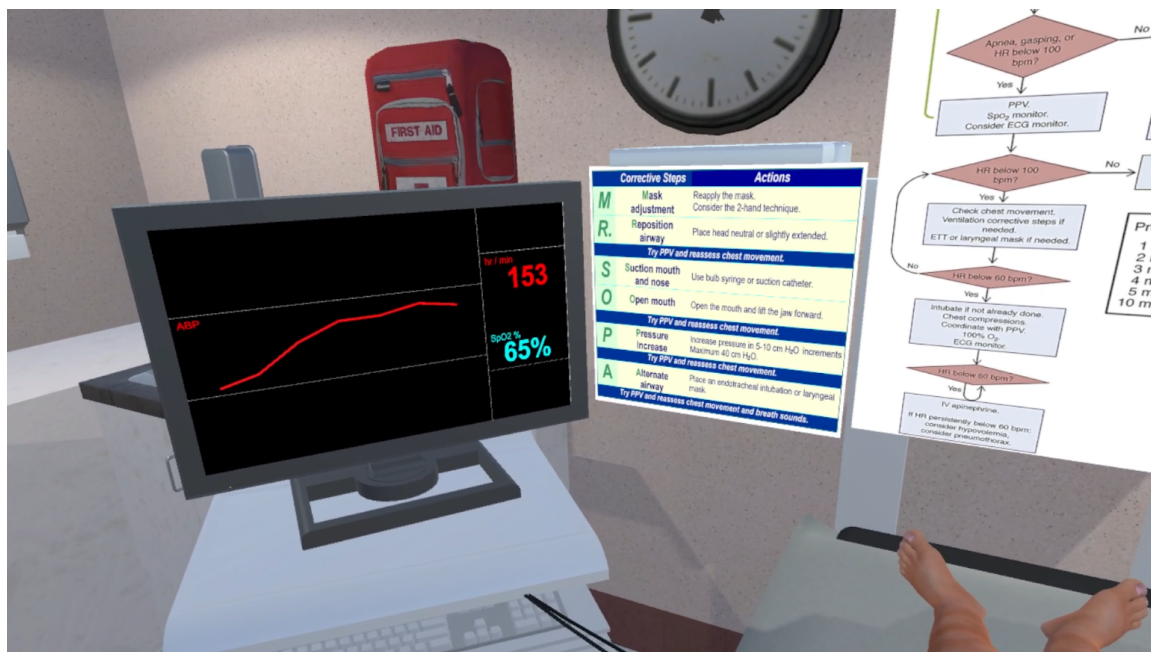


Figure 4.4.5: The monitor used to reflect the information it receives from the ECGs attached to the baby's chest. It is on the left side of the user's viewpoint and the values change every second.

Hand

In order for the user to feel immersed and feel more belonging to the simulation, a hand was used in this project in a way that would be closest to the real human hand. During the simulation, the user can move this hand as desired in the x, y, and z axes with the help of the HTC VIVE Controller held in their right hand. The right hand is also used to hold the bag valve mask required for breathing during neonatal resuscitation. The user can squeeze the bag valve mask object that they are holding in their right hand with the help of the trigger button of the VIVE Controller, and thus the hand object moves with the help of the squeeze animation.

4.4.3 Non-Interactive Objects

The higher the realism in training simulations, the more effective the simulation is in terms of refreshing the information from a trainee's perspective. In order for the simulation environment to be immersive, an environment was tried to be created in the project as in the working environments of the users. That's why we drew our inspiration from the Eastern Health Neonatal Intensive Care Unit (NICU). The walls, floors and ceiling of the space in the simulation were designed to resemble this room so that the users could feel a better sense of presence. Wall colours were chosen to match the colours of the NICU room. During the simulation, the door, the corridor seen from the door, cabinets and the first aid kit were added to the left side of the position where the user was standing. The medicine cabinet, a desk, and a window with a view of Memorial University were added on the right side.

NRP 7th edition posters (Figure 2.1.1) were hung on the infant warmer to assist healthcare workers in the neonatal resuscitation procedure (Figure 4.4.3). These posters were added with Unity's canvas feature. In order not to tire the eyes of the users, it was made one-to-one with the resolution in the high resolution and simulation environment and added in a solid way. On the other hand, the poster of "mask adjustment, reposition the airway, suction mouth/nose, open the mouth, increase the peak inspiratory pressure (PIP), airway (MRSOPA)", which is an important neonatal resuscitation action sequence, is placed on the front of the infant warmer by the user. Finally, the "targeted pre-ductal saturations" data has been added to the Unity Canvas in a position the user can see. These pieces of information provide relevant context which might help the user when applying neonatal resuscitation procedures in their simulation.

4.5 Room Design

In this simulation, there are three rooms in total. When the program starts, the user's first room is the welcome room, followed by the tutorial and then the simulation room. All rooms are similar to each other but with different equipment and objects. For example, while there are no objects to interact with in the welcome room, the infant and doctor avatars in the tutorial room are the same as the infant and doctor avatars in the simulation room.

4.5.1 Teleport

The teleport feature of SteamVR package is used for traveling between rooms [76]. Teleport locations where the user will be located were determined for each room and a unique name tag was created for each of these in Unity. The starting point is pre-defined and fixed in the first room when the user starts the VR simulation. The user can move to different parts of the room by physically moving in real life if they want, but when they teleport to another room, the location to go has been pre-defined and determined. For the tutorial and simulation rooms, this location was determined to be the front of the infant warmer, which is the most suitable position to do positive pressure ventilation.

4.5.2 Menu

The user can travel between the rooms with the help of the menu. To open the menu, the user has to press the trackpad button of the HTC VIVE Controller in his right hand. After pressing the trackpad, the menu appears in the user's view. When the user moves their head with the VR Headset, the menu also moves along. In other

words, the menu always remains in the user's perspective. This feature is achieved by selecting the "Screen Space - Camera" feature of the "Render Mode" part of Unity's Canvas object. There are three options in the menu, which are placed according to the user's point of view; "Tutorial", "Start" and "Exit". The controller in the right hand of the user represents the hand in the simulation. When the user moves the VIVE controller that they are holding, the hand in the virtual environment also moves. The user brings the hand over the option they want to select from the application menu and does this by moving the control in their right hand in the air. When the hand in the simulation hovers over the menu button, the background of the menu button becomes red. This situation tells the user that the option to select is highlighted. The user selects the highlighted option with the help of the trigger button on the VIVE Controller, which corresponds to the index finger. While the menu is visible, the user can use the trackpad button again to close it.

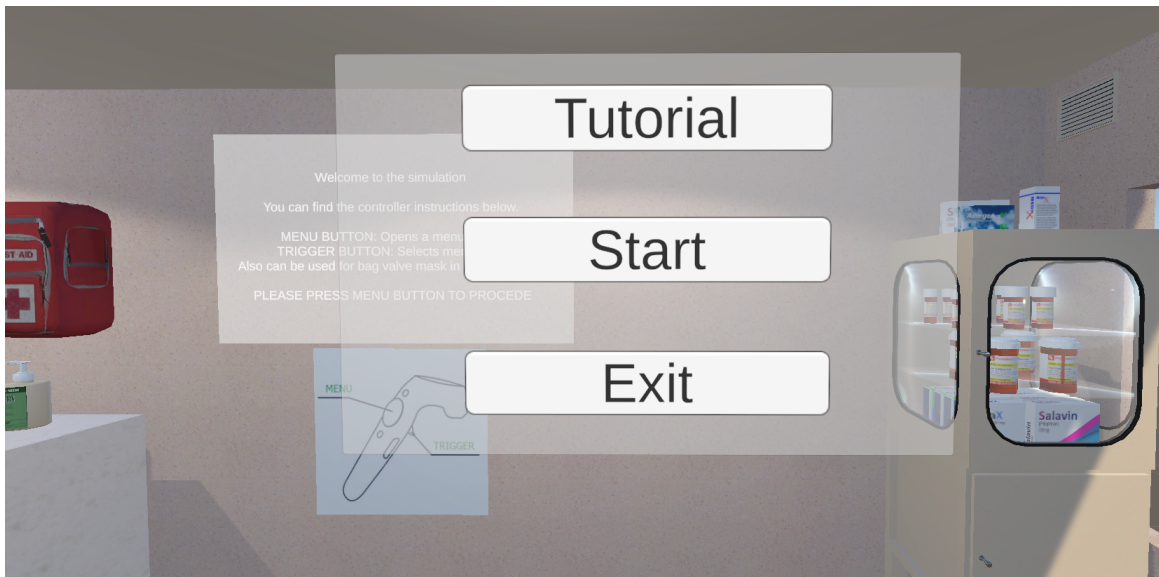


Figure 4.5.1: The menu in the simulation. It follows the user's camera and moves wherever they look. Menu items highlight red when controller hovers over them

4.5.3 First Room (Welcome Room)

The welcome room is the room where the user gets familiar with the simulation environment, gets the opportunity to know the controls and checks that all equipment is working. When the program starts, it automatically starts from this room, and there is no object that the user can interact with because the purpose is to introduce the user to the environment around. On the wall in front of the user, there is an information canvas where the functions of the buttons on the equipment and the controller are explained.

The first room is also the room where the sound, which is of great importance in simulations, is controlled. In order to reflect the hospital ambience, background “hospital sound” is added and set at a low level such that it is not disturbing/distracting the user. It is important for the user to hear the sounds from the simulation clearly because most of the information and guidance in the simulation is done with sound effects. For example, it is important for the users to hear what the doctor avatar is saying as he is guiding the user. Another example includes the sound when the bag valve mask is squeezed while PPV is applied, which gives feedback that the bag is squeezed appropriately and also gives an immersive experience. Each user is asked if they hear the sounds clearly before they start the simulation.

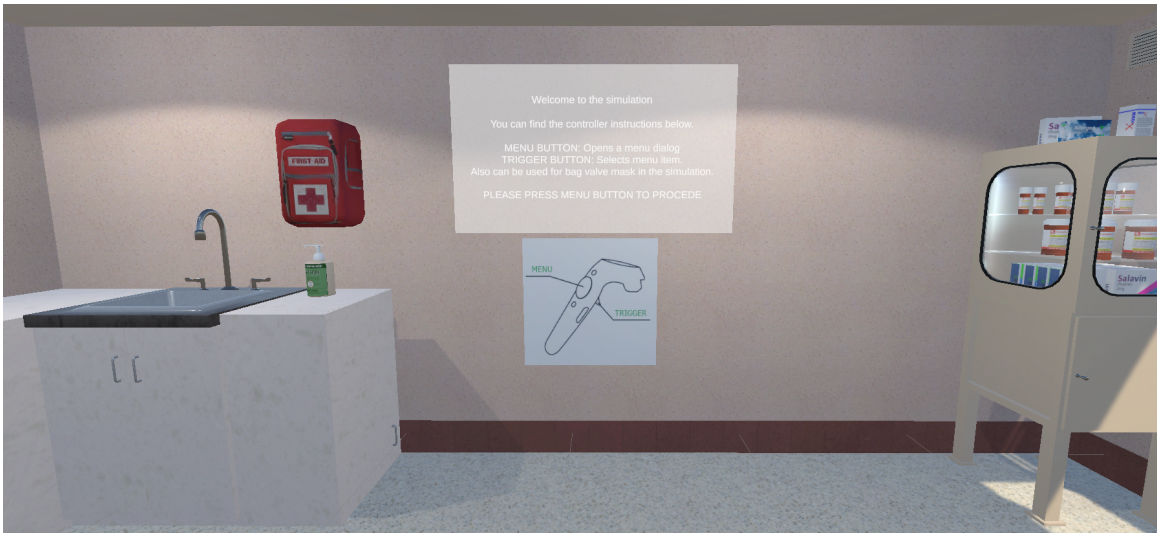


Figure 4.5.2: An example view from the welcome room.

4.5.4 Second Room (Tutorial Room)

The second room is called the “Tutorial Room”. The structure of this room is the same as the Welcome Room. However, unlike the welcome room, there is an infant warmer in front of the user, an infant on the infant warmer, a doctor’s avatar who welcomes the user, and NRP information posters on the infant warmer that they can look at during the simulation. In order to draw the attention of the user to these posters, arrows pointing to the posters have been placed on top of them. The doctor avatar is located on the user’s right side, next to the infant warmer. This arrangement is the location of the person who will help the user who will do the PPV in the neonatal resuscitation procedure as part of a team. The user can move the bag valve mask with the help of the HTC VIVE Tracker in their left hand. The controller in the user’s right hand represents the user’s hand, as in other rooms. The doctor avatar looks at the user during the conversations for an immersive experience. This feature has been implemented with Unity’s “Animation Rigging” package. The head

of the doctor avatar is set to follow the VR camera, that is, the user.

4.5.5 Third Room (Simulation Room)

The third room is called the “Simulation Room”. After the user understands the system in the welcome room and masters the equipment in the tutorial room, they teleport to this room to start the neonatal resuscitation training simulation. The simulation starts shortly after they are teleported to this room. The simulation room design is the same as the other rooms. The placement of the objects is the same so that the user feels familiar. Unlike other rooms, there is a pulse monitor on the left side of the user, where they can monitor the infant’s vital signs. During the training simulation, the data received from the oximeter attached to the infant’s wrist is reflected on this monitor. When the user turns their head to the left, they can easily observe this data.

Again, unlike the other rooms, there are two different objects on the avatar of the doctor. The first is the stethoscope that he will use when necessary during the simulation and the oximeter that he puts on the infant. The visibility of these objects is initially set as invisible, and the visibility of these objects is made visible, when necessary, in the later phases of the training.

Another object that does not exist in other rooms but in the simulation room is the analog clock on the wall opposite the user. This clock is a real-time clock and has been set for the user to follow the neonatal resuscitation process and to check the time when necessary.

4.6 Timelines

Timelines is one of Unity's features where you can track and control features such as sound, animation and visibility of objects throughout time and use these features as a package. Multiple different features can be included and triggered simultaneously in a timeline. Each timeline has a name, coordinate (x,y,z point) and trigger time. Sound, animation or visibility of objects can be positioned anywhere along the timeline, and for how long these objects take place can also be specified. Timeline can also be used as a cut-scene or cinematic. To add the Timeline feature to the project, the latest version was found and added from Unity Packages Manager.

The use of a timeline in this project is of great importance in training simulation. The doctor avatar in NRP training helps the user, guides the user in the simulation, and warns the user when necessary. The position of the doctor avatar, his animations, the text dialogs he says during the simulation and the visibility of some objects according to the scene are created using the timeline feature. For example, the name of the timeline which is used in this project that the doctor greets the user at the beginning is "Entrance Timeline". The doctor animations used in this timeline are "waving hands", "doctor idle", and "talk", respectively. The doctor avatar first waves at the user, then pauses to idle and then talks while giving information about the neonate. Adjusting the order of these animations and how long each animation lasts can be done in the Timeline.

Animations are one of the cornerstones of virtual reality simulations. We can determine the closeness to real life by the quality of the animations. The more the objects in the simulation comply with the laws of physics, the more realistic the simulation will be. Animations can be produced by developers, as well as ready-made packages from large companies. Unfortunately, such a formation does not exist in

the medical field. But there are ready-made animation websites created for computer games. For example, Mixamo is a product of Adobe [77]. In general, animations of first-person shooters (FPS) or 3rd person-view video games are concentrated on this website. There are also common animations, such as the character waving or bowing. They can be used anywhere in the project by downloading files with the FBX extension from Mixamo and saving the animation in Unity separately.

Another way of producing animations can be generated from the animation panel in Unity. There are various unity assets that use this animation panel as infrastructure. One of the best examples of these is the Umotion Pro Animation Editor package available in the Unity Asset Store. This package is intended for objects with humanoid rigs. It provides skeletal animation, transform animations, inverse kinematics (IK), and child-of-constraint features. On account of Umotion, the limbs of the avatars used in the simulation can be animated as desired. For example, for the stethoscope usage animation of the doctor avatar, the doctor must first lean toward the infant and then move the stethoscope tip in his hand toward the infant's chest. For this, in the project, each joint of the humanoid doctor avatar was moved to provide a realistic animation. The animations in the project are briefly explained below.

Another feature in the Timeline is sound files. In this project, as mentioned before, the doctor avatar is designed to assist the user (the NRP trainee), guide and warn when necessary. We thought that the doctor avatar would give the user a more immersed feeling by performing these directions and warnings vocally, just like a doctor helps in real life. Therefore, from the beginning to the end of the simulation, the doctor avatar speaks to the user when necessary. Providing this speech takes place with the help of audio files. Audio files are added to timelines, and the times to be triggered are determined by the programmer. For example, in the timeline where the

doctor avatar greets the user, when the waving animation and the “Hello, welcome to the neonatal resuscitation training simulation“ sound file is triggered at the same time, the doctor avatar in the simulation greets the user audibly while waving. These audio files are created with “Text-to-Speech” (TTS) technology. There are many TTS websites on the Internet. Companies such as Google, Amazon, and IBM offer this service as a paid premium membership or as a free membership with fewer features. However, we did not prefer this because the audio files in the services they offer are like robotic speech. For the Virtual Reality simulation, we purchased a service called Hearling [78]. Hearling, is one of the websites where you can get the Wavenet feature and TTS feature and download the created audio files which is one of the closest TTS speech to human natural speech conversion technologies, so that the user can feel more immersed. Thus, when the doctor avatar speaks in the simulation, the user will feel an experience closer to reality.

Neonatal resuscitation is a team procedure. There must be at least two, and in some cases there are three people, and they are in communication with each other throughout the procedure. For this reason, we thought that the one-sided speech of the doctor avatar in the simulation would cause a lack of realism in the simulation, and we decided that there should be another voice that also represents the character of the user. This voice will represent the user and will guide the user on where to ask questions in real life by asking questions at necessary places throughout the training. For example, when the user needs to learn the heart rate, the voice representing them will ask, “What is the heart rate?”, and at this point the user will understand that they need to ask about the heart rate in a real-life situation. In response to this question, the doctor avatar will say what the heart rate is. Thus, there will be a simulated dialogue between the doctor avatar and the user, and good communication, which is required for neonatal resuscitation to be successful.

One of the Text-to-Speech features is that the gender of the person who will give the speech can be selected. You can get the same sentence with both male and female tones. In the simulation, since the doctor avatar is male, the doctor avatar voice files created with TTS were also recorded with a male voice tone. To avoid confusion throughout the simulation, TTS sound files, which were created with a female voice tone representing the trainee, were used. Thus, the user could easily distinguish between two different gender tones and follow the dialogues easily.

The Unity game object, which is assigned as the audio source of the doctor avatar, is placed at the location of the avatar as a child of the avatar object, and while the avatar moves during the animations, the audio source also moves with the avatar due to its child object feature. The “Spatial Blend” feature, which is one of the properties of the audio source, takes a value between 0 and 1, where 0 is false, 1 is true, and the float numbers in between contain the value of how spatial the audio source will be. In this project, this value has been set to 1 to give the impression that the doctor avatar’s conversations are coming spatially from the avatar. On the other hand, the “Reverb Zone Mix” feature is also set to 3D. This feature makes the sound three-dimensional. Since the sound files are triggered within the timelines, the “Play on awake” feature is set to “false” so that the sound files are not played when the simulation starts. The “play on awake” feature is kept in only one file and in a loop, which is the “neonatal intensive care unit” background sound file that provides hospital environment sound in the simulation.

Finally, the visibility of some objects in the simulation has been added to the timelines. These objects, the stethoscope, the nasal aspirator for the infant’s nose, the oximeter, and the electrocardiogram (ECG) leads that are placed on the infant’s chest, are made visible when appropriate, according to the training flow. When the

simulation starts, their visibility is set to invisible. For example, in the animation where the doctor avatar is suctioning the baby’s nasal passages, the nasal aspirator is set to be visible as the first element of the timeline chart. Then, the doctor avatar performs a suction animation on the nose, and after this animation, the nasal aspirator visibility is set to hidden. Another example is the timeline where the doctor avatar places ECG leads. In this timeline, the doctor avatar first says, “I am placing the ECG Leads”, then the ECG Placement animation takes place. While this animation continues, the visibility of the ECG Lead-1, Lead-2 and Lead-3 objects and the wires connecting the leads to the Pulse monitor is set to “Active” at short intervals. After the animation is complete, the “Post-playback state” property of the Lead object in the timeline is set to “Active” so that the ECG leads and wires remain visible in the rest of the simulation flow. The ECG insertion timeline is shown in Figure 4.6.1.

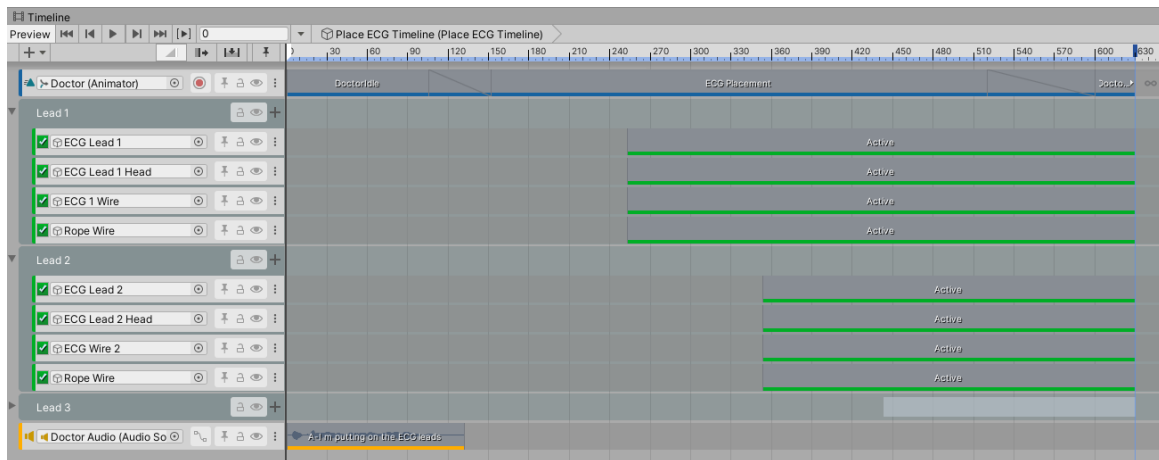


Figure 4.6.1: The Place ECG Timeline created in Unity

Timelines in the project were created in two different areas known as tutorial room timelines and simulation room timelines. Tutorial timelines are timelines used in the tutorial room, while simulation timelines are timelines used after the simulation starts. Thus, the location and content of the timelines were easily distinguishable during development.

4.6.1 Tutorial Room Timelines

Doctor Idle Timeline

Used when the doctor avatar is not speaking or when an action is expected from the user.

Tutorial Timeline

It is the timeline where the doctor avatar meets the user, and the user hears the doctor avatar's voice for the first time. At the same time, the user also greets so that the user becomes familiar with the voice that will represent him/her in the simulation.

Items Timeline

It is the timeline where the doctor avatar shows the NRP posters to the user, and the arrows on the posters are in an endless loop until the timeline ends. This timeline includes "Doctor Idle" and "Talking" animations.

Bag Valve Mask Timeline

It is the timeline where the arrow pointing to the bag valve mask that the user will use in the training simulation and the bag valve mask itself are introduced. It is also the tutorial timeline explaining that the HTC Vive Tracker in the user's left hand represents the bag valve mask in the simulation. The animation of the doctor avatar pointing to the bag valve mask on the left of the user is also found in this timeline.

Example Mask Timeline

Since this project is a neonatal resuscitation training simulation, it is necessary to show that the mask object in the simulation fits perfectly in the baby's mouth and, at the same time, to teach the user proper usage. In this timeline, the proper fit of the mask to the baby's mouth is demonstrated to the user with a temporary mask object and the arrow showing this object. In this part, the user is only asked to observe.

Place Mask Timeline

After training so that the mask is placed in the infant's mouth in the proper position, the doctor avatar requests the user to attempt the exact placement. The tutorial continues when the user moves the HTC Vive Tracker in the left hand and places the bag valve mask, which is represented by the left hand in the simulation, onto the infant's mouth.

Grab Bag Timeline

In this timeline, the doctor avatar asks the user to hold the bag part of the mask that the user has placed on the infant's mouth with their right hand and squeeze it.

Finishing Timeline

After the tutorial session is completed, the doctor avatar indicates and thanks the user, accompanied by the "Thumbs Up" animation, that the tutorial has been completed. He asks the user to open the menu by using the button of the HTC VIVE Controller in their right hand to select the simulation to start.

4.6.2 Simulation Room Timelines

Entrance Timeline

It is the first timeline of the simulation workflow. The doctor avatar introduces himself and gives information about the infant to the user (Infant information is explained in detail under the Workflow topic, Section 4.7. After the user asks for the heart rate, the visibility of the stethoscope object, accompanied by the heart rate checking animation, is turned on during the heart rate check and then becomes hidden. The doctor avatar provides information after a heart rate check and requests the user to start PPV. The reason for this request is that the project is a training simulation. The user understands that they should start PPV in accordance with the information provided. In order to reinforce this, the female voice representing the user's voice also says, "I'm starting PPV" and the user is expected to start PPV.

Putting Oximeter Timeline

While the user continues the PPV, the doctor avatar informs the user that he is placing the pulse oximeter on the infant's right hand. The visibility status of the Oximeter game object is made visible, and the "Post-playback state" property is set to "Leave As Is" so that the object remains visible until the end of the simulation after it becomes visible.

You Should Start PPV Timeline

This is the timeline where the doctor avatar warns the user that he/she should start PPV when they have not started themselves. It repeats at certain periodic intervals until the user starts the PPV.

Second Finished Timeline

The doctor avatar checks the infant's vital signs after the user starts the first PPV. This timeline is the timeline where doctor avatar tells the user to begin "MRSOPA" after he indicates that the infant is not breathing.

Suction Please Timeline

This is the timeline in which the user requests suction from the doctor avatar of the infant's mouth and nose.

Avatar Suction Timeline

The doctor avatar indicates that he will suction the infant's mouth and nose. Next, the doctor avatar performs the suction animation. The nasal aspirator object appears because the visibility of the nasal aspirator object is made visible in the avatar's hand. The animation is completed after the doctor has suctioned both infant's nostrils with a nasal aspirator. The female voice representing the user says, "I am continuing PPV"; therefore, it provides the user with the information that "PPV should be continued after the suction process". Thus, the user understands that s/he needs to continue the PPV.

Remove the Mask Timeline

The doctor avatar states that he will perform the suction action while the user continues PPV. At this point, the user should pause the PPV process by removing the mask from the infant's face, that is, by taking their hands away from the infant. If the user continues PPV even though the avatar has stated that he will do the suction, the

timeline, including “Please remove the mask so I can do the suction” audio content by the doctor avatar is triggered until the user removes their hands and allows the avatar to perform the suction process. If the user raises their hands and allows the avatar to suction, this timeline will not be activated.

Increase Squeeze Timeline

According to the NRP workflow, this is the timeline in which the doctor avatar requests the user to squeeze the bag faster since there is no rise in the infant’s chest.

There is a Chest Rise Timeline

The user asks the doctor avatar the question, “Is there a chest rise?” to learn if there is a rise in the infant’s chest and if all the previous operations are done correctly, this timeline is triggered, and the avatar informs the user by saying “Yes, there is a chest rise”.

Monitor on Your Left Timeline

After the doctor avatar puts the oximeter on the infant and attaches the ECG leads to the infant’s chest, the infant’s vitals can be displayed on the Pulse monitor located on the left side of the user. The doctor avatar expresses this with the help of an animation pointing to the left side of the user and informing the user. Thus, when users turn their heads with the headset to the left, they can also see the Pulse monitor displaying the vital signs.

Place ECG Timeline

This is the timeline where the doctor avatar puts the ECG leads. The visibility values of the ECG lead heads and the cables connected to these heads become visible, along with the animation where the doctor avatar attaches ECG leads to the infant's chest.

Stats Timeline

The user requests the doctor avatar to inform them about the values in this timeline. After the avatar informs the heart rate information to the user, the user asks the avatar to get information about oxygen saturation. Then, the avatar tells the user the oxygen saturation information by “looking at the infant warmer animation”. After saying that the saturation data is low and he will increase, he makes a move to the knob on the infant warmer that adjusts the oxygen values. Thus, the user understands that the oxygen values have been changed.

Stats Improving Timeline

While the user continues the PPV, the doctor avatar informs the users that the infant's values have returned to normal.

Free Flow Timeline

The female voice representing the voice of the user in the simulation states that they will stop PPV and will try free-flow oxygen for the infant whose vital values return to normal. The doctor avatar indicates that the infant has stabilized and the training simulation has been successfully completed. As the simulation ends, the

doctor avatar claps and gives a thumbs-up in the direction of the user. Thus, the user understands that he has successfully completed the training simulation.

4.7 Workflow

There is always a workflow in educational training, including NRP. The workflow in the training simulation in this project is based on the neonatal resuscitation algorithm, particularly the 7th edition of NRP, Figure 2.1.1 (the current at the time of writing). The training simulation begins by stating that the initial steps have been completed and includes PPV. The user then continues performing NRP as if in a real-life situation.

A states mechanism can be used to define a workflow when developing a virtual reality simulation in Unity. A Finite State Machine (FSM) is a model of behaviour consisting of various states and actions and transitions between these states with various conditions. An FSM has input, exit, input and transition actions. States show the current status of an object and can help determine how the environment will be shaped and treated according to that state of the object. For example, the PPV action triggered by the user pressing the button is a state of the bag valve mask. Similarly, the start of the timeline, which includes the speaking animation of the doctor avatar, is a state. A nice feature of states is that they are independent of other states and actions. For example, while the user presses the button of the controller on their right hand to perform PPV, at the same time, the doctor avatar speaking animation can be triggered, and the infant's vitals can be observed on the Pulse monitor. All these states can proceed independently of each other. The simulation can pass from one state to another if the predetermined condition occurs. The variables controlled in

these conditions are the FSM variables. The event to be triggered when the state changes is the action of the triggered state.

Playmaker, available in the Unity Asset Store, is one of the most used FSM additions by game developers in Unity [79]. It is a package where you can easily create States, Events and Actions, and run your own C# scripts. It is a software with which you can easily track and change the state of the variables that you will define as public.

For example, there is a finite state machine (FSM) used in this project corresponding to this statement: “After the Doctor avatar tells the user to start PPV, it checks if the user has started PPV and triggers an event if it has started,”. This FSM is shown in Figure 4.7.1. The variable called “startedPPV”, which is assigned as a public variable, is first set to “false” when the PPV is started by the user. Then, when the user presses the trigger button of the HTC VIVE Controller in their right hand with the index finger, this public variable takes the value “true”. On the other hand, this FSM checks if the value of this state is “true”. If this state is “false”, it transitions to the “Wait 2 seconds” FSM, and after waiting 2 seconds, it comes back to this FSM and rechecks the state. If this state is set to “true”, the “mask initially used event” is triggered and moves to the next FSM in the workflow.

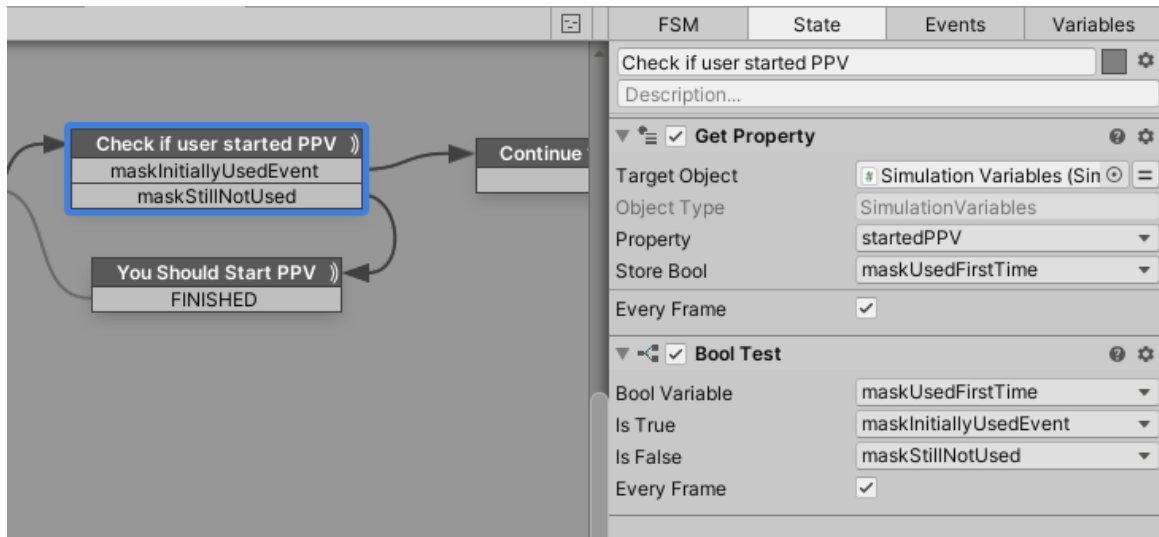


Figure 4.7.1: Finite State Machine that checks if the user started PPV in Unity

The first of the three rooms in this project has been developed for the user to get to know the environment and equipment and adapt. Therefore, no state mechanism is used in this room as it is a linear sequence. The other two rooms, the tutorial and simulation rooms, each have their own workflow, thus separated FSMs are used for each of these rooms. Within these FSMs there are separated/independent timelines for each room, as previously described.

4.7.1 Tutorial Workflow

The following events are part of the sequence that implements the tutorial workflow.

- The user starts the tutorial by selecting the first room, the welcome room, with the help of the menu. The user is teleported to the tutorial room, and the tutorial workflow is triggered.
- Visibility of the NRP poster and bag valve mask arrows to be used in the tutorial

is set to hidden. In other words, public variables are reset.

- The values of the public variables “tutorialMaskPlaced” and “tutorialMaskSqueezed” are set to “false”.

- After the variables are initially set, the “Tutorial Timeline” is triggered and the doctor avatar explains that he will give information about the simulation and equipment. The user also hears the female voice for the first time, which represents the user’s own voice in the simulation. After greetings, the user becomes able to distinguish the voice of the avatar and the voice that represents the user.

- The arrows on the NRP posters on the infant warmer in front of the user appear and point to the posters by moving repeatedly.

- The “Items Timeline” is triggered, and the avatar points to NRP posters that will help the user throughout the simulation and help the user notice.

- After the user notices the posters, the visibility of the arrows on the posters becomes hidden. The arrow on the bag valve mask on the left hand of the user becomes visible. Since this arrow object is the child object of the bag valve mask, the arrow moves with the bag valve mask object even if the user moves the HTC VIVE Tracker. The user can clearly see the arrow while examining the bag valve mask.

- The “Bag Valve Mask Timeline” is triggered, and the avatar points to the bag valve mask, telling the user that it is in their left hand. If the bag valve mask is not in the user’s hand, the avatar requests the user to take it.

- After the user becomes familiar with the bag valve mask equipment in their left hand, the arrow visibility on the equipment becomes hidden, and the “Doctor Avatar Idle Timeline” is triggered. During this idle period, the user is expected to inspect the equipment.

- In order to position the mask in the neonatal resuscitation procedure, which is important to position correctly, the sample mask object and the infant objects below it, are recursively activated. The location of this mask object is on the infant's mouth and is positioned based on the educational situation.

- The "Example Mask Timeline" is triggered, and the avatar tells the user that the proper mask positioning should be as shown.

- The example mask object and infant objects are deactivated and disappear from the user's field of view.

- After teaching the proper mask positioning, the avatar prompts the user to try it by themselves and asks the user to place the mask properly on the infant's mouth.

- The user brings the bag valve mask, symbolized by the HTC VIVE Tracker, which they hold with their left hand, close to the infant's mouth, and when it reaches a certain distance from the infant's mouth, the mask is automatically placed in the proper position. Thus, the user will have tried the mask's proper placement on-site. After placing the mask, the "maskPlaced" public variable is set to "true" and the "maskPlacedEvent" is triggered, and the transition to the next FSM is made.

- After the mask is positioned correctly, the "Grab Bag Timeline" is triggered, and the avatar instructs the user to hold the bag with the right hand and press the trigger button of the controller with the index finger.

- The user brings the controller, which they hold with their right hand, closer to the connection part of the bag valve mask object, and when it reaches a certain distance, the hand object moves to the position of grasping the bag. The hand object remains on the bag with the grip animation until the user presses the trigger button with the index finger. When the user presses the trigger button with their index

finger, the animation of squeezing the bag and also the bulging animation of the bag takes place according to the pressing value. After this is triggered by the user, the “bagSqueezedEvent” is triggered, and the transition to the final FSM takes place.

- In the last FSM of the tutorial workflow, the “Finishing Timeline” is executed. The avatar congratulates the user and tells them to use the menu to start the simulation.

The text script of the tutorial workflow described above is as follows:

* User is teleported to the tutorial room.

Avatar: Welcome to the tutorial. I'm Dr. John.

User: Hello, doctor!

Avatar: I will assist you during the simulation. But before that, let's do a quick tutorial about the simulation and the equipment.

* NRP posters arrows appear.

Avatar: You can see the information about NRP in front of you on the infant warmer.

* The arrow on the bag valve mask appears

Avatar: The bag valve mask that you will use during the simulation is on your left. Please take the mask in your hand.

* The user takes the bag valve mask.

Avatar: The proper positioning of the mask on the infant's face is demonstrated in front of you.

Avatar: Now, you try. Please place the mask in your hand on the infant's face.

* The user places the mask in the infant's mouth and waits.

Avatar: Perfect! Now, grab the blue bag with your right hand and press the trigger button with your index finger to squeeze it.

* The user holds the bag with their right hand and presses the trigger button with their index finger. The hand object performs the bag squeeze animation.

Avatar: Good job! When you are ready, please press the menu button and start the training simulation.

User: Thank you, doctor!

* The user presses the menu button and selects the simulation option. It teleports to the simulation room, and the simulation starts.

4.7.2 Simulation Workflow

- The user starts the training simulation by selecting the “Start” option from the application menu.
- First, the training simulation data is reset. The bag valve mask, nasal aspirator object, oximeter object, ECG leads and stethoscope of the avatar, all of which the user will use in the simulation, and the infant objects of these objects are deactivated recursively as resources for later use. Also, public variables used in the training simulation, “startedPPV” and “canStartPPV” are set to “false”. These variables and objects will be assigned “true” or “activated” when used later.
- The “Entrance Timeline” is started. This timeline begins with the introduction of the doctor avatar and the user. In this way, the user remembers the same set of sounds they observed in the tutorial. As mentioned earlier, the NRP algorithm is followed in this project, so the simulation starts with the initial steps completed. However, the avatar needs to pass the information from the initial steps to the user, and this timeline gives information about the infant. The voice representing the user requests the avatar to check the infant’s heart rate. While the avatar is checking the heart rate with the stethoscope, the stethoscope object and the child objects below it become active. The avatar, which also checks whether the infant is breathing or not, informs the user of this information and tells the user to start PPV. In line with this information, in order to reinforce that the user should start PPV in this training simulation, the female voice representing the user says, “I’m starting PPV” and gives the user a kind of training on what to do.

- The system waits for the user to place the bag valve mask in the left hand on the infant’s mouth and start PPV with the controller in the right hand. When the user presses the trigger button of the controller in their right hand with the index finger, the “startedPPV” state takes the value “true”, the “maskInitiallyUsedEvent” is triggered, and the workflow continues. If the user does not press the button of the controller in their right hand and cannot start PPV, the “maskStillNotUsed” event is triggered and moves to the next FSM.
- In the next FSM, the “startedPPV” state is checked and iterates until this condition is met. If this state is “false”, the “You Should Start PPV Timeline” is started, and the avatar tells the user that they need to start PPV with the help of the audio file. If the user presses the button and sets the state to “true”, it reverts to the previous FSM, and the “maskInitiallyUsed” event is triggered.
- The user continues PPV for 15 seconds in accordance with the NRP algorithm.
- While the user continues the PPV, the “Putting Oximeter Timeline” plays, and the animation of the avatar placing the oximeter object on the infant is activated. The oximeter object and the infant object below it become visible.
- “15 Seconds Finished Timeline” is played after the user performs PPV for 15 seconds. In this timeline, the avatar says 15 seconds are up. The user asks for heart rate and chest rise. The heart rate checking animation plays as the avatar stethoscope object becomes visible. Next, the avatar crouches and checks for chest rise. He states that the heart rate has not increased, and the infant has no chest rise, and this timeline ends with the avatar doctor saying that the user should start MRSOPA.
- While MRSOPA. is being performed, the user must remove the mask from the

infant's face, move its head, and then reposition it. In order to convey this to the training simulation user, the voice representing the user states, "I'm removing the mask to reposition the head". Thus, the user understands that they need to move the HTC VIVE Tracker, which they are holding in their left hand, representing the bag valve mask, and remove it from the infant's face.

- In this FSM, the infant's head must be repositioned due to MRSOPA. FSM-Flow, which is added to the neck object to which the infant's head is attached in the hierarchy of the infant object, is triggered. The "userCanRepositionHead" state is checked in the FSM within the FSM-Flow located in the infant's neck object, and if it is "true", the "RotateHead" method in the "RepositionHead" C# script is added to the infant's neck object, and the object is executed. This method takes "minSize, maxSize, waitTime, angle" inputs. In this method, in which Euler transformation is used, the infant's head rotates in the angle parameter dimensions from "minSize" value to "maxSize" value on the neck axis, and after reaching "maxSize" value, it rotates in the opposite direction and regains its head position. Thus, the repositioning of the infant's head, which is used in MRSOPA., is taught to the user and performed. After this FSM has finished, the system returns to the simulation FSM-Flow, and the flow continues.
- After the infant's head repositioning movement is performed in MRSOPA., it is conveyed to the user via a sound indicating that the mask should also be repositioned. To achieve this, the female voice representing the user says, "I'm repositioning the mask", indicating to the user that they should reposition the mask.
- The user continues PPV for a certain period after mask repositioning.

- When the user starts PPV again, the “userRemovedMask” public variable is set to “false” to be used later in the workflow to check whether the mask is on the infant’s face or not. The “shouldRemoveMask” variable is also set to “true”, and the workflow continues with the next FSM.
- “Suction Please Timeline” starts. Within this timeline, after the MRSOPA adjustments, the user requests the avatar to recheck the chest rise. The user requests the infant’s mouth and nose to be suctioned by the avatar, who informs the user that there is no chest rise.
- In order for the avatar to perform suction animation, the user must pull the bag valve mask off the infant’s face. If the user has removed the mask, the variable “userRemovedMask” is set to “true” in the C# script. This variable is controlled in this FSM as a loop. If this condition is met, “canStartSuction” is triggered and the flow continues to the next FSM. If the user did not remove the mask and this variable contains the value “false”, the “removeMaskEvent” will be triggered, and the flow will switch to the “Remove Mask” FSM.
- In the “Remove Mask” FSM, the avatar tells the user, “Please remove the mask” to indicate that the user should remove the mask. When the user removes the mask, the variable “userRemovedMask” is set to “true” and returns to the previous control FSM.
- After the user removes the mask, the nasal aspirator (enema) object and the visibility of the infant objects connected to it are made visible for the avatar suction process.
- Next, the “Avatar Suction Timeline” FSM starts for avatar suction. The avatar holding the nasal aspirator object, which is visible in this timeline, performs

the suction animation. This animation includes both nostril suction operations. Then, the avatar states that the user should continue PPV. The female voice representing the user says, “I’m continuing PPV” so the user understands that they need to continue PPV.

- In order for the user to start PPV again, the “startedPPV” variable from the public variables is set as “false” and the “canStartPPV” variable is set as “true”.
- The “startedPPV” variable is set to “true” when the user brings the mask close to the infant’s mouth, presses the button with their right hand and starts PPV. This variable remains “false” if the user has not started PPV. This variable is checked in this FSM, and “startedPPVEvent” is triggered if the user started PPV, and “notStartedPPVEvent” event is triggered if the user has not started PPV.
- “You Should Start PPV Timeline” starts in the FSM, which is triggered by the “notStartedPPVEvent” event. In this timeline, an audio file representing the avatar will be played, telling the user to start PPV.
- “Increase Squeeze Timeline” is activated after the user continues PPV for a certain period. In this timeline, the user asks if there is a chest rise. The avatar then gives feedback that there is no chest rise and that the user needs to squeeze the mask harder. The faster the trigger button of the HTC VIVE Controller in the user’s right hand is pressed, the more pressure is applied, and the bulge animation on the bag is animated according to the applied pressure. Then, the user is informed by the voice representing the trainee that s/he needs to press the button harder and continue PPV.
- After the correct application of MRSOPA. and suction procedures, the user/trainee

again asks if there is a chest rise. The avatar informs the user that there is a chest rise and must continue PPV for 30 seconds. As we mentioned earlier, one of the useful features of FSMs was that simultaneous FSMs could be triggered. While the avatar is saying that there is a chest rise, the “babyCanBreathEvent” event is triggered to the FSM in the FSM-Flow that is added to the infant’s pelvis object can run simultaneously. The “StartScalingBaby” method in the C# script named “Breath” triggered by this event is executed, and the infant’s chest region, x,y,z scaling values increase by the “growFactor” parameter over time and begin to decrease in the opposite direction after reaching “maxSize” value. After the scaling value reaches 0, it starts to increase until it reaches 1 again. Thus, the breathing animation of the infant’s chest will take place until the end of the simulation.

- While the user continues PPV for 30 seconds, the values created by the oximeter that the avatar puts on the infant begins to reflect on the monitor on the user’s left (Figure 4.4.5). The “Pulse Physiology Engine” Unity package is used to generate these values. “Pulse Data HR”, for heart rate and “Pulse Data Oxygen” for oxygen objects from the scripts in Pulse Engine become active. These scripts, if the neonatal resuscitation action is implemented correctly, should generate random values within the range of values determined according to the NRP algorithm. Therefore, it takes min and max values and produces a random value in that range. For example, heart-rate values between 145 beats per minute (bpm) and 148 bpm, 1 per second (frequency = 1) and variability = 0.7 are given for this project. Thus, the heart-rate values seen on the monitor may change once a second or stay the same. Likewise, the Oxygen values change randomly, 1 per second, with the min value being 56 and the max value being 60. Thus, the user can observe the infant’s values on the monitor.

- “Monitor on Your Left Timeline” is triggered for the user to notice the monitor on the left. In this timeline, the avatar tells the user that the monitor is to their left and points with his hand. The user is expected to observe the monitor on the left and look at the values.
- While the user continues PPV, the doctor avatar places ECG leads on the infant’s chest. For this, “Place ECG Timeline” is run. In this timeline, the placement animation takes effect after the avatar tells the user to place the ECG leads. While the animation continues, the “ECG-Lead-1” object and the corresponding infant objects become active at the same time. In addition to the ECG lead, the cable connected to the lead becomes active. The other end of this cable is connected to the Pulse Monitor. Likewise, after the “ECG-Lead-2” and “ECG-Lead-3” objects are active, the animation is completed. Meanwhile, the user continues PPV.
- After all ECG leads are placed, and the user continues PPV for 30 seconds, the user asks to see if the infant’s vitals have changed. The Avatar says the infant’s vitals are improving, and it is starting to breathe. Afterwards, the user asks for oxygen saturation. The avatar tells the oxygen saturation value and indicates that the oxygen saturation values are low. Avatar informs that he will increase oxygen saturation by 30%. After saying this, the avatar animates towards the oxygen saturation handle object next to the infant warmer and states that he increased it.
- After increasing the Oxygen saturation, new values are sent to the variables imported by the script in the “Pulse Data HR” and “Pulse Data Oxygen” objects. New values for heart rate; min value = 150, max value = 154. New values for Oxygen; min value = 67, max value = 70 with the help of the event. Since

the Pulse Engine will assign a random value between these values, the user observes on the monitor on the left side that the infant's vital values increase and improve.

- After the values increase, it proceeds to the FSM with the “Stats Improving Timeline” and the avatar notifies the infant's vital values using the new values. In this timeline, the avatar tells that the infant's vitals are improving and informs of new vitals data.
- “Free Flow Timeline” is played in the final FSM, and the user is told to switch to free flow. Avatar says the infant's values are stable and good after free flow. Finally, the avatar congratulates the user for completing the simulation. “Thumbs-up” and “Clapping” animations play while greeting. Through this feedback, the user understands that the simulation is over.

Chapter 5

Results

5.1 Data collection and analysis

As described in the methods and materials section, participants were asked to complete several surveys at various points in the study. Table 5.1.1 summarizes the data collected. Briefly, participants were asked to complete a demographics survey before starting the simulation training. Confidence was assessed before commencing the training and after completing training using the first technology they were enrolled in. Instructor evaluation was only performed after round 1, completion of simulation using either technology, comparing 360° video with VR simulation. Lastly, usefulness, ease of use, motion sickness, and presence were evaluated both after round 1 and after round 2. As such, various data analyses and comparisons were made. This is depicted in Figure 5.1.1.

Table 5.1.1: Data collected at various time points during the study: pre-training, after completing the first simulation (after round 1), and after completing the second simulation using the second technology (after round 2).

	Pre-training	After round 1	After round 2
Demographics	✓		
Confidence	✓	✓	
Instruction Evaluation		✓	
Usefulness		✓	✓
Ease of Use		✓	✓
Motion Sickness		✓	✓
Presence		✓	✓

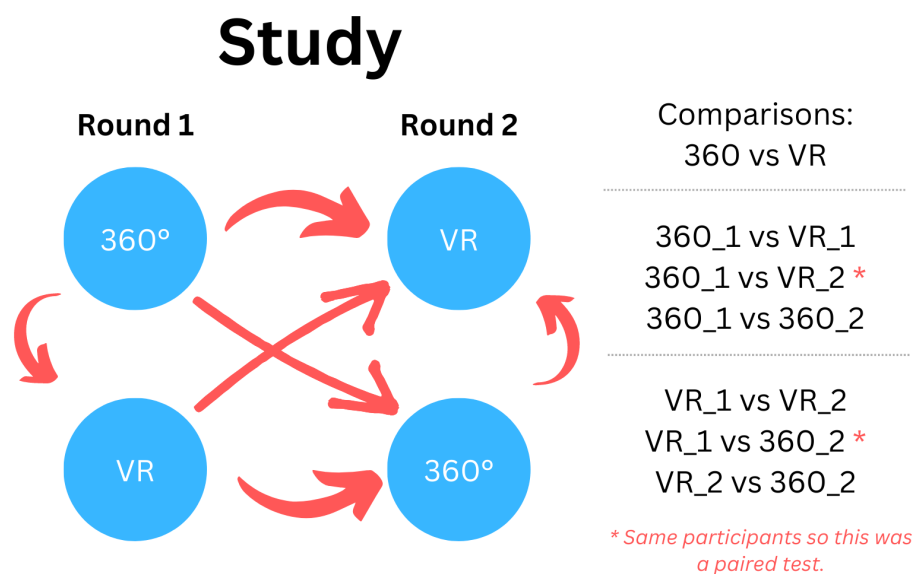


Figure 5.1.1: Study design and the various comparison analyses made between the groups.

5.2 Demographics

The 30 participants were randomized into two groups as previously described, either to 360° video or VR simulation. Prior to starting the session, participants were asked to complete a demographic questionnaire. The results are summarized in Table 5.2.1. As evident from this table, the study involved mainly females (28/30), with 15 in the 360° video group and 13 in the VR simulation group. The 2 males were in the VR simulation group.

With regards to the healthcare professional role, the majority were registered nurses (15/30), 6 in the 360° video group and 9 in the VR simulation group. The rest of the participants were staff physicians, resident physicians, clinical associates, respiratory therapists, and medical and respiratory therapy students.

The majority of the participants had been in practice for about 0-5 years (16/30); 8 in each group. Similarly, the majority of the participants had about 0-5 years of experience as an NRP provider (22/30); 11 in each group. Lastly, most of the participants had completed NRP training in about a year's time (16/30); 8 in each group.

Overall, there was no statistically significant difference in composition between the two randomized groups. Statistical analysis using the p-value Pearson's Chi-squared test was performed, which showed that there is no association between group assignment (360° video or VR simulation) and the demographic variables, as shown in Table 5.2.2.

Table 5.2.1: Demographic distribution of the Participants in each of the randomized groups: 360° video and VR simulation.

Factor's Assessed		360° Video First	VR Simulation First
Gender	Female	15	13
	Male	0	2
Role	Registered Nurse	6	9
	Licensed Practical Nurse	1	0
	Pediatrician	1	1
	Clinical Associate	1	1
	Pediatric Resident	2	3
	Obstetric Resident	1	1
	Respiratory Therapist	1	0
	Medical Student	1	0
	Respiratory Therapy student	1	0
Years in Practice	0-5 years	8	8
	6-10 years	1	2
	11-15 years	1	2
	16-20 years	0	2
	More than 20 years	5	1
Years as NRP Provider	0-5 years	11	11
	6-10 years	2	0
	11-15 years	0	1
	16-20 years	0	3
	More than 20 years	2	0
Years since last NRP training	0-1	8	8
	2	7	4
	3	0	3

5.3 Ease of Use

One of the factors that we assessed in the study was the ease of use of the technology. Pair-wise Wilcoxon testing was used for statistical analysis to determine if

Table 5.2.2: p-value Pearson's Chi-squared test showing no association between group assignment and demographic variables.

Variable	X-squared	p-value Pearson's Chi-squared test with p-value calculated by Monte Carlo simulations, 10000 replicates	
Role	4.8	0.934	
Years	5.33	0.334	
Years in NRP	0	1	0-5 years vs. >5 years
Last NRP training	3.818	0.197	
Gender	2.143	0.476	
		Conclusion: There is no association between group assignment (360_1/VR_2 or 360_2/VR_1) and demographic variables	

the VR technology was given higher ratings than the 360° video technology. When comparing the 360° video condition with the VR simulation condition, overall, there were no statistical differences in the rankings regarding the ease of use. Both groups rated VR to be moderately easy to use, as evidenced in Figure 5.3.1.

Next, we analyzed if completing the simulation using the specific technology in the first round vs. in the second round affects the ratings. As such, we compared data in various combinations, as shown in Figure 5.1.1.

When comparing 360_1 (people who tried 360° video first) vs. VR_1 (people who tried VR simulation first), there were no statistical differences in ease-of-use ratings. This is evidenced in Figure 5.3.2.

Similarly, there was no difference comparing the ease-of-use ratings from participants completing comparing 360° video vs. VR simulation, both completed in the

second round (Figure 5.3.3), 360° video in the first round vs. the same participants completing VR simulation in the second round (Figure 5.3.4), completing 360° video in second round vs. VR simulation in the first round (Figure 5.3.5).

There was also no difference in ease-of-use ratings between participants completing 360° video in the first round vs. the same participants completing 360° video in the second round (Figure 5.3.6). Similarly, there was no difference in ease-of-use ratings between participants completing VR simulation in the first round vs. those completing VR simulation in the second round (Figure 5.3.7). Paired pair-wise Wilcoxon test was used for statistical analysis. All p-values were corrected for multiple testing using the False Discovery Rate (FDR) method.

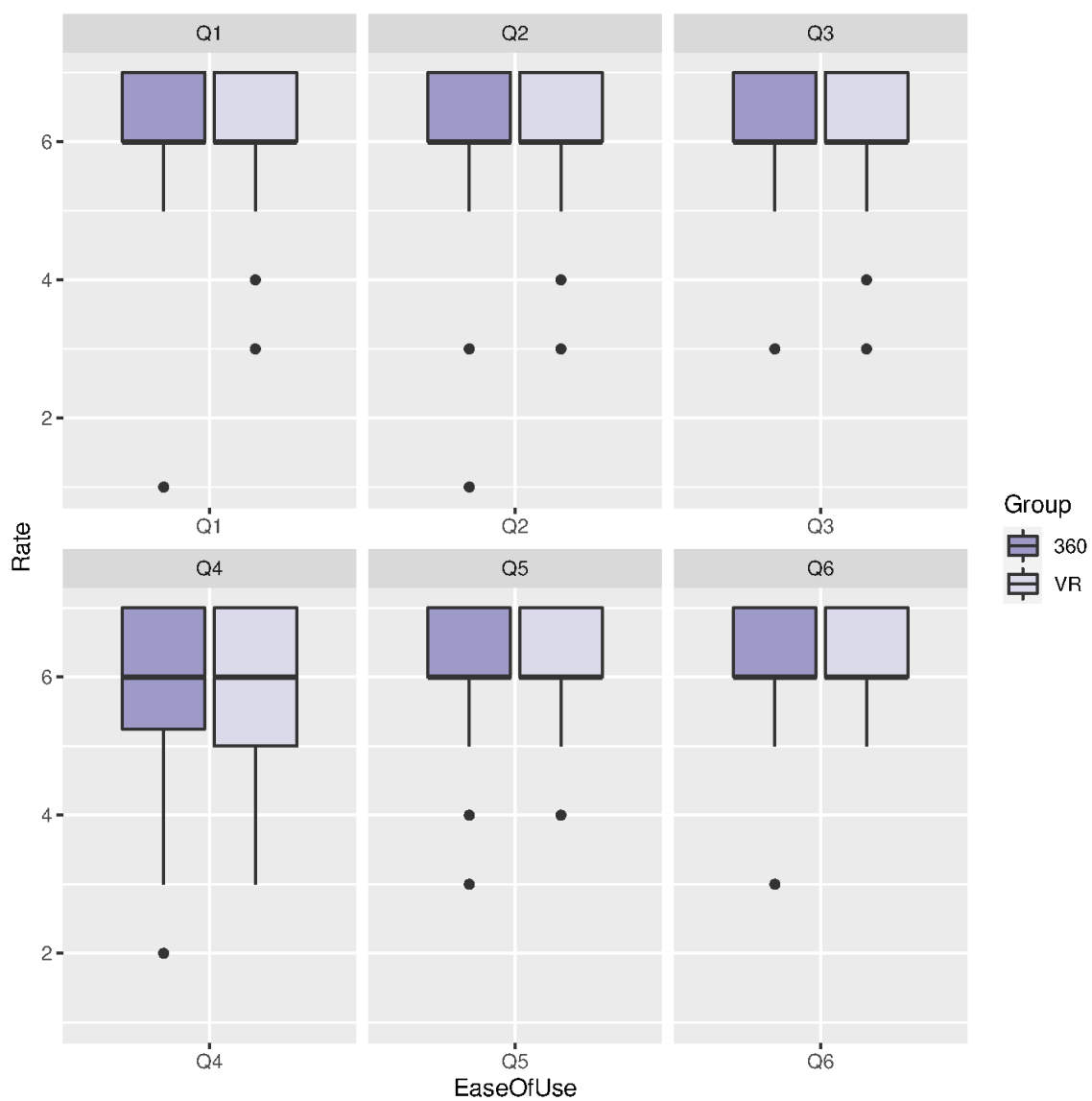


Figure 5.3.1: Ease of Use, overall comparison of 360° video vs. VR groups

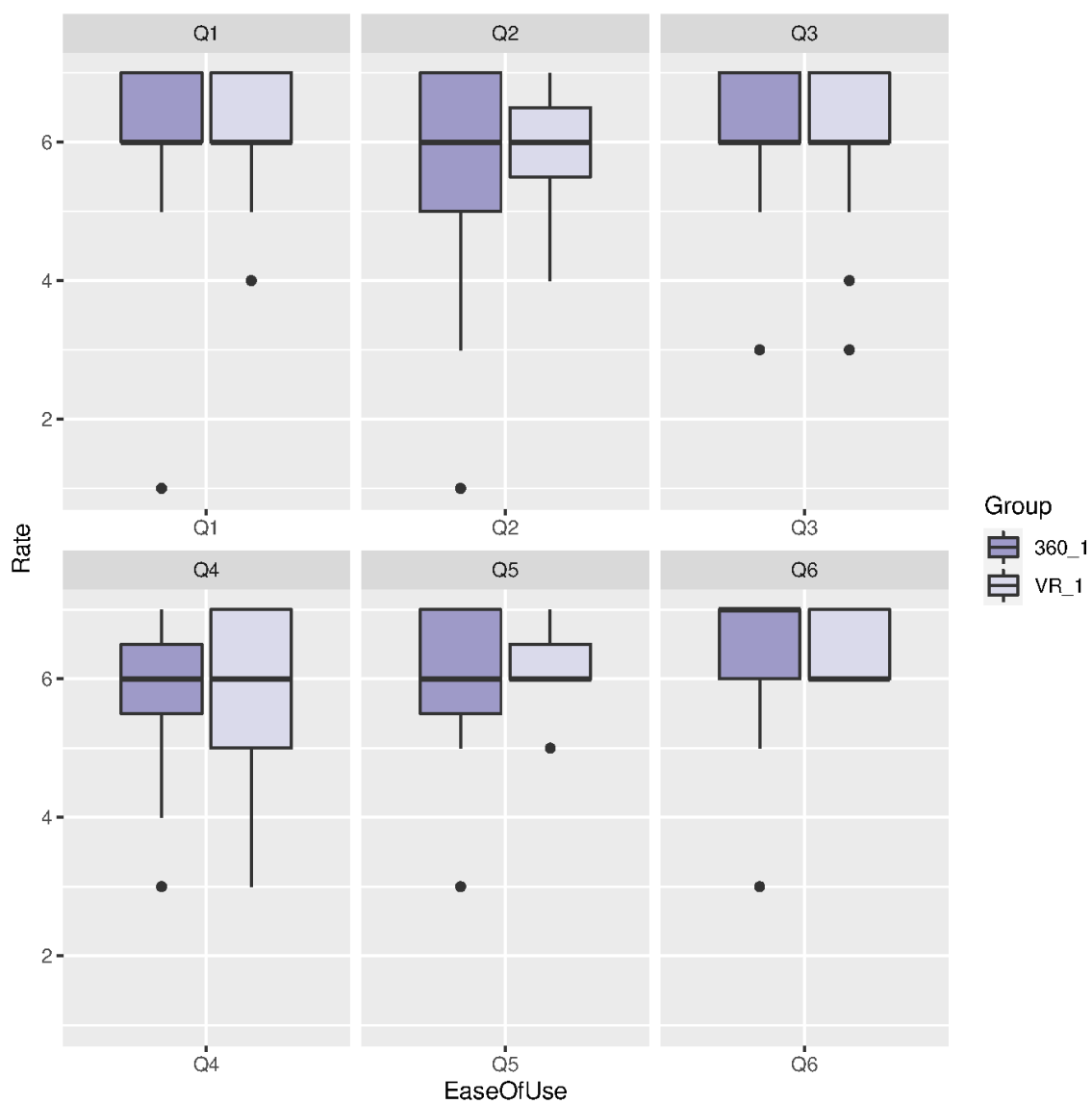


Figure 5.3.2: Ease of use rating comparing 360° video in first round vs. VR simulation in first round.

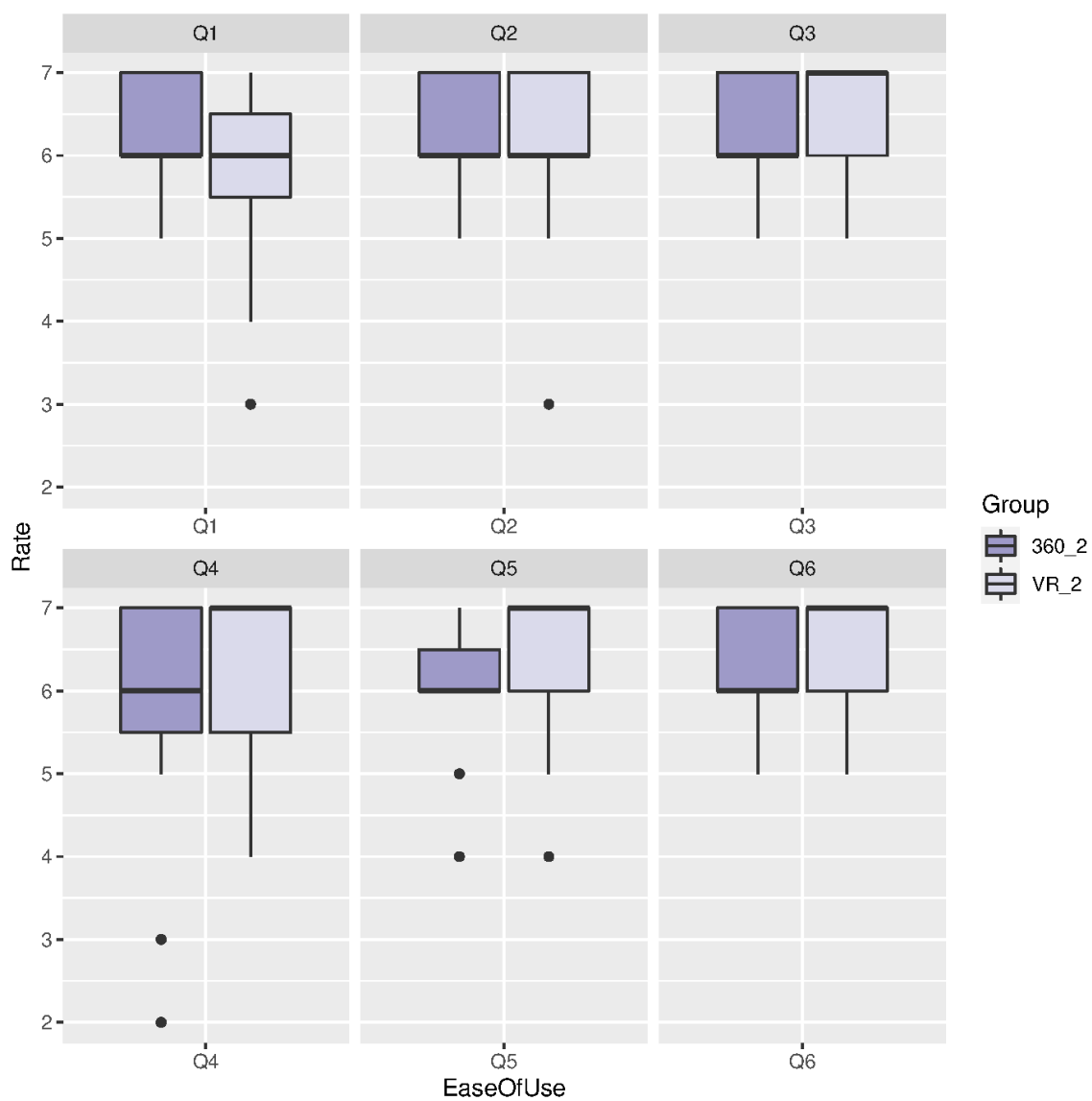


Figure 5.3.3: Ease of use rating comparing 360° video vs. VR simulation, both completed in the second round.

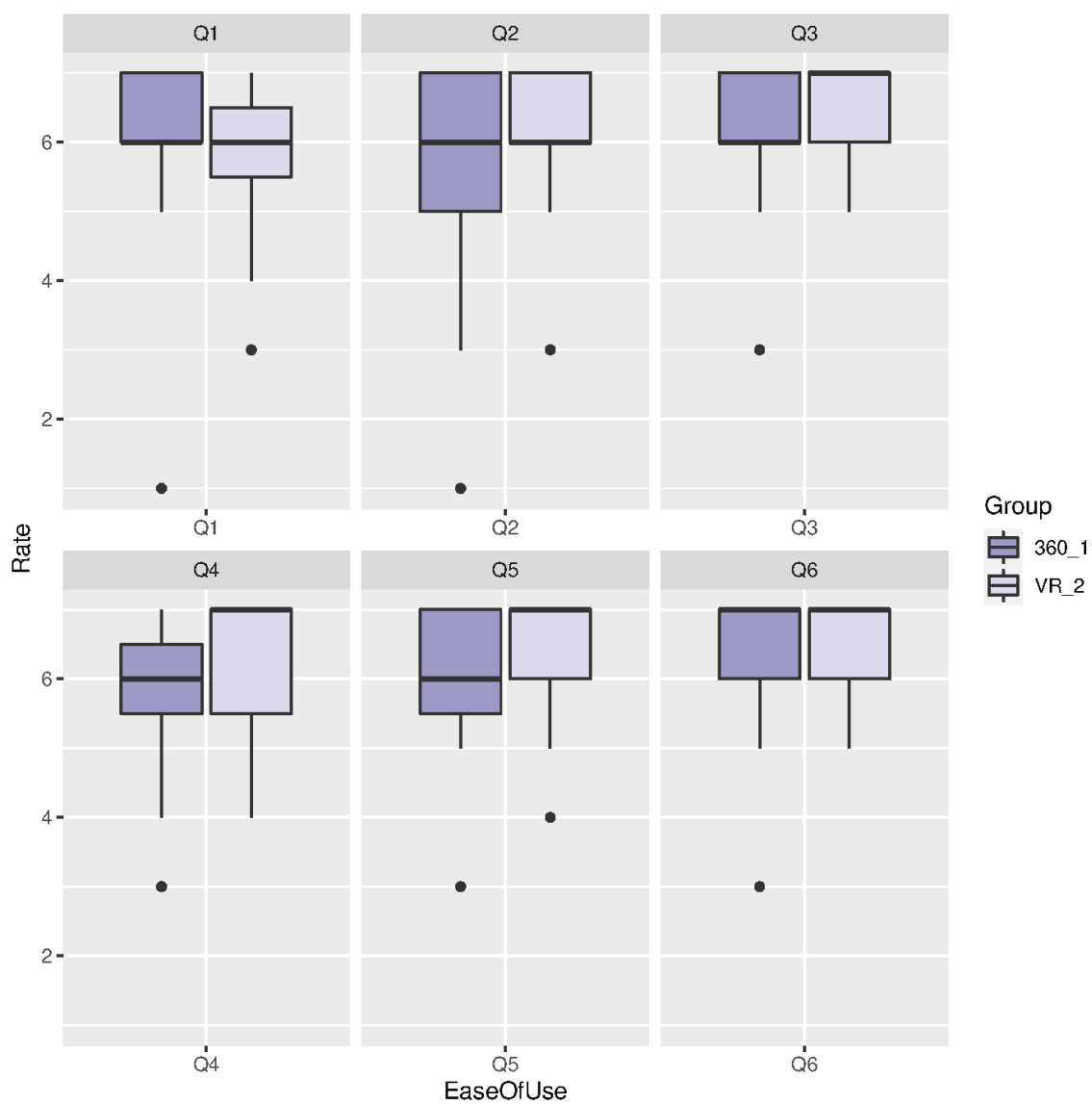


Figure 5.3.4: Ease of use rating comparing 360° video in first round vs. VR simulation in second round.

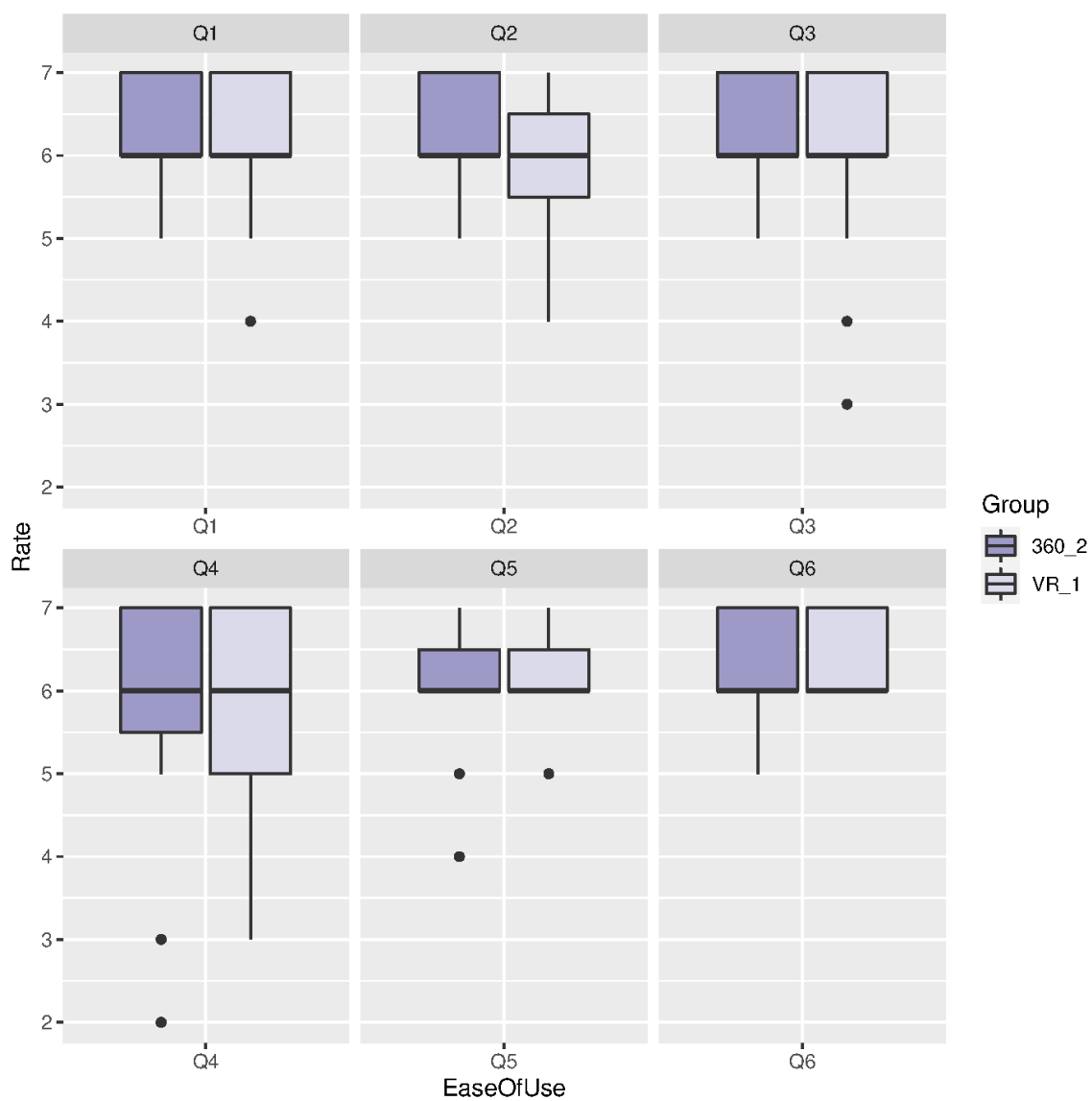


Figure 5.3.5: Ease of use rating comparing 360° video in second round vs. VR simulation in the first round.

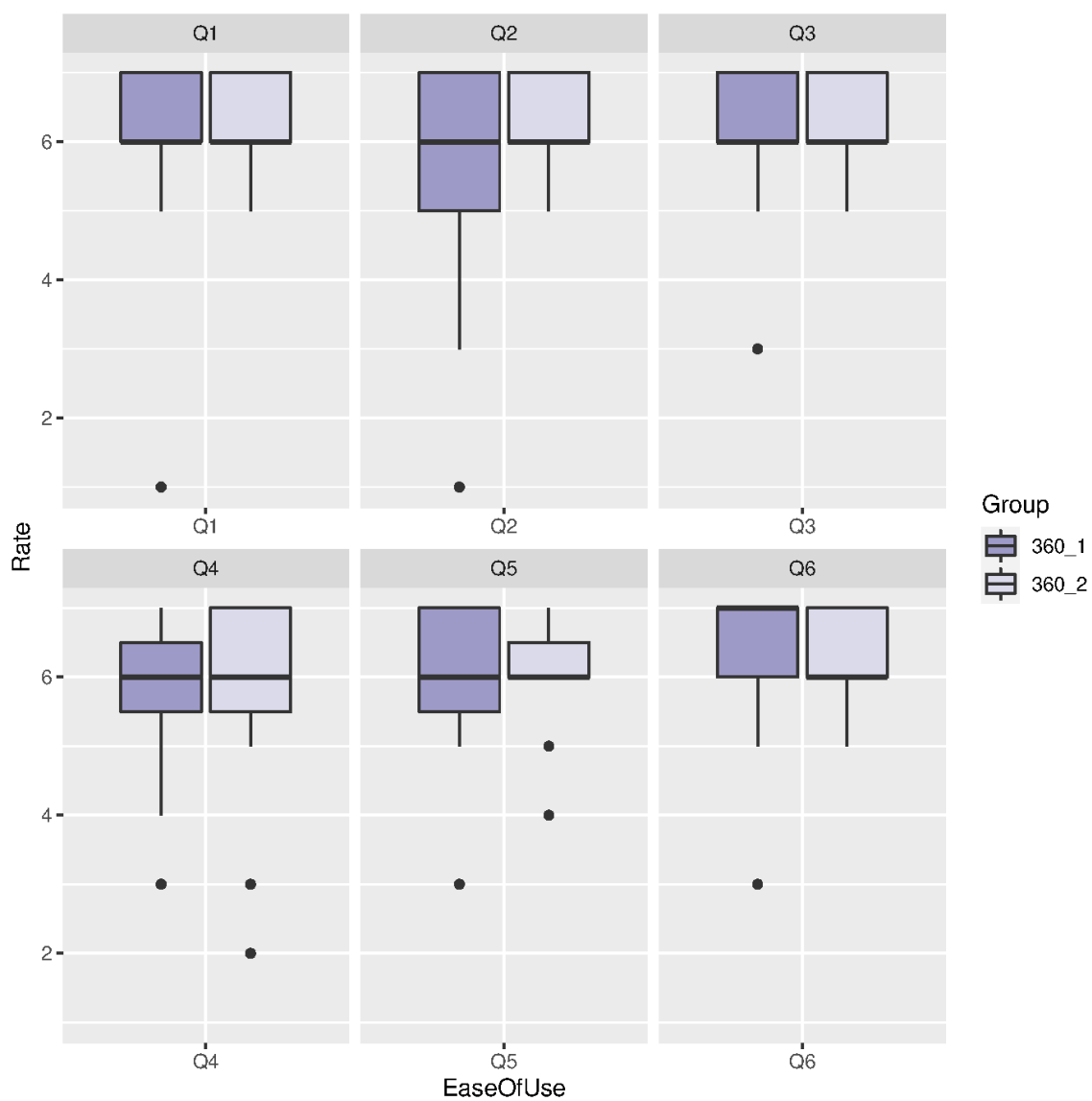


Figure 5.3.6: Ease of use rating comparing 360° video in the first-round vs. 360° video in the second round.

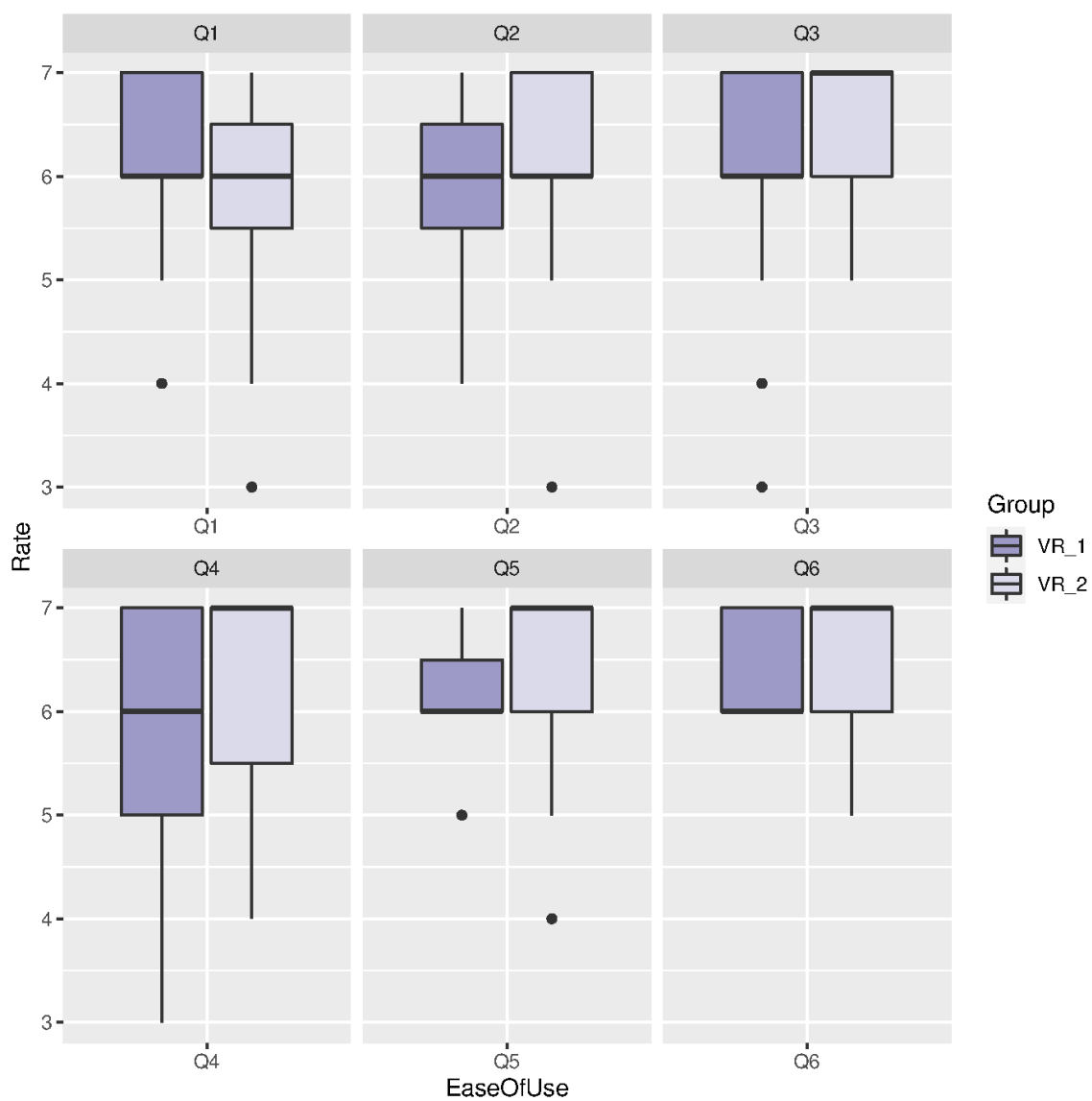


Figure 5.3.7: Ease of use rating comparing VR simulation in the first-round vs. VR simulation in the second-round.

5.4 Presence

The second factor that we assessed in the study was the feeling of being immersed in the simulation, “Presence”. Pair-wise Wilcoxon tests were used for statistical analysis to determine if the VR group had higher ratings. All p-values were corrected for multiple testing using the False Discovery Rate (FDR) method.

When comparing the 360° video condition with the VR condition overall, the VR condition had a higher rating for presence. Particularly, VR had significantly higher ratings for the visual and auditory aspects of the environment involving the participants (Figure 5.4.1, Q1,2, adjusted p-value<0.01). Participants also rated VR simulation significantly higher for being able to actively survey or search the environment using vision, closely examine objects, and examine objects from multiple viewpoints than 360° video (Q6, Q9, and Q10, adjusted p-value<0.01). Lastly, presence also includes how much participants feel immersed in the environment. Participants rated VR simulation higher for being involved in the virtual environment experience, and senses being completely engaged in the experience than 360° video (Q11, 13, adjusted p-value<0.01). Similarly, participants reported being involved in the experimental task to the extent that they lost track of time and had moments during the virtual environment experience where they felt completely focused on the task environment significantly more in VR simulation than in 360° video (Q15, A16, adjusted p-value<0.01).

There was no statistical difference in the ratings between VR simulation and 360° video for questions pertaining to how closely the experience was to a real-world experience (Q3, Q5, adjusted p-value>0.05). No statistical difference was noted for Q14, comparing the extent of events occurring outside the virtual environment distracting

the experience in the virtual environment. Low ratings were obtained for both conditions, meaning very little distraction impacted the participants' experience in the virtual environment.

Next, we analyzed if completing simulation using the specific technology in the first-round vs. in the second-round affected the ratings. As such, we compared data in various combinations, as shown in Figure 5.1.1. The results are summarized in Table 5.4.1 below.

In most cases, there is a statistically significant difference between VR simulation vs. 360° video, except when comparing the response of participants completing 360° video first vs. completing the VR simulation. This is the only group where there is almost no statistically significant difference between them, with the exception of questions Q1, Q2, Q9, Q10, and Q11. As previously mentioned, Q1 and Q2, related to the visual and auditory aspects of the environment involving the participants. Questions 9, 10, and 11 addressed being able to examine objects. Overall, participants rated VR simulation higher than 360° video for presence, except for participants completing 360° video first vs. VR simulation first. This suggests that completing the survey without seeing the other technology to compare to could yield skewed results, particularly in a group of participants not very experienced in VR technologies.

Table 5.4.1: Group comparisons showing a statistical difference for presence between 360° video vs. VR simulation.

	360 vs. VR		360_1 vs. VR_1		360_2 vs. VR_2		360_1 vs. VR_2		360_2 vs. VR_1	
	360	VR	360_1	VR_1	360_2	VR_2	360_1	VR_2	360_2	VR_1
Q1	p: 1.44E-06		p: 0.0025		p: 0.0001		p: 0.0007		p: 0.0018	
	μ : 4	μ : 6	μ : 4	μ : 6	μ : 3	μ : 7	μ : 4	μ : 7	μ : 3	μ : 6
	σ : 2.14	σ : 0.96	σ : 2.09	σ : 0.88	σ : 2.18	σ : 1.05	σ : 2.09	σ : 1.05	σ : 2.18	σ : 0.88
	p: 0.0002		p: 0.0187		p: 0.003		p: 0.0015		p: 0.0036	

Continuation of Table 5.4.1										
	360 vs. VR		360_1 vs. VR_1		360.2 vs. VR_2		360_1 vs. VR_2		360.2 vs. VR_1	
	360	VR	360_1	VR_1	360.2	VR_2	360_1	VR_2	360.2	VR_1
Q2	$\mu: 4$ $\sigma: 2.34$	$\mu: 6$ $\sigma: 1.19$	$\mu: 4$ $\sigma: 2.37$	$\mu: 6$ $\sigma: 1.30$	$\mu: 4$ $\sigma: 2.38$	$\mu: 6$ $\sigma: 1.10$	$\mu: 4$ $\sigma: 2.37$	$\mu: 6$ $\sigma: 1.10$	$\mu: 4$ $\sigma: 2.38$	$\mu: 6$ $\sigma: 1.30$
Q3	p: 0.1951		p: 0.746		p: 0.0317		p: 0.15		p: 0.2004	
	$\mu: 5$ $\sigma: 1.46$	$\mu: 6$ $\sigma: 1.07$	$\mu: 6$ $\sigma: 1.36$	$\mu: 5$ $\sigma: 1.10$	$\mu: 5$ $\sigma: 1.52$	$\mu: 6$ $\sigma: 1.01$	$\mu: 6$ $\sigma: 1.36$	$\mu: 6$ $\sigma: 1.01$	$\mu: 5$ $\sigma: 1.52$	$\mu: 5$ $\sigma: 1.10$
Q4	p: 0.0217		p: 0.4385		p: 0.0041		p: 0.0602		p: 0.0328	
	$\mu: 5$ $\sigma: 1.24$	$\mu: 6$ $\sigma: 0.83$	$\mu: 6$ $\sigma: 1.18$	$\mu: 6$ $\sigma: 0.88$	$\mu: 5$ $\sigma: 1.28$	$\mu: 6$ $\sigma: 0.74$	$\mu: 6$ $\sigma: 1.18$	$\mu: 6$ $\sigma: 0.74$	$\mu: 5$ $\sigma: 1.28$	$\mu: 6$ $\sigma: 0.88$
Q5	p: 0.2582		p: 0.8056		p: 0.0349		p: 0.5		p: 0.0942	
	$\mu: 6$ $\sigma: 1.25$	$\mu: 6$ $\sigma: 1.00$	$\mu: 6$ $\sigma: 1.18$	$\mu: 5$ $\sigma: 1.03$	$\mu: 5$ $\sigma: 1.32$	$\mu: 6$ $\sigma: 0.85$	$\mu: 6$ $\sigma: 1.18$	$\mu: 6$ $\sigma: 0.85$	$\mu: 5$ $\sigma: 1.32$	$\mu: 5$ $\sigma: 1.03$
Q6	p: 0.001		p: 0.101		p: 0.0008		p: 0.0128		p: 0.004	
	$\mu: 6$ $\sigma: 1.19$	$\mu: 6$ $\sigma: 0.84$	$\mu: 6$ $\sigma: 1.36$	$\mu: 6$ $\sigma: 0.83$	$\mu: 6$ $\sigma: 1.05$	$\mu: 7$ $\sigma: 0.83$	$\mu: 6$ $\sigma: 1.36$	$\mu: 7$ $\sigma: 0.83$	$\mu: 6$ $\sigma: 1.05$	$\mu: 6$ $\sigma: 0.83$
Q7	p: 0.0227		p: 0.3011		p: 0.0091		p: 0.0118		p: 0.1397	
	$\mu: 6$ $\sigma: 0.96$	$\mu: 6.5$ $\sigma: 0.68$	$\mu: 6$ $\sigma: 1.22$	$\mu: 7$ $\sigma: 0.74$	$\mu: 6$ $\sigma: 0.64$	$\mu: 7$ $\sigma: 0.64$	$\mu: 6$ $\sigma: 1.22$	$\mu: 7$ $\sigma: 0.64$	$\mu: 6$ $\sigma: 0.64$	$\mu: 7$ $\sigma: 0.74$
Q8	p: 0.012		p: 0.0557		p: 0.0893		p: 0.0061		p: 0.1158	
	$\mu: 6$ $\sigma: 1.14$	$\mu: 7$ $\sigma: 0.95$	$\mu: 6$ $\sigma: 1.36$	$\mu: 6$ $\sigma: 0.72$	$\mu: 6$ $\sigma: 0.92$	$\mu: 6$ $\sigma: 1.13$	$\mu: 6$ $\sigma: 1.36$	$\mu: 6$ $\sigma: 1.13$	$\mu: 6$ $\sigma: 0.92$	$\mu: 6$ $\sigma: 0.72$
Q9	p: 3.81E-06		p: 0.0006		p: 0.0016		p: 0.0017		p: 0.0007	
	$\mu: 4$ $\sigma: 1.31$	$\mu: 6$ $\sigma: 1.02$	$\mu: 4$ $\sigma: 1.53$	$\mu: 6$ $\sigma: 0.82$	$\mu: 5$ $\sigma: 1.05$	$\mu: 6$ $\sigma: 1.22$	$\mu: 4$ $\sigma: 1.53$	$\mu: 6$ $\sigma: 1.22$	$\mu: 5$ $\sigma: 1.05$	$\mu: 6$ $\sigma: 0.82$
Q10	p: 0.0001		p: 0.0454		p: 0.0002		p: 0.0073		p: 0.0025	
	$\mu: 5$ $\sigma: 1.76$	$\mu: 6$ $\sigma: 1.05$	$\mu: 5$ $\sigma: 1.68$	$\mu: 6$ $\sigma: 1.12$	$\mu: 5$ $\sigma: 1.78$	$\mu: 6$ $\sigma: 0.96$	$\mu: 5$ $\sigma: 1.68$	$\mu: 6$ $\sigma: 0.96$	$\mu: 5$ $\sigma: 1.78$	$\mu: 6$ $\sigma: 1.12$
	p: 8.43E-07		p: 0.0031		p: 0.0001		p: 0.0003		p: 0.0007	
	$\mu: 4$	$\mu: 6$	$\mu: 4$	$\mu: 6$	$\mu: 3$	$\mu: 6$	$\mu: 4$	$\mu: 6$	$\mu: 3$	$\mu: 6$

Continuation of Table 5.4.1										
	360 vs. VR		360_1 vs. VR_1		360.2 vs. VR_2		360_1 vs. VR_2		360.2 vs. VR_1	
Q11	360	VR	360_1	VR_1	360.2	VR_2	360_1	VR_2	360.2	VR_1
	σ : 1.72	σ : 0.97	σ : 1.98	σ : 0.83	σ : 1.40	σ : 1.13	σ : 1.98	σ : 1.13	σ : 1.40	σ : 0.83
Q12	p: 0.0387		p: 0.1823		p: 0.0706		p: 0.0967		p: 0.0325	
	μ : 6	μ : 6	μ : 6	μ : 6	μ : 6	μ : 7	μ : 6	μ : 7	μ : 6	μ : 6
	σ : 1.09	σ : 0.87	σ : 1.32	σ : 0.70	σ : 0.83	σ : 1.03	σ : 1.32	σ : 1.03	σ : 0.83	σ : 0.70
Q13	p: 0.0016		p: 0.0688		p: 0.0059		p: 0.0043		p: 0.0073	
	μ : 6	μ : 6	μ : 6	μ : 6	μ : 6	μ : 7	μ : 6	μ : 7	μ : 6	μ : 6
	σ : 1.30	σ : 0.79	σ : 1.03	σ : 0.70	σ : 1.51	σ : 0.90	σ : 1.03	σ : 0.90	σ : 1.51	σ : 0.70
Q14	p: 0.9056		p: 0.5885		p: 0.9502		p: 0.7748		p: 0.7855	
	μ : 2	μ : 1	μ : 2	μ : 2	μ : 2	μ : 1	μ : 2	μ : 1	μ : 2	μ : 2
	σ : 1.05	σ : 1.18	σ : 1.16	σ : 0.80	σ : 0.96	σ : 1.50	σ : 1.16	σ : 1.50	σ : 0.96	σ : 0.80
Q15	p: 0.0031		p: 0.2165		p: 0.0016		p: 0.0172		p: 0.004	
	μ : 4.5	μ : 6	μ : 5	μ : 5	μ : 4	μ : 6	μ : 5	μ : 6	μ : 4	μ : 5
	σ : 1.88	σ : 1.73	σ : 2.02	σ : 1.85	σ : 1.75	σ : 1.52	σ : 2.02	σ : 1.52	σ : 1.75	σ : 1.85
Q16	p: 0.0009		p: 0.2481		p: 0.0002		p: 0.0096		p: 0.0118	
	μ : 5	μ : 6	μ : 6	μ : 6	μ : 5	μ : 7	μ : 6	μ : 7	μ : 5	μ : 6
	σ : 1.31	σ : 1.03	σ : 1.22	σ : 1.16	σ : 1.36	σ : 0.84	σ : 1.22	σ : 0.84	σ : 1.36	σ : 1.16
Q17	p: 0.01		p: 0.1231		p: 0.02		p: 0.076		p: 0.0068	
	μ : 5	μ : 6	μ : 5	μ : 6	μ : 5	μ : 6	μ : 5	μ : 6	μ : 5	μ : 6
	σ : 1.14	σ : 1.01	σ : 1.10	σ : 1.10	σ : 1.22	σ : 0.92	σ : 1.10	σ : 0.92	σ : 1.22	σ : 1.10

When looking at the responses from participants who completed 360° video in the first-round vs. in the second round, as expected, there was no difference between the ratings. As previously implied, the average ratings for questions 1, 2, 9, 10 and 11 were lower compared to other questions. The median for these questions ranged from 3-5, as evidenced in Figure 5.4.6.

Another question that was rated low was question 14, which as previously described, was a negative question, asking participants to what extent did events occurring outside the virtual environment distracted from their experience in the virtual environment. Low ratings imply very little distraction in the VR environment. Participants rated 360° video well on other questions, with a median range of 5-6.

We also assessed responses from participants completing VR simulation in the first-round vs. the second round. As expected, no difference between the groups was observed. Except for question 14, which was rated low, the remaining first 17 questions were rated quite high, with a median range of 5-7, as evidenced in Figure 5.4.7. For VR simulation, 15 additional questions were asked on the questionnaires.

Questions 18 to 32 were related to features only applicable to VR simulation, as previously described in the methodology. Briefly, these questions addressed participants' actions in the VR simulations, such as how much they felt in control of events, how responsive the environment was to their actions, and how natural their actions seemed. They also addressed being actively able to survey the VR environment using touch, how well participants could move around, and the quality of the visual setting overall. Participants rated high on these questions with a median range of 5-7, except for questions 25, 27, 28, 30 and 32, which had a median range of 2-3. These questions were negative questions, and a low score is a positive outcome.

Question 25 asked if there were any delays between actions and expected outcomes, and it was rated low, with a median of 2, meaning that there were little delays. Question 27 inquired about the visual display quality interfering/distracting participants from performing assigned tasks or required activities. This was rated low, with a median of 2 as well, implying that the visual display quality was not interfering/distracting. Questions 27 and 32 inquired about the control devices interfering

with the performance of the tasks and how easily it was to adjust the control devices to interact with the virtual environment. They were rated low, meaning that the controls did not interfere with the performance of the task, and it was easy to adjust them to interact with the environment. Lastly, question 30 inquired about focusing on using the display and control devices instead of the virtual experience and experimental tasks, which was rated low, meaning that they did not focus significantly on display and control devices that would affect their virtual learning simulation.

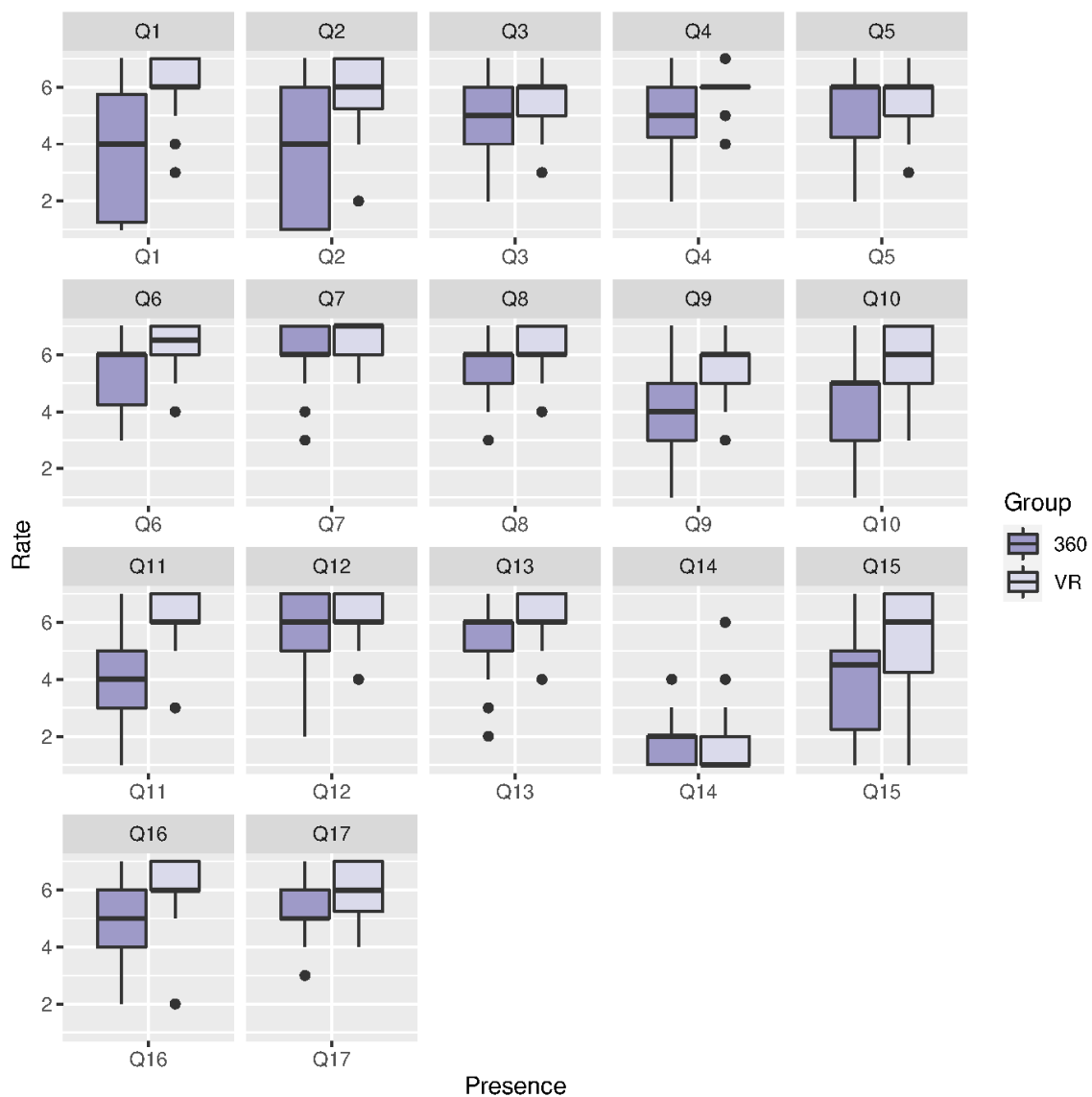


Figure 5.4.1: Presence, overall comparison of 360° video vs. VR groups

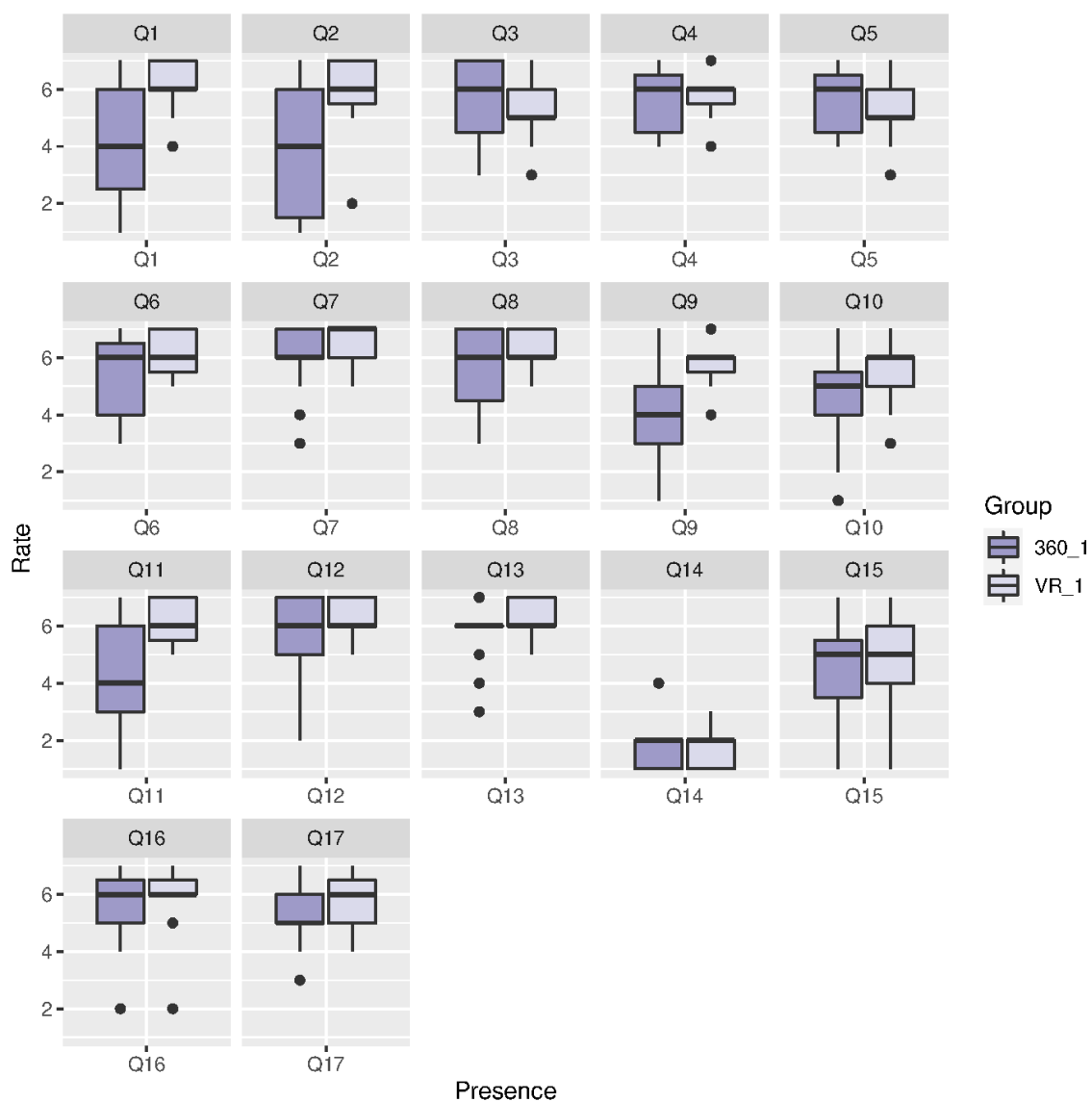


Figure 5.4.2: Presence rating comparing 360° video in first round vs. VR simulation in first round.

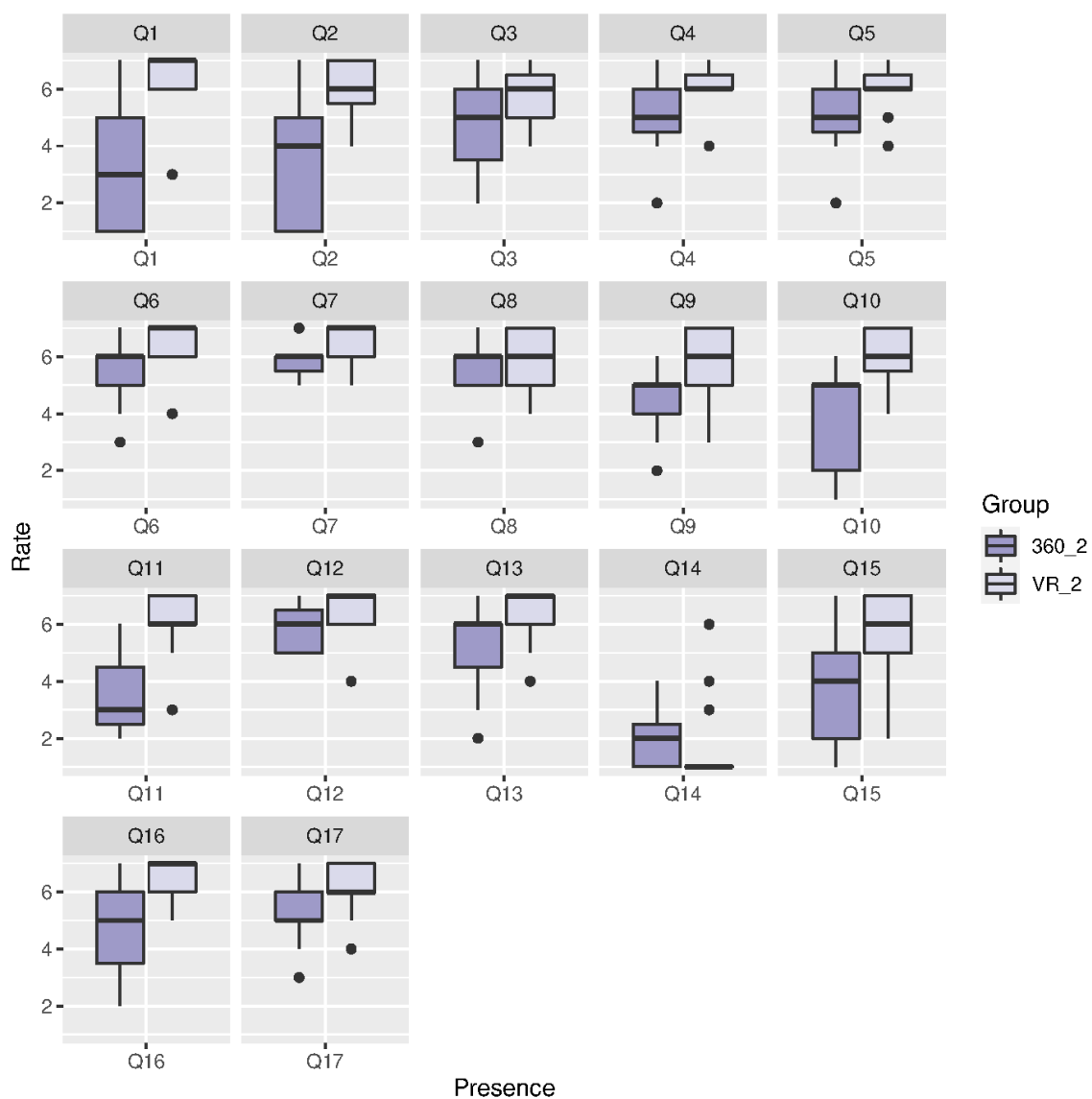


Figure 5.4.3: Usefulness rating comparing 360° video vs. VR simulation, both completed in the second round.

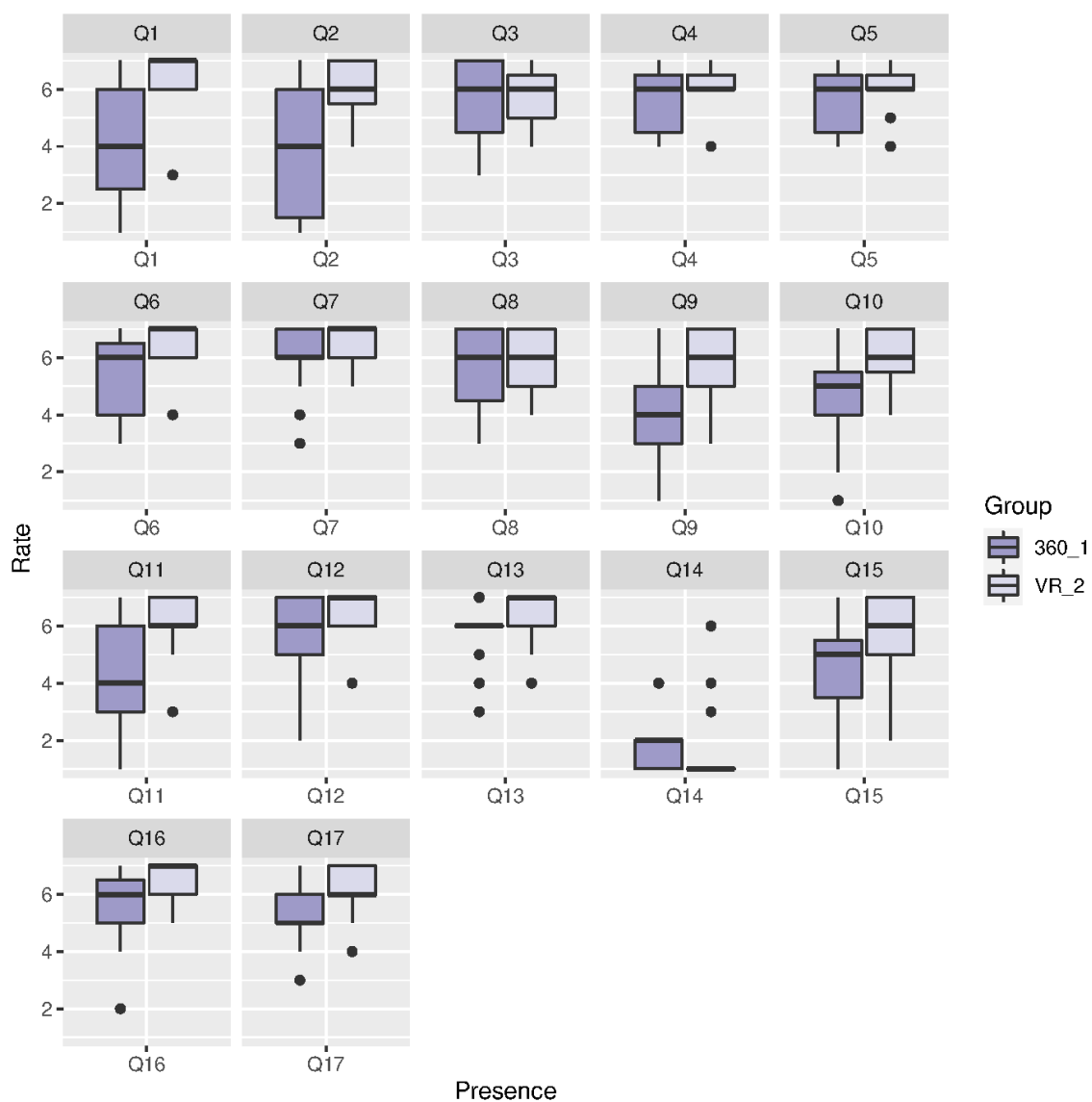


Figure 5.4.4: Presence rating comparing 360° video in first round vs. VR simulation in second round.

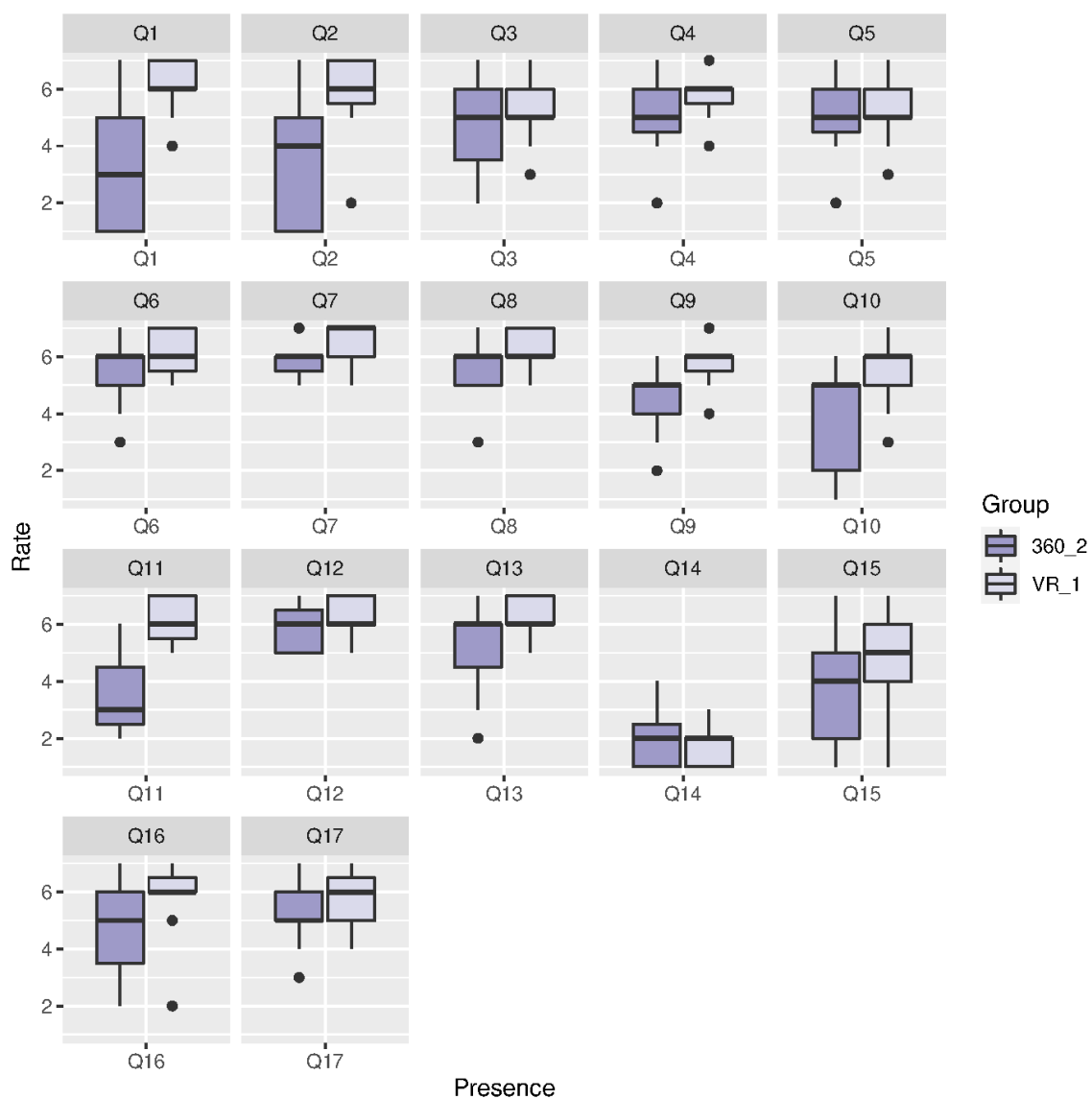


Figure 5.4.5: Presence rating comparing 360° video in second round vs. VR simulation in the first round.

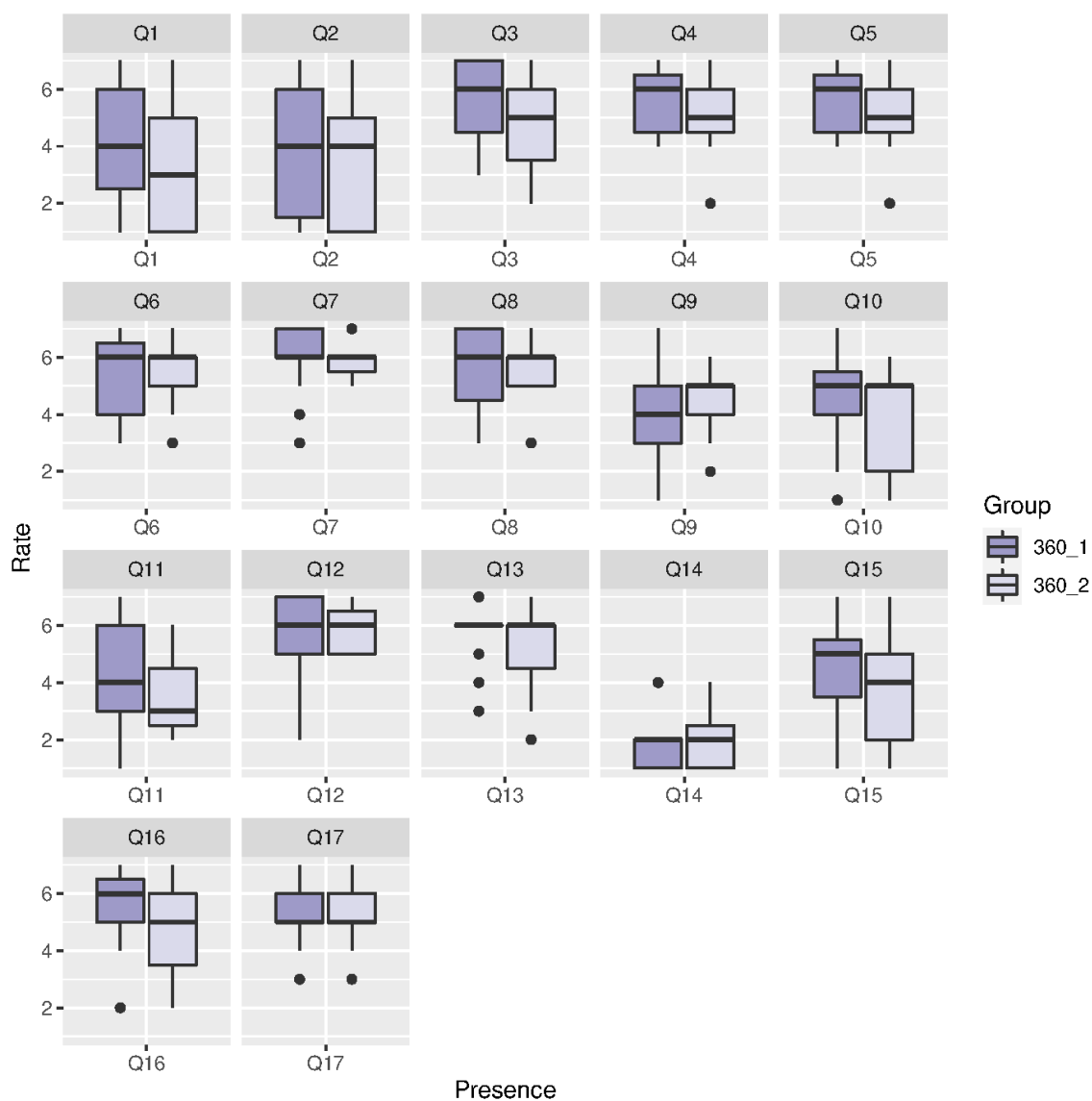


Figure 5.4.6: Presence rating comparing 360° video in the first-round vs. 360° video in the second round.

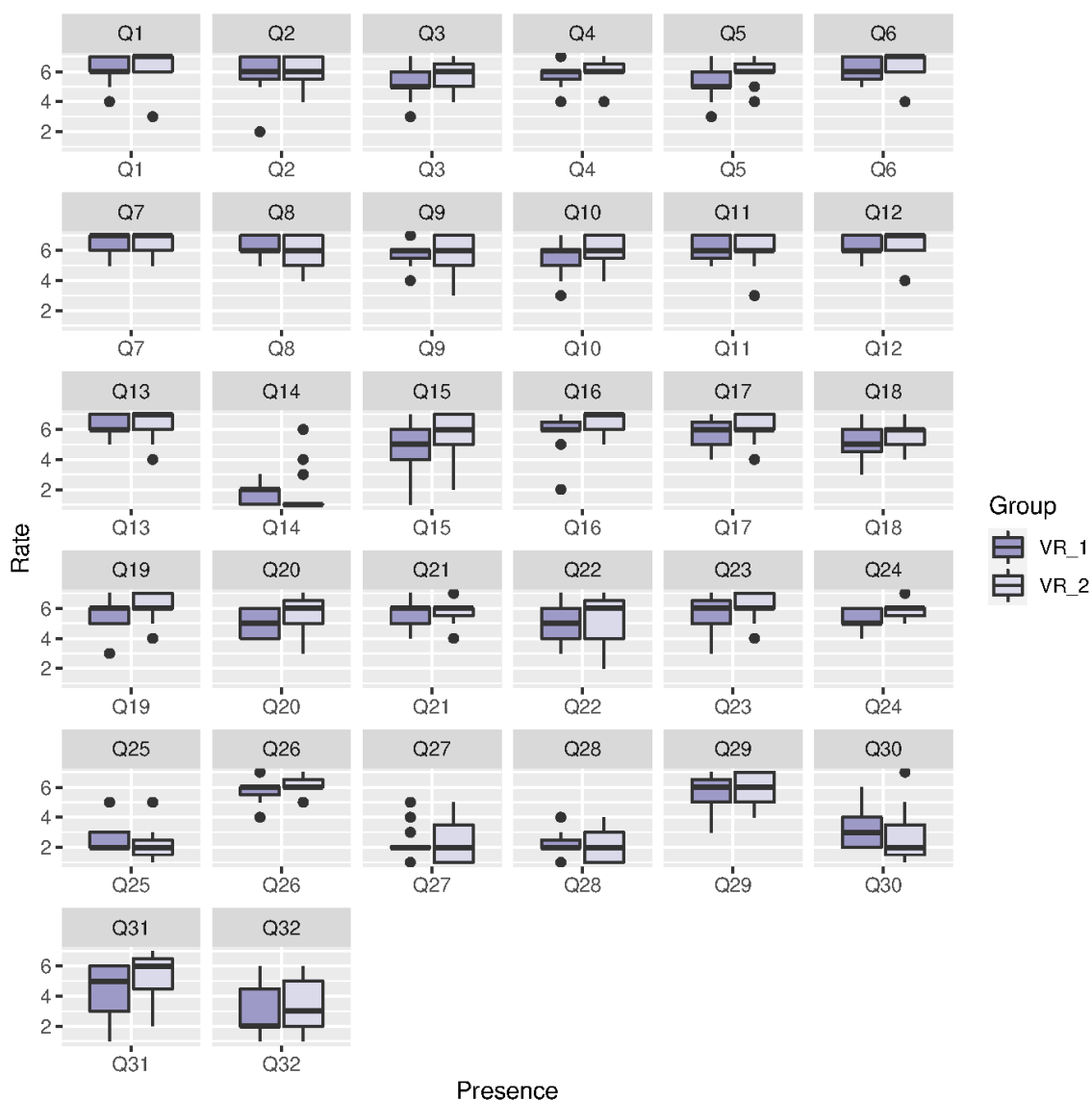


Figure 5.4.7: Presence rating comparing VR simulation in the first-round vs. VR simulation in the second-round.

5.5 Usefulness

Another factor we assessed in this study is the usefulness of 360° video vs. VR simulation in NRP training for healthcare professionals. When comparing responses

from participants completing 360° video vs. VR simulation, VR simulation ratings overall were higher than for 360° video, as shown in Figure 5.5.1 and Table 5.5.1. Particularly, VR simulation ratings were very significantly higher with adjusted p -value <0.01 for questions 2 and 4, which assessed if using virtual reality would improve participants' learning performance, and if it would enhance their learning effectiveness.

Next, we analyzed if completing the simulation using the specific technology in the first-round vs. in the second-round affects the ratings. In fact, we compared data in various combinations, as shown in Figure 5.1.1. The results are summarized in Table 5.5.1 below.

As evidenced by the table, when comparing responses from participants completing 360° video first vs. VR simulation first, without exposure to the other technology, there is no statistically significant difference between them, except for question 3. In contrast, when comparing responses from participants completing 360° video in the second-round vs. VR simulation in the second round, VR simulation ratings are statistically significantly higher than 360° video as shown in Figure 5.5.3. This implies that after seeing both technologies, VR simulation ratings were higher for usefulness. This is consistent with the higher VR ratings for usefulness when comparing ratings from the participants completing 360° video first vs. VR simulation second, or vice versa (Figure 5.5.4, Figure 5.5.5). In other words, when comparing the ratings from the same participants completing both technologies, VR ratings were overall higher in either order.

When assessing usefulness ratings from 360° video from the first and the second rounds (Figure 5.5.7), participants rated usefulness high, with median ratings of 5-6. Similarly, when looking at usefulness ratings from VR simulation in the first round and second rounds, participants rated higher, with median ratings of 6-7. This further

validates the statistical differences seen in Table 5.5.1, and Figure 5.5.1.

Table 5.5.1: Group comparisons showing a statistical difference for usefulness between 360° video vs. VR simulation.

	360 vs. VR		360_1 vs. VR_1		360_2 vs. VR_2		360_1 vs. VR_2		360_2 vs. VR_1	
	360	VR	360_1	VR_1	360_2	VR_2	360_1	VR_2	360_2	VR_1
Q1	p: 0.0289		p: 0.8475		p: 0.0018		p: 0.0402		p: 0.0209	
	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 5$	$\mu: 7$	$\mu: 6$	$\mu: 7$	$\mu: 5$	$\mu: 6$
	$\sigma: 1.24$	$\sigma: 0.89$	$\sigma: 0.74$	$\sigma: 0.74$	$\sigma: 1.41$	$\sigma: 0.90$	$\sigma: 0.74$	$\sigma: 0.90$	$\sigma: 1.41$	$\sigma: 0.74$
Q2	p: 0.006		p: 0.5636		p: 0.0006		p: 0.0885		p: 0.0046	
	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 5$	$\mu: 7$	$\mu: 6$	$\mu: 7$	$\mu: 5$	$\mu: 6$
	$\sigma: 1.17$	$\sigma: 1.03$	$\sigma: 0.74$	$\sigma: 0.83$	$\sigma: 1.41$	$\sigma: 1.06$	$\sigma: 0.74$	$\sigma: 1.06$	$\sigma: 1.41$	$\sigma: 0.83$
Q3	p: 0.0109		p: 0.6443		p: 0.0011		p: 0.0266		p: 0.0165	
	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 5$	$\mu: 7$	$\mu: 6$	$\mu: 7$	$\mu: 5$	$\mu: 6$
	$\sigma: 1.29$	$\sigma: 0.93$	$\sigma: 0.80$	$\sigma: 0.83$	$\sigma: 1.41$	$\sigma: 0.90$	$\sigma: 0.80$	$\sigma: 0.90$	$\sigma: 1.41$	$\sigma: 0.83$
Q4	p: 0.0013		p: 0.4382		p: 0.0001		p: 0.0289		p: 0.0007	
	$\mu: 5$	$\mu: 6$	$\mu: 5$	$\mu: 6$	$\mu: 5$	$\mu: 7$	$\mu: 5$	$\mu: 7$	$\mu: 5$	$\mu: 6$
	$\sigma: 1.12$	$\sigma: 1.00$	$\sigma: 0.74$	$\sigma: 0.91$	$\sigma: 1.28$	$\sigma: 0.83$	$\sigma: 0.74$	$\sigma: 0.83$	$\sigma: 1.28$	$\sigma: 0.91$
Q5	p: 0.0177		p: 0.5663		p: 0.0035		p: 0.1882		p: 0.0029	
	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 5$	$\mu: 7$	$\mu: 6$	$\mu: 7$	$\mu: 5$	$\mu: 6$
	$\sigma: 1.24$	$\sigma: 0.98$	$\sigma: 0.64$	$\sigma: 0.74$	$\sigma: 1.46$	$\sigma: 0.99$	$\sigma: 0.64$	$\sigma: 0.99$	$\sigma: 1.46$	$\sigma: 0.74$
Q6	p: 0.0191		p: 0.6816		p: 0.0024		p: 0.0466		p: 0.0209	
	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 6$	$\mu: 5$	$\mu: 7$	$\mu: 6$	$\mu: 7$	$\mu: 5$	$\mu: 6$
	$\sigma: 1.44$	$\sigma: 0.86$	$\sigma: 1.10$	$\sigma: 0.80$	$\sigma: 1.44$	$\sigma: 0.83$	$\sigma: 1.10$	$\sigma: 0.83$	$\sigma: 1.44$	$\sigma: 0.80$

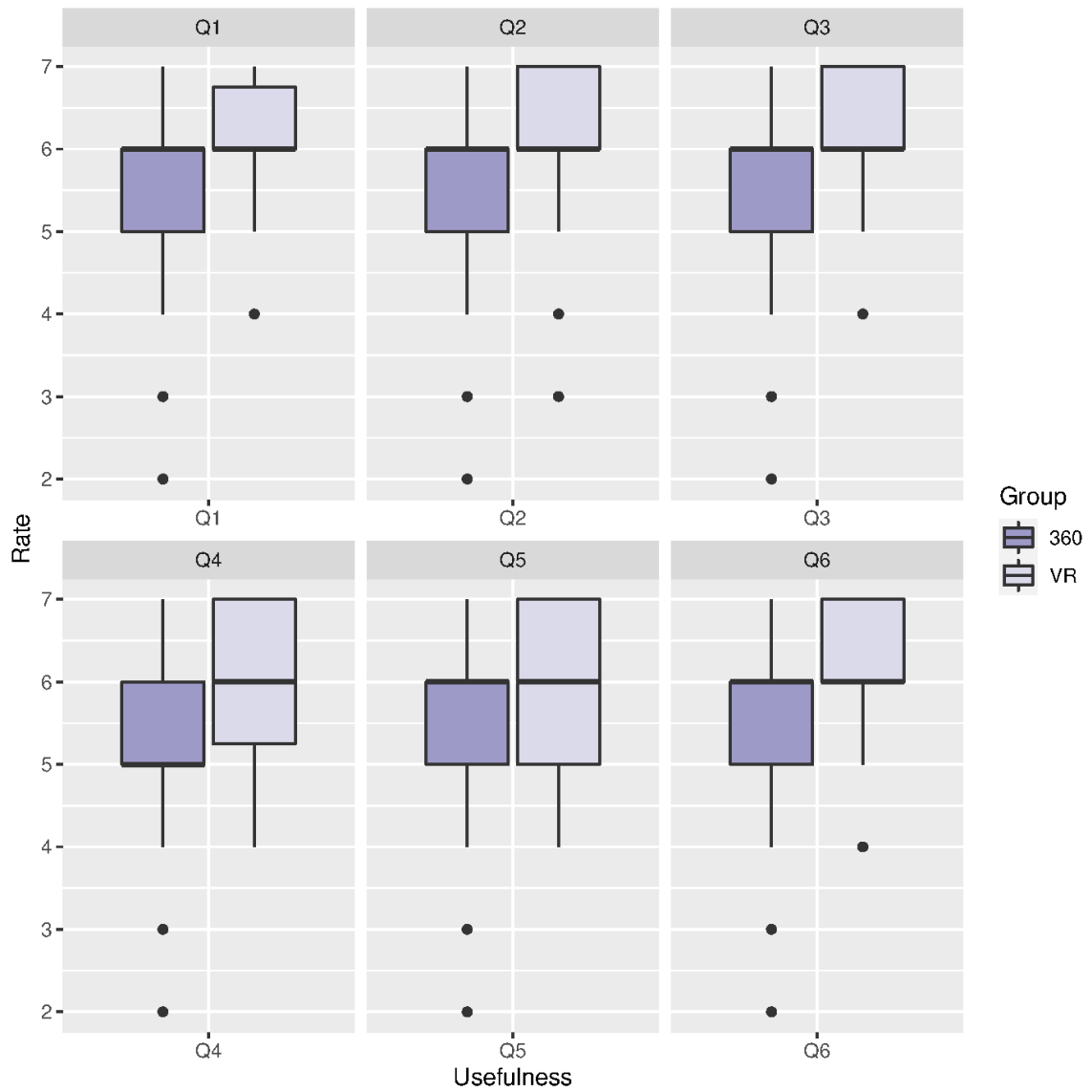


Figure 5.5.1: Usefulness, overall comparison of 360° video vs. VR groups

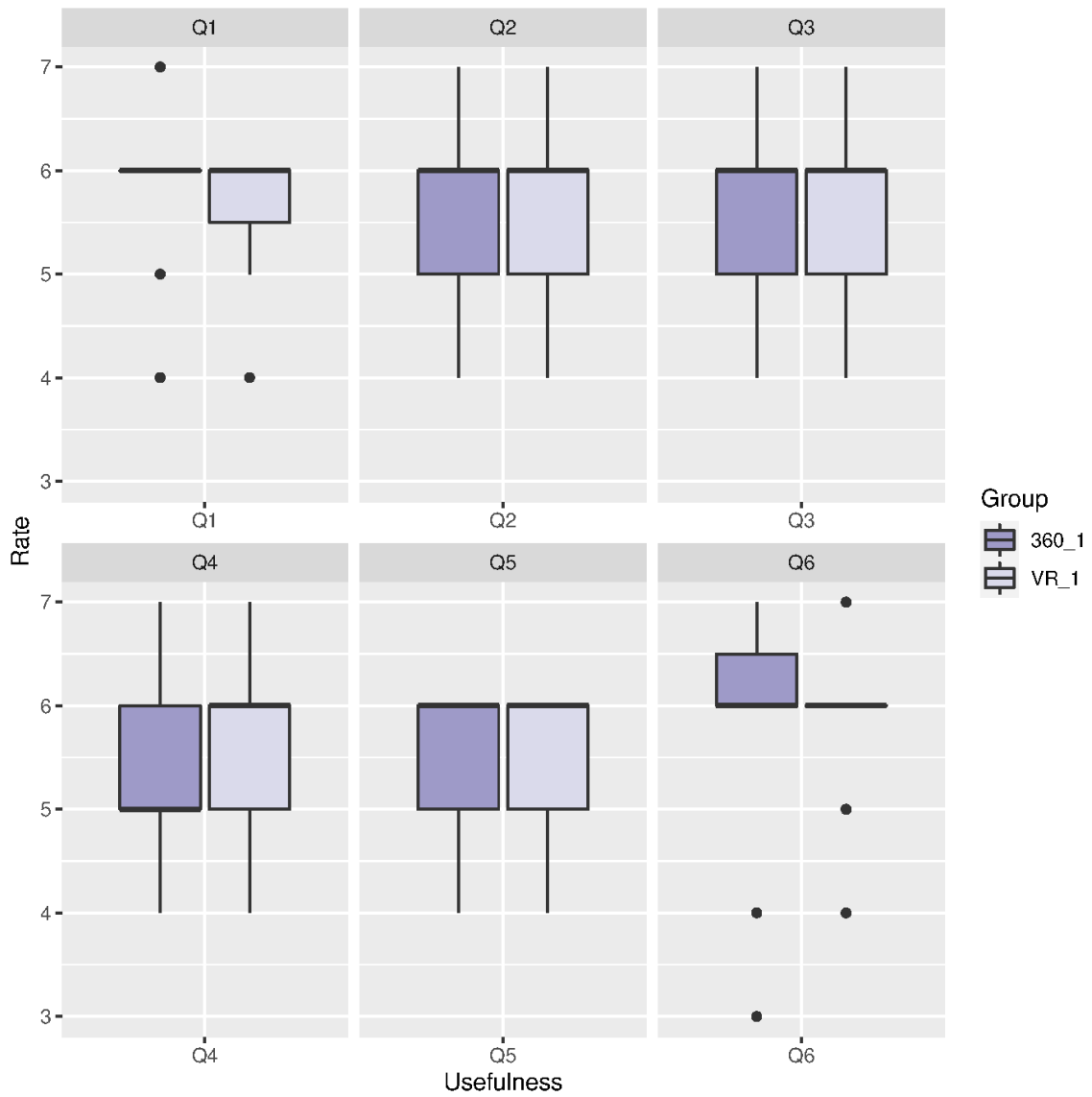


Figure 5.5.2: Usefulness rating comparing 360° video in first round vs. VR simulation in first round.

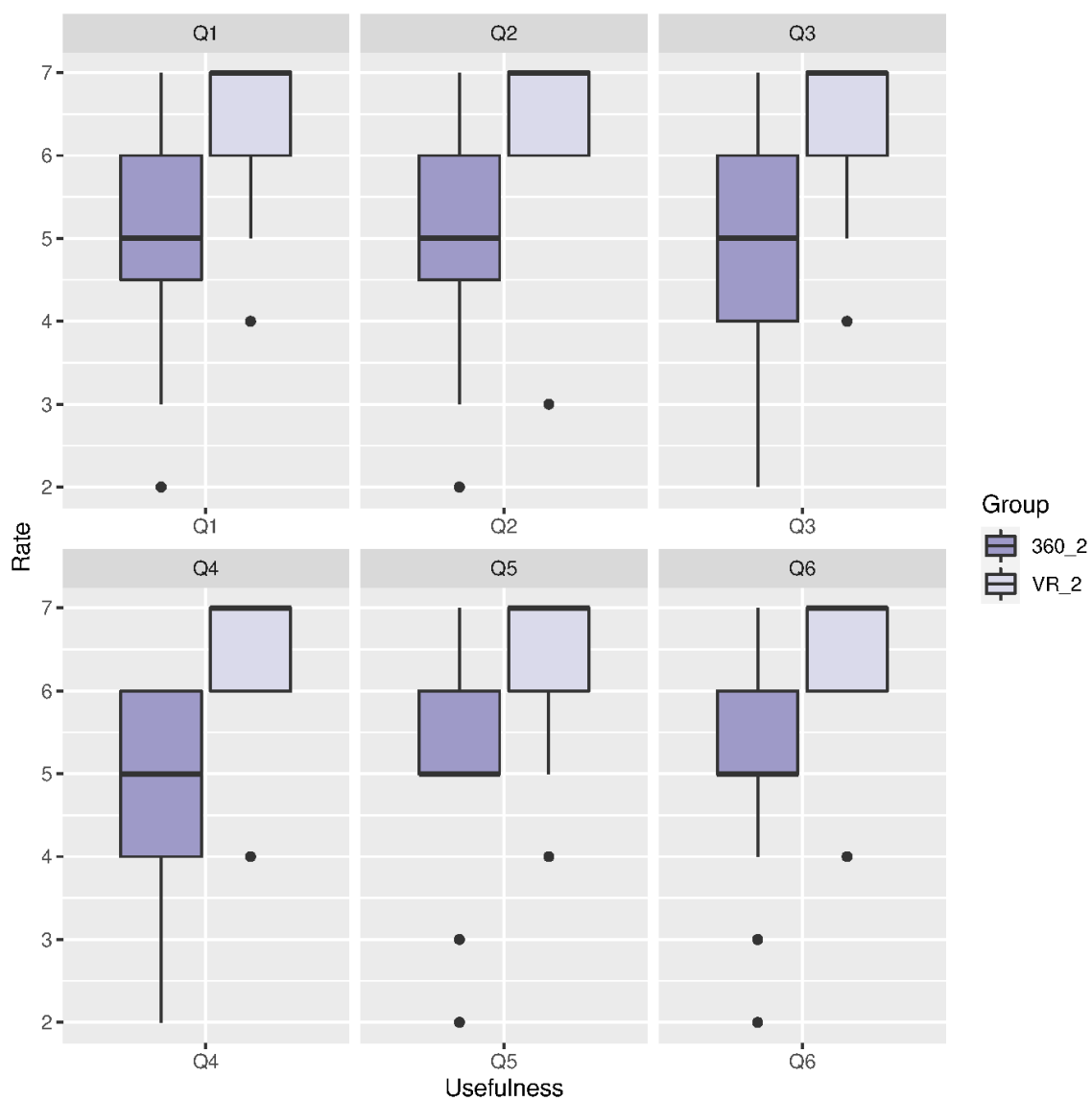


Figure 5.5.3: Usefulness rating comparing 360° video vs. VR simulation, both completed in the second round.

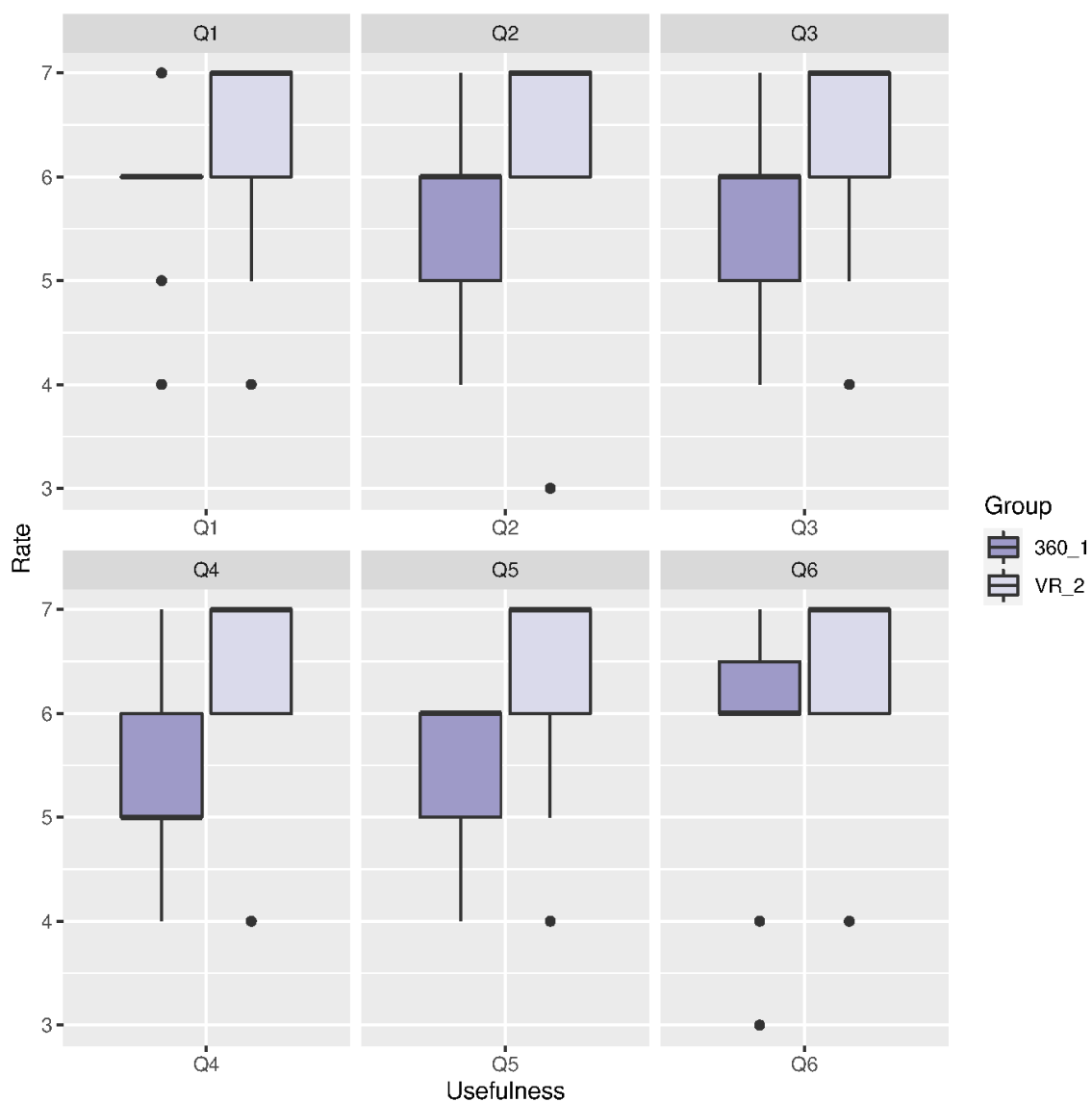


Figure 5.5.4: Usefulness rating comparing 360° video in first round vs. VR simulation in second round.

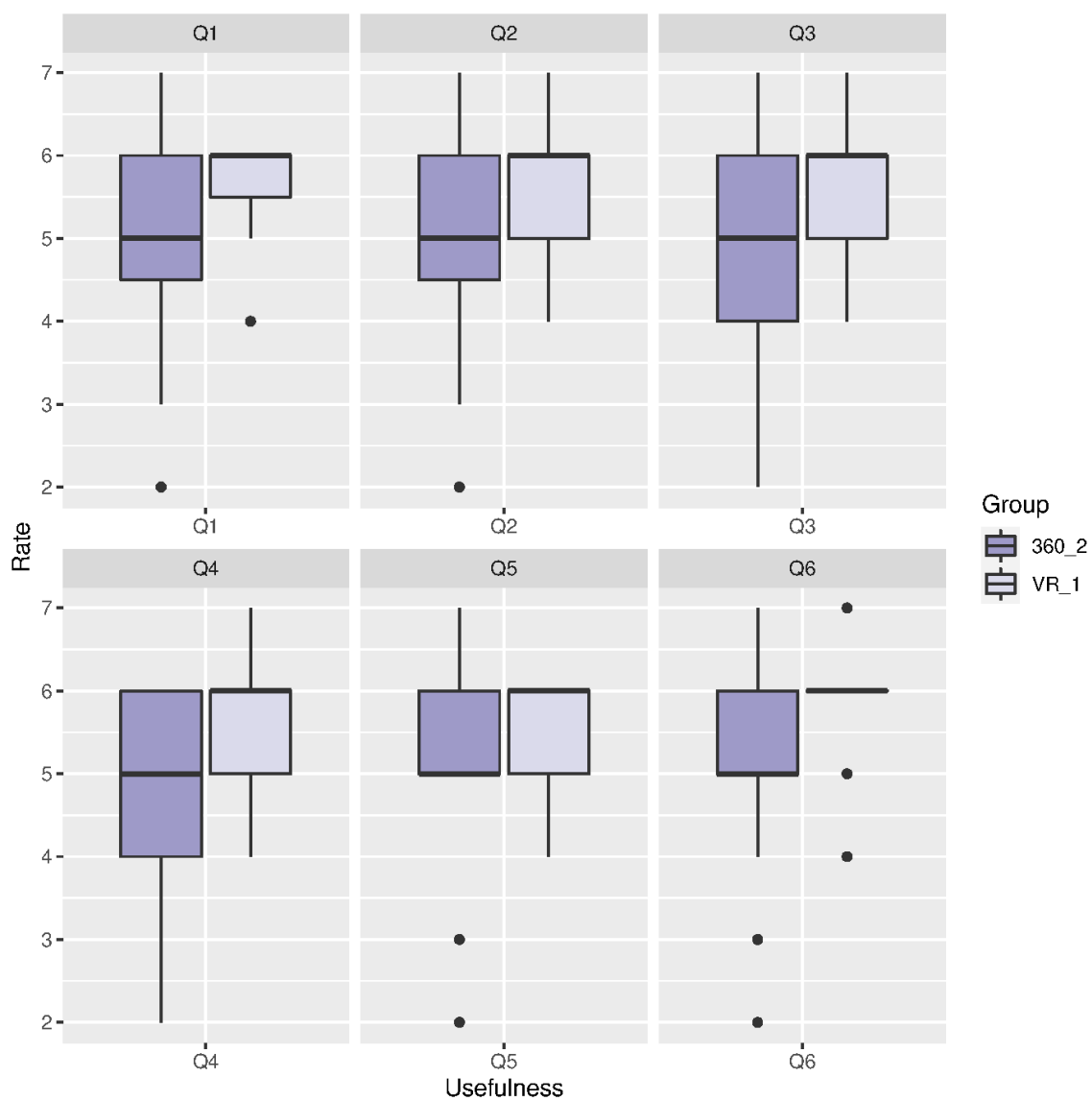


Figure 5.5.5: Usefulness rating comparing 360° video in second round vs. VR simulation in the first round.

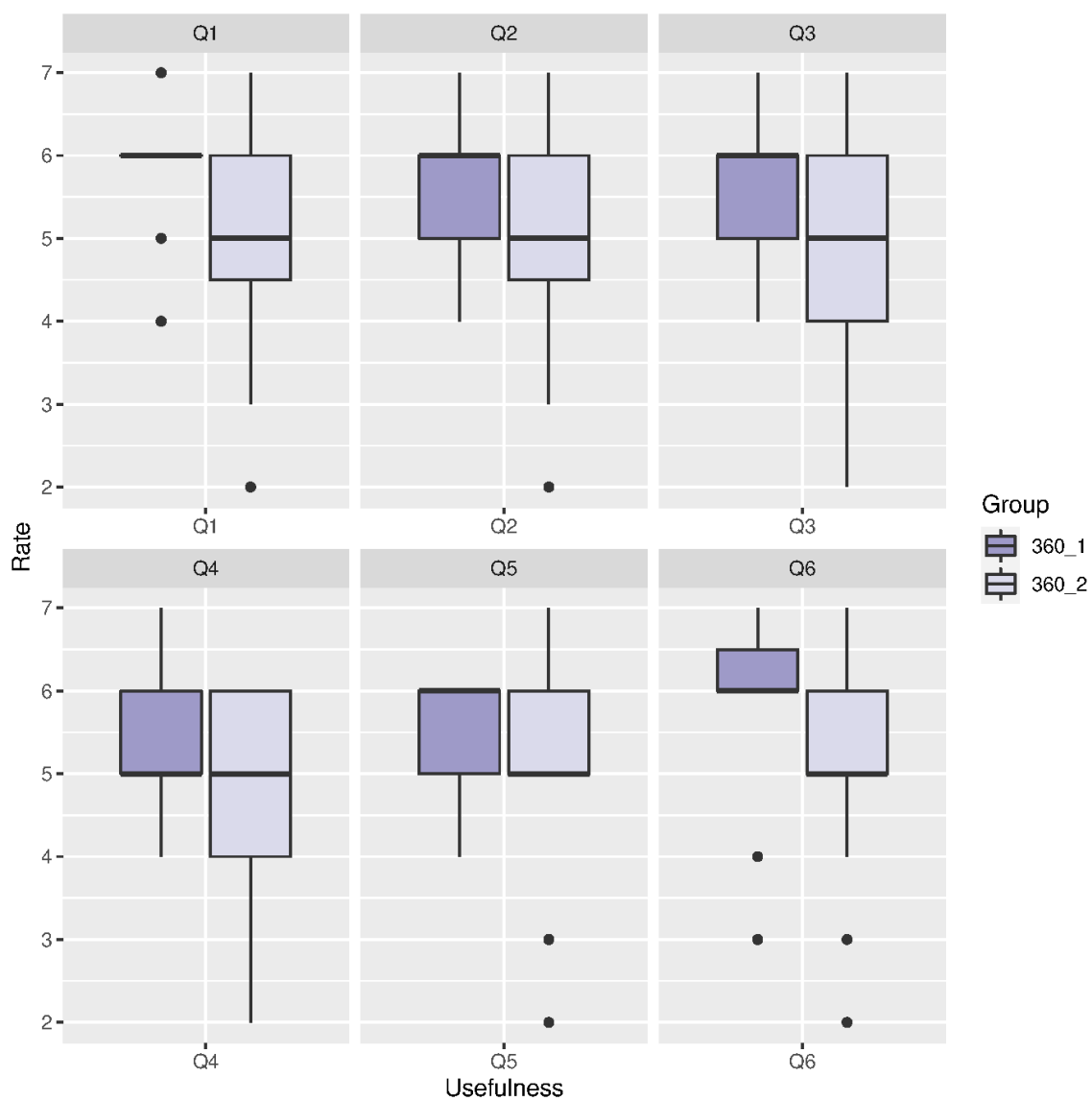


Figure 5.5.6: Usefulness rating comparing 360° video in the first-round vs. 360° video in the second round.

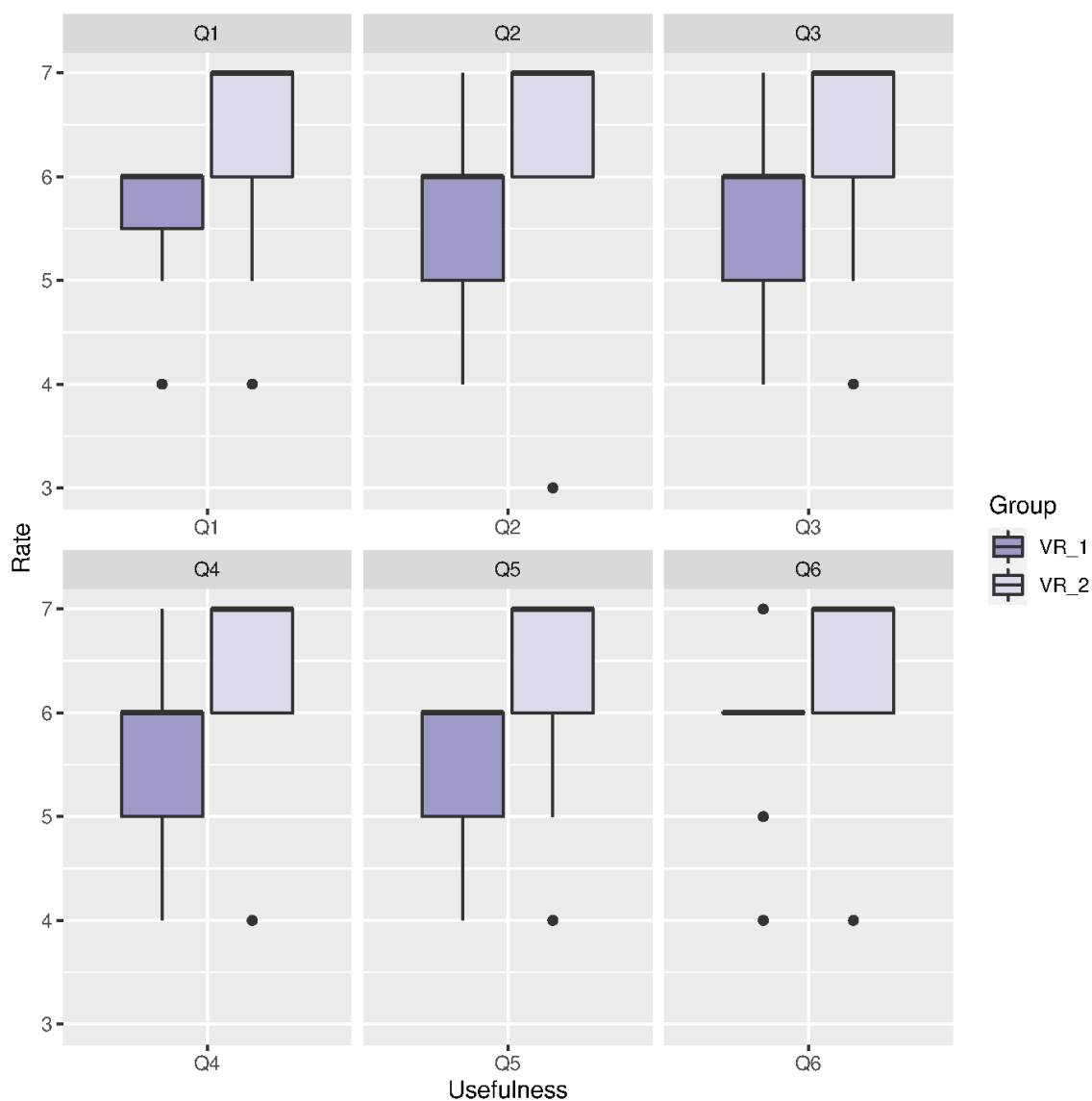


Figure 5.5.7: Usefulness rating comparing VR simulation in the first-round vs. VR simulation in the second-round.

5.6 Motion Sickness

The participants were also asked to complete a sickness survey to assess if they had any side effects and/or symptoms while using the VR technologies. Overall,

participants rated very low for any sickness during the 360° video and VR simulation, with median ratings of 1 for both technologies, as evidenced in Figure 5.6.1, Figure 5.6.6 and Figure 5.6.7.

As with other factors, we compared different group combinations to see if there was any difference with respect to motion sickness between 360° video and VR simulation. As shown in Table 5.6.1, there was no statistical difference between ratings for 360° video and VR simulation for sickness for almost all group combinations, except for ratings from participants completing both technologies in the second round (Figure 5.6.2, Figure 5.6.3, Figure 5.6.4, Figure 5.6.5). When comparing 360° video and VR simulation, participants rated slightly higher for eye strain, difficulty focusing, and blurred vision with VR simulation.

Table 5.6.1: Group comparisons showing a statistical difference for motion sickness between 360° video vs. VR simulation.

	360 vs. VR		360.1 vs. VR.1		360.2 vs. VR.2		360.1 vs. VR.2		360.2 vs. VR.1	
	360	VR	360.1	VR.1	360.2	VR.2	360.1	VR.2	360.2	VR.1
Discomfort	p: 0.5068		p: 0.9315		p: 0.0821		p: 1		p: 0.6813	
	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$
	$\sigma: 0.25$	$\sigma: 0.25$	$\sigma: 0.35$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0.35$	$\sigma: 0.35$	$\sigma: 0.35$	$\sigma: 0$	$\sigma: 0$
Fatigue	p: 1		p: 1		p: 1		p: 1		p: 1	
	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$
	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$	$\sigma: 0$
Headache	p: 0.2851		p: 0.5191		p: 0.1753		p: 0.5		p: 1	
	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$
	$\sigma: 0.18$	$\sigma: 0.25$	$\sigma: 0.26$	$\sigma: 0.26$	$\sigma: 0$	$\sigma: 0.26$	$\sigma: 0.26$	$\sigma: 0.26$	$\sigma: 0$	$\sigma: 0.26$
Eye strain	p: 0.2803		p: 0.8511		p: 0.0191		p: 0.1729		p: 0.9772	
	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$	$\mu: 1$
	$\sigma: 0.55$	$\sigma: 0.50$	$\sigma: 0.74$	$\sigma: 0.35$	$\sigma: 0$	$\sigma: 0.62$	$\sigma: 0.74$	$\sigma: 0.62$	$\sigma: 0$	$\sigma: 0.35$
	p: 0.2798		p: 0.8217		p: 0.0368		p: 0.5		p: 0.5793	

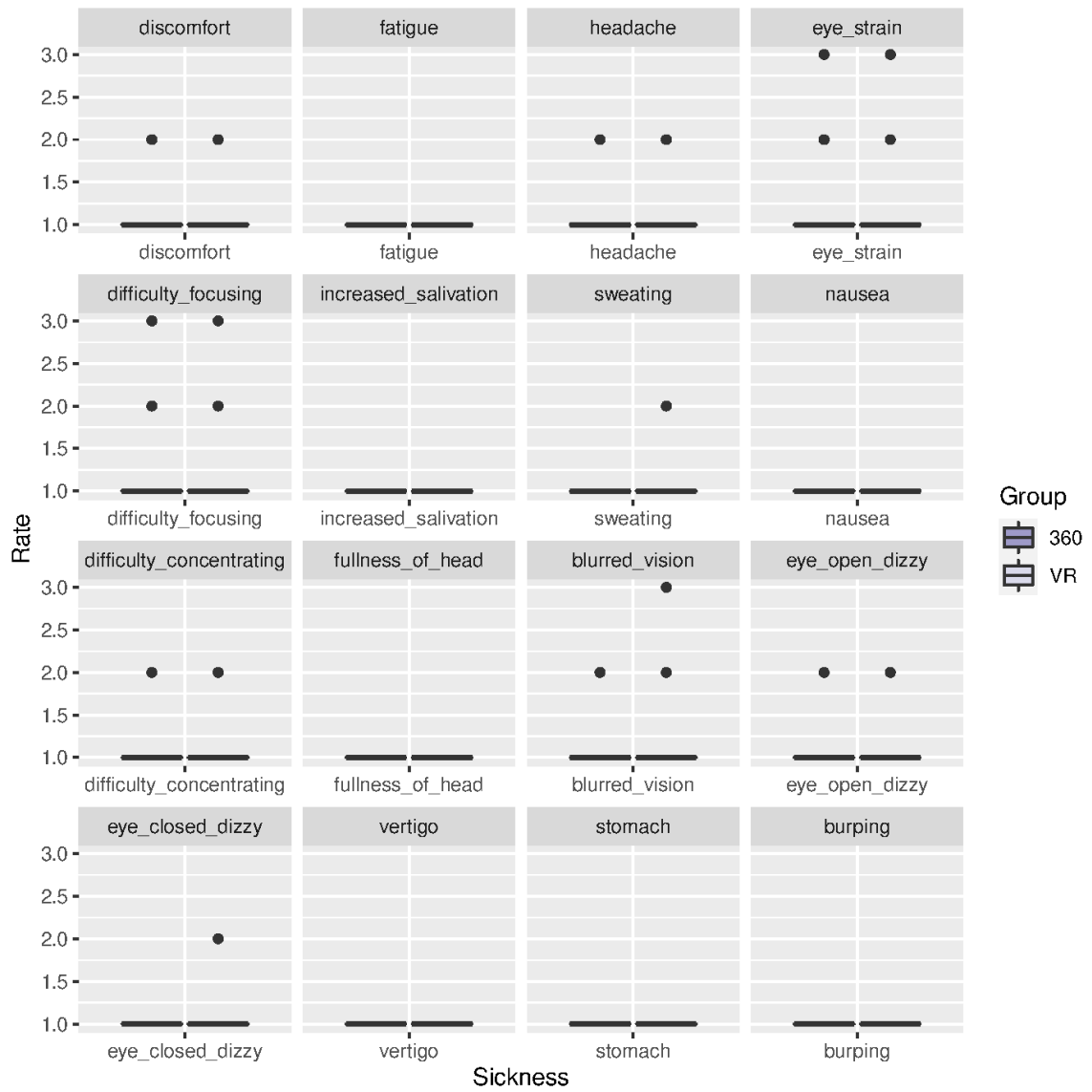


Figure 5.6.1: MotionSickness, overall comparison of 360° video vs. VR groups.

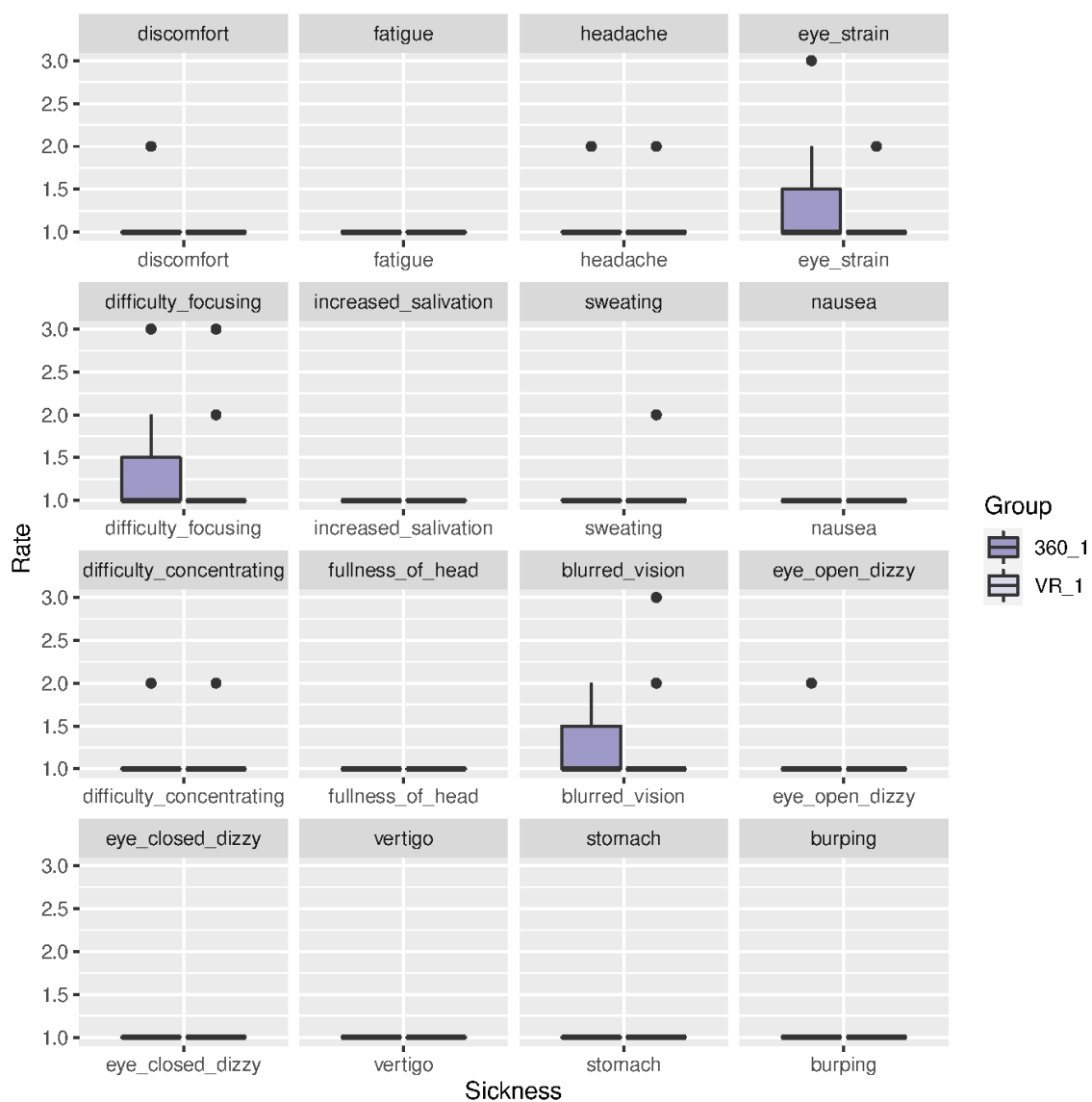


Figure 5.6.2: MotionSickness rating comparing 360° video in first round vs. VR simulation in first round.

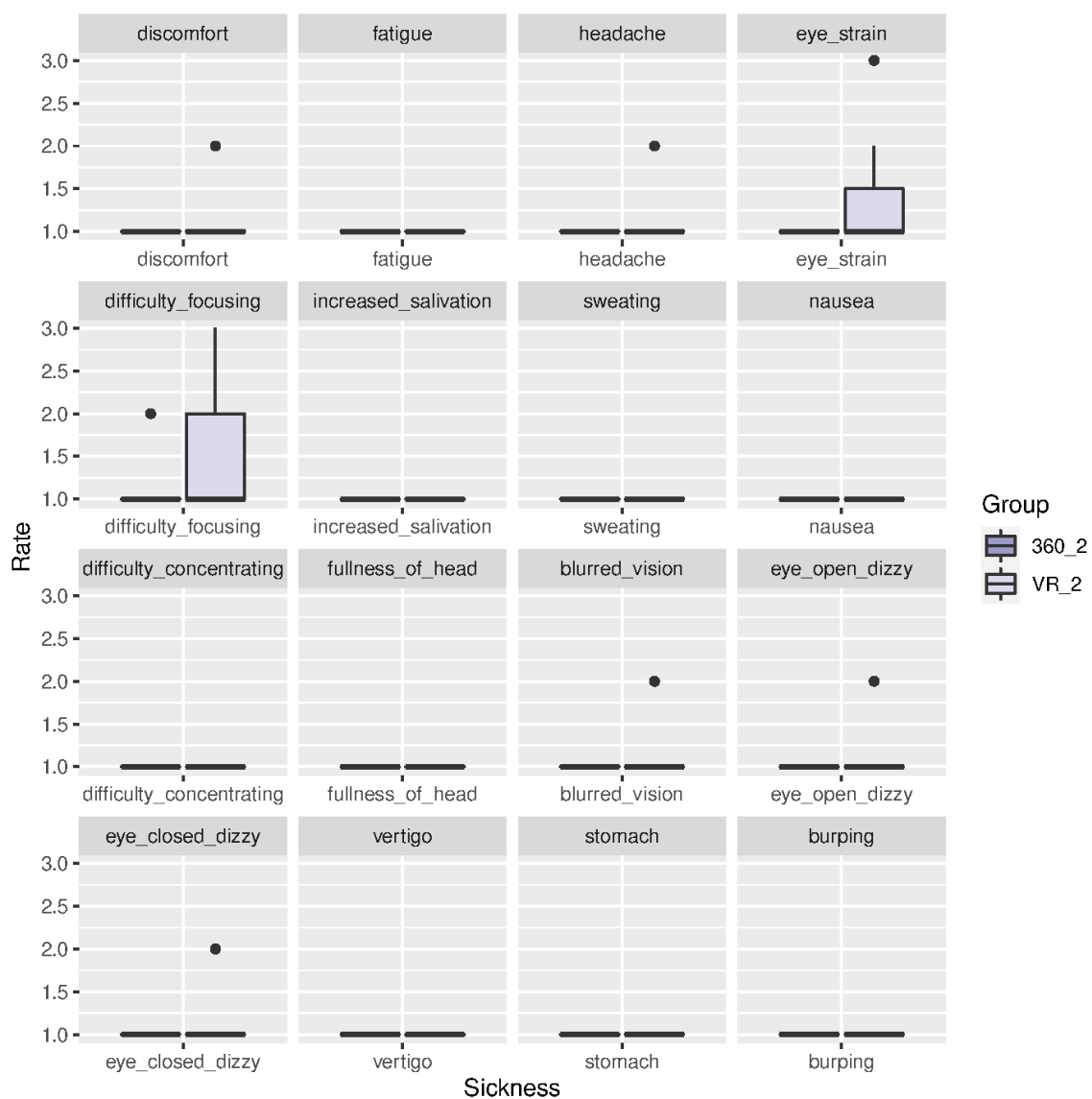


Figure 5.6.3: MotionSickness rating comparing 360° video vs. VR simulation, both completed in the second round.

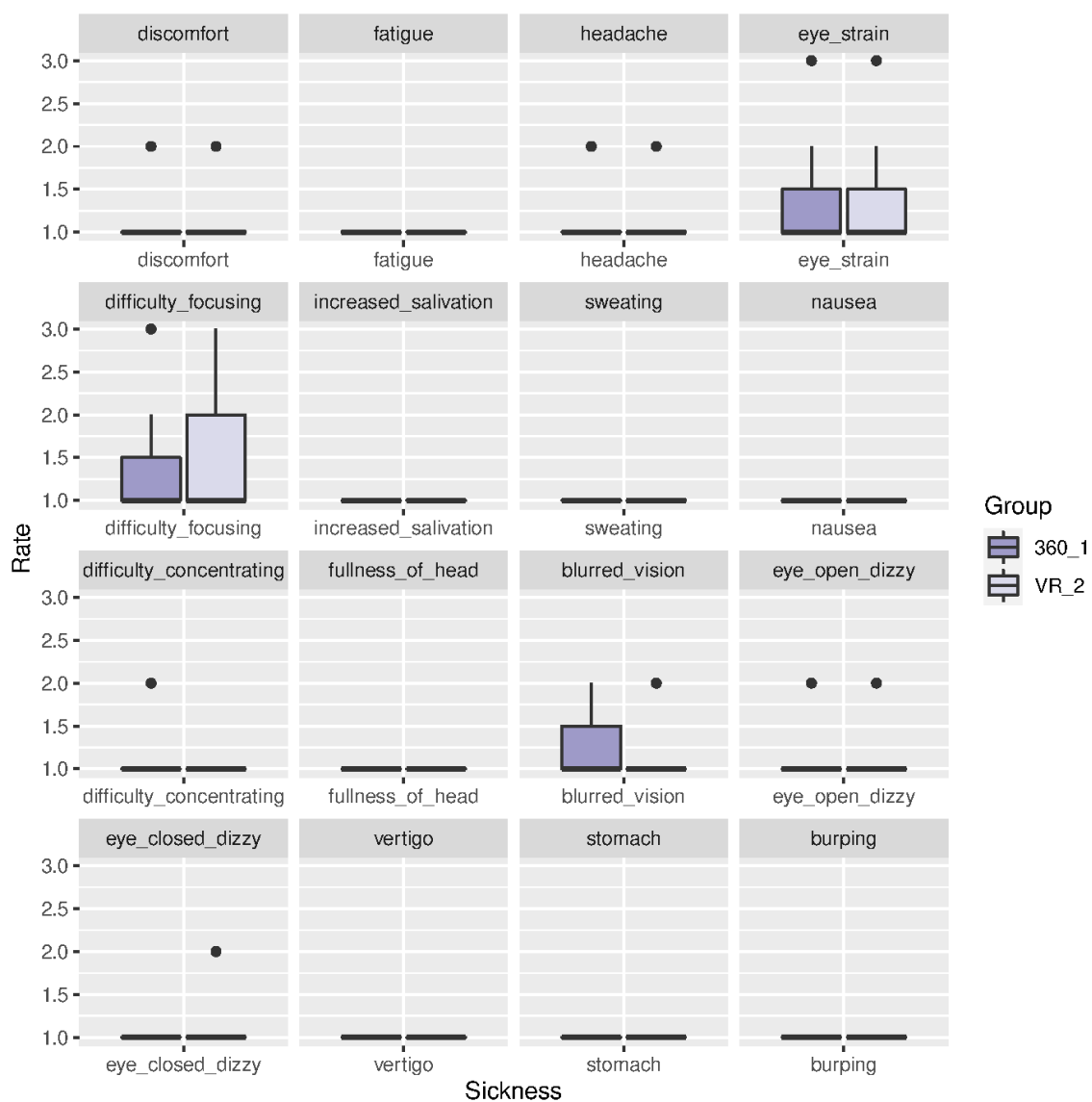


Figure 5.6.4: MotionSickness rating comparing 360° video in first round vs. VR simulation in second round.

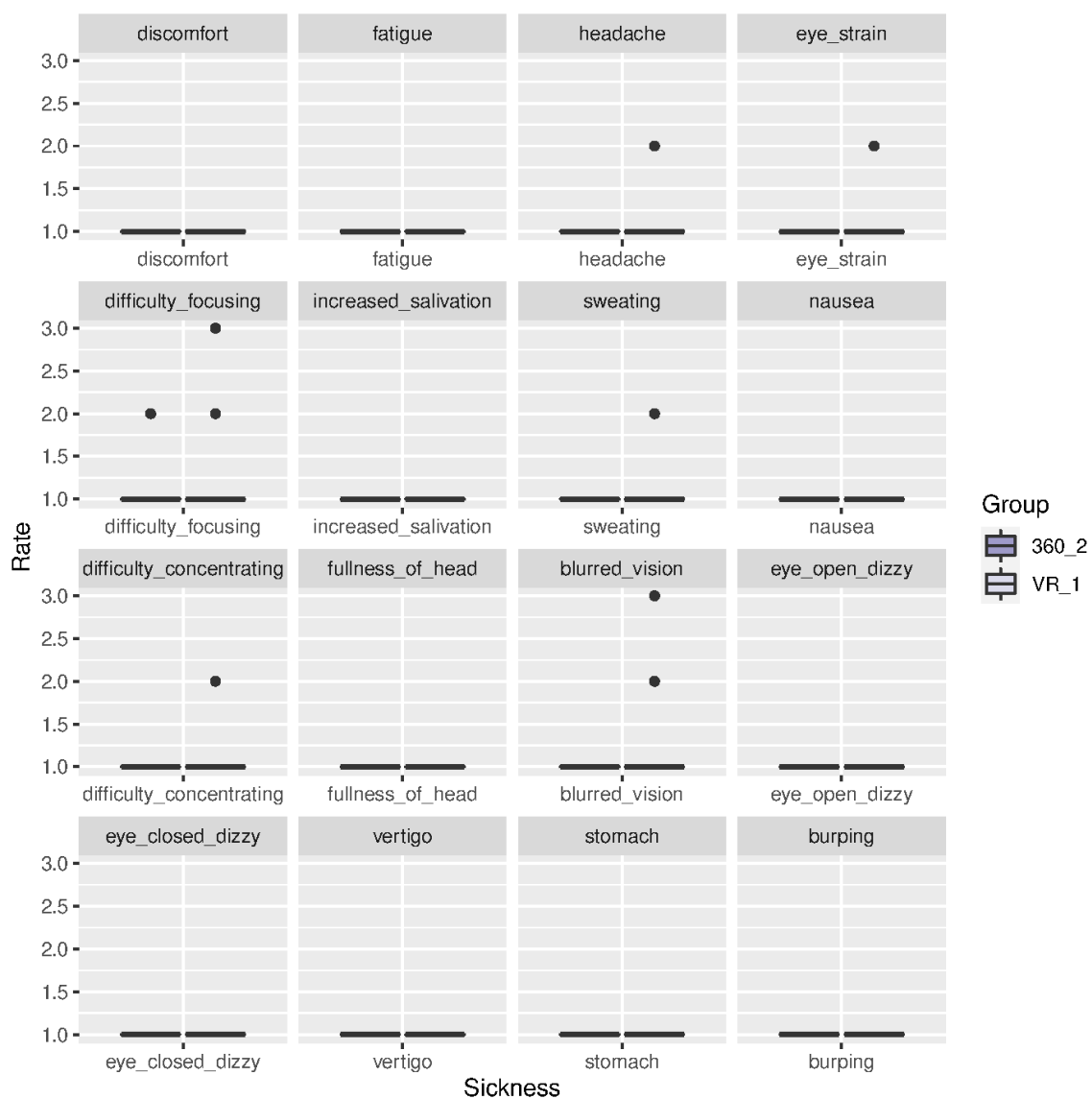


Figure 5.6.5: MotionSickness rating comparing 360° video in second round vs. VR simulation in the first round.

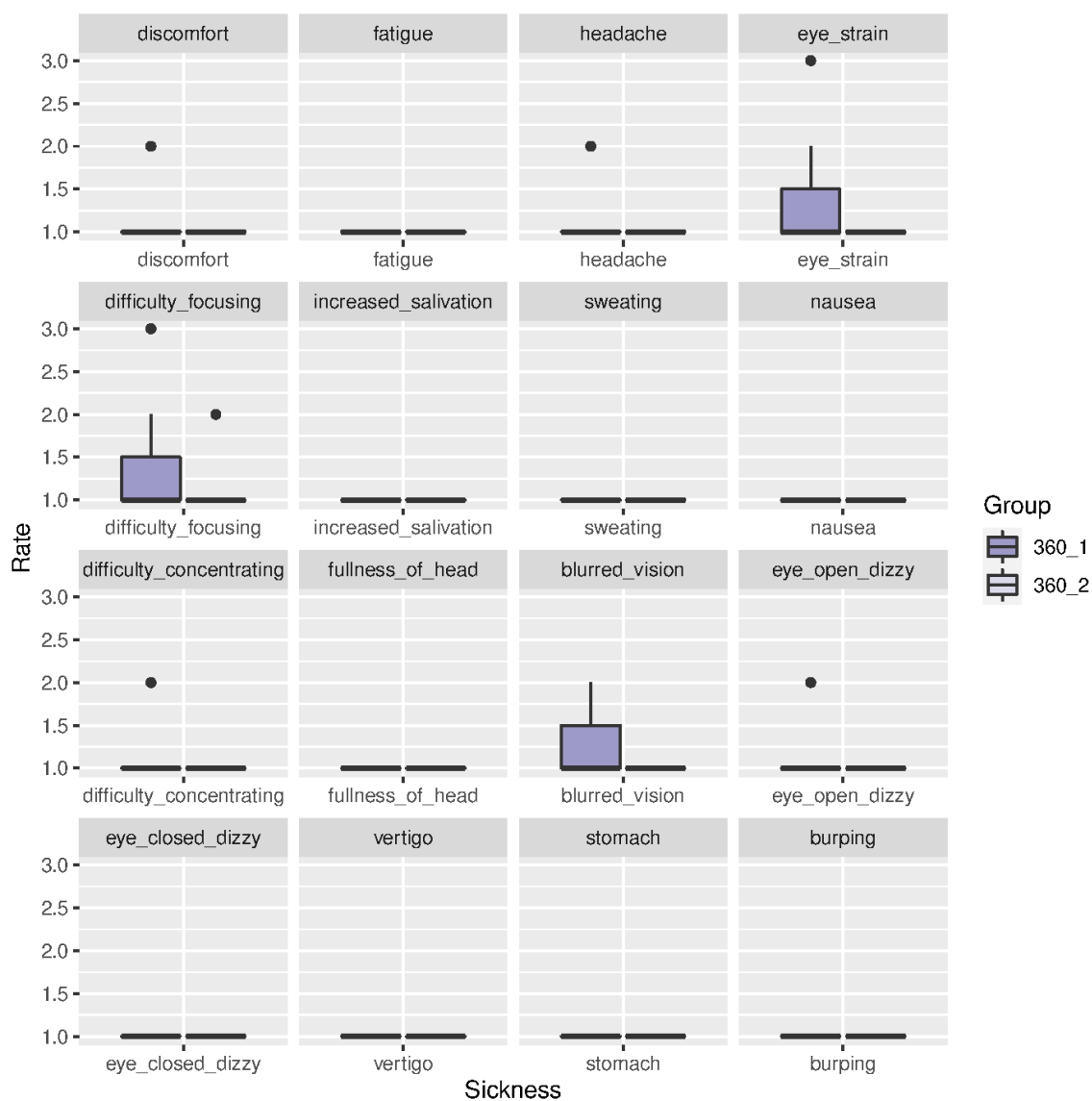


Figure 5.6.6: MotionSickness rating comparing 360° video in the first-round vs. 360° video in the second round.

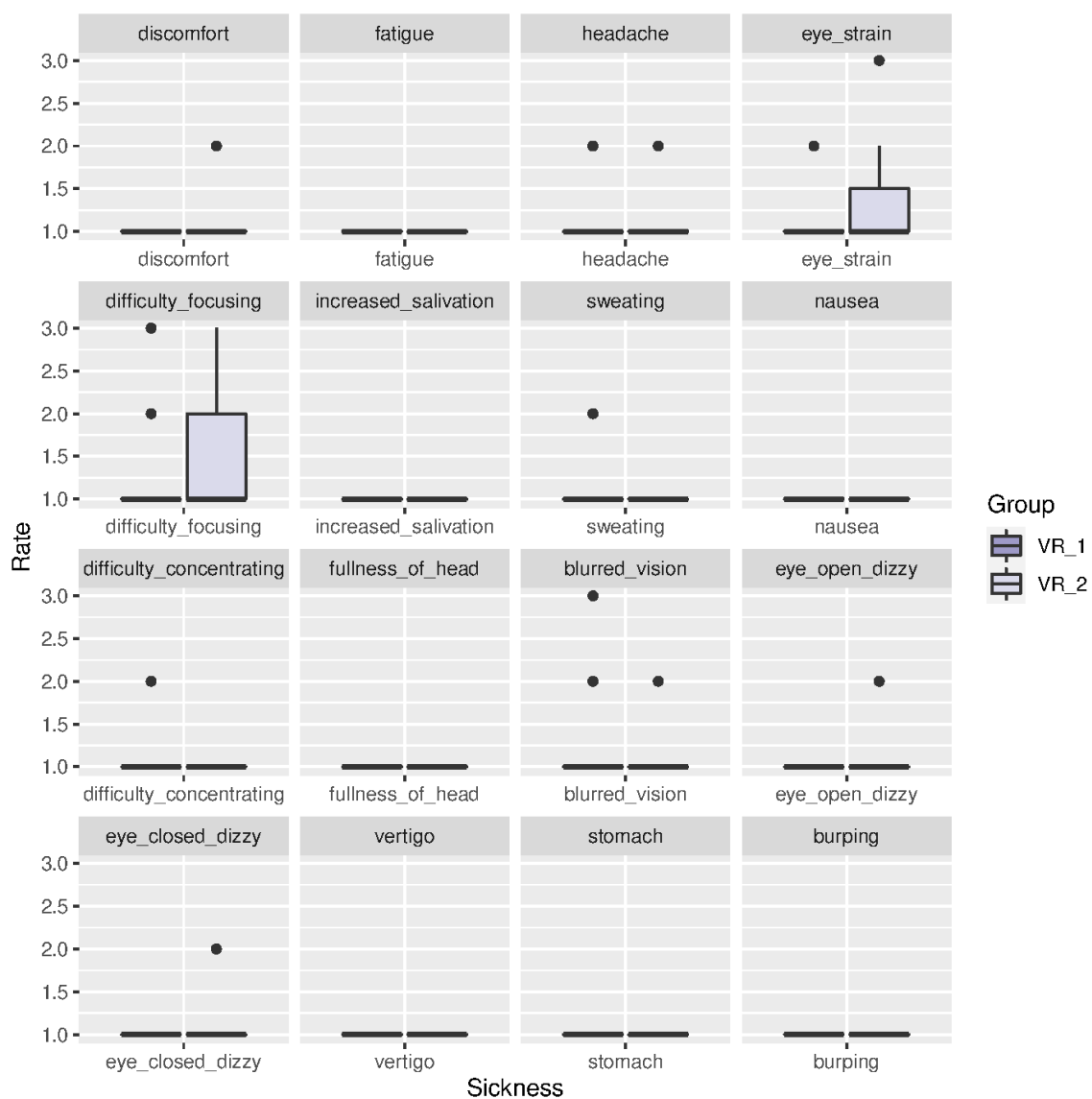


Figure 5.6.7: MotionSickness rating comparing VR simulation in the first-round vs. VR simulation in the second-round.

5.7 Confidence in Neonatal Resuscitation Skills

The last factor that we assessed using questionnaires was participant confidence in neonatal resuscitation skills. We first asked participants to complete the confidence questionnaire prior to completing training with the assigned technology. This was done to get a baseline for comparison confidence between the two groups, “pre-confidence”, shown in Figure 5.7.1.

As seen in the figure, there is no statistical difference in “pre-confidence” in neonatal resuscitation skills between participants before completing either 360° video or VR simulation. The median range for all questions is 70-90% confidence level.

The participants were once again asked to complete the confidence questionnaire after completing training. As seen in Figure 5.7.2, there was no difference in confidence between participants completing 360° video vs. VR simulation in the post-completing survey. The median range for all questions is 80-100% confidence level for both groups.

The difference between “pre-confidence” and “confidence” ratings was obtained for each group to assess if there was any impact on confidence with the training provided. The results are summarized in Figure 5.7.3. Participants had higher confidence in “demonstrating correct mask placement” and “re-evaluating newborn response after 30 seconds of effective PPV (HR and spontaneous respirations)” after VR simulation than after watching the 360° video (adjusted p-value<0.05). No statistical difference was noted in other questions assessing confidence.

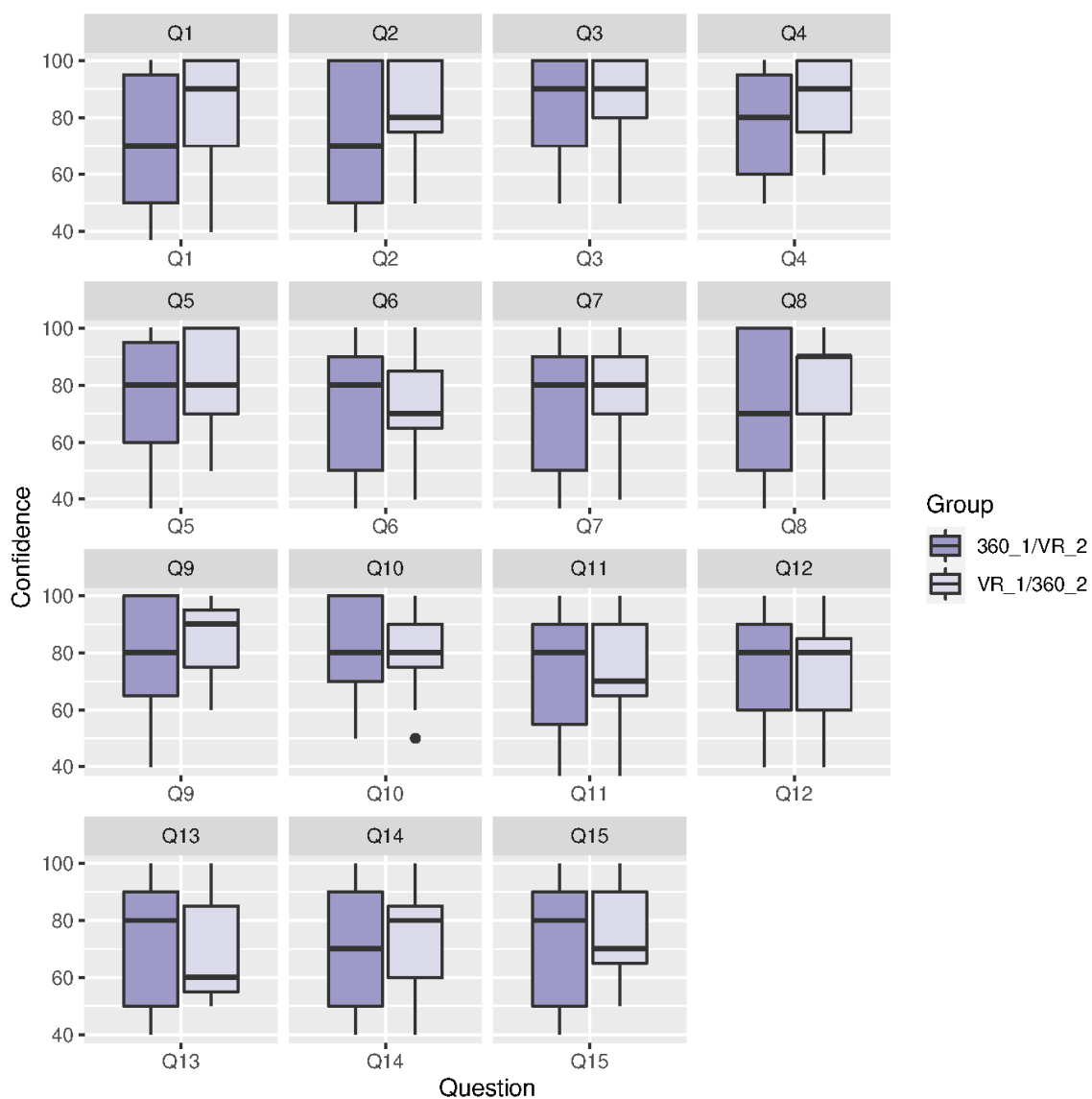


Figure 5.7.1: “Pre-Confidence” ratings from participants before completing training with either technology, 360° video first/VR second, vs. VR first/360° video second.

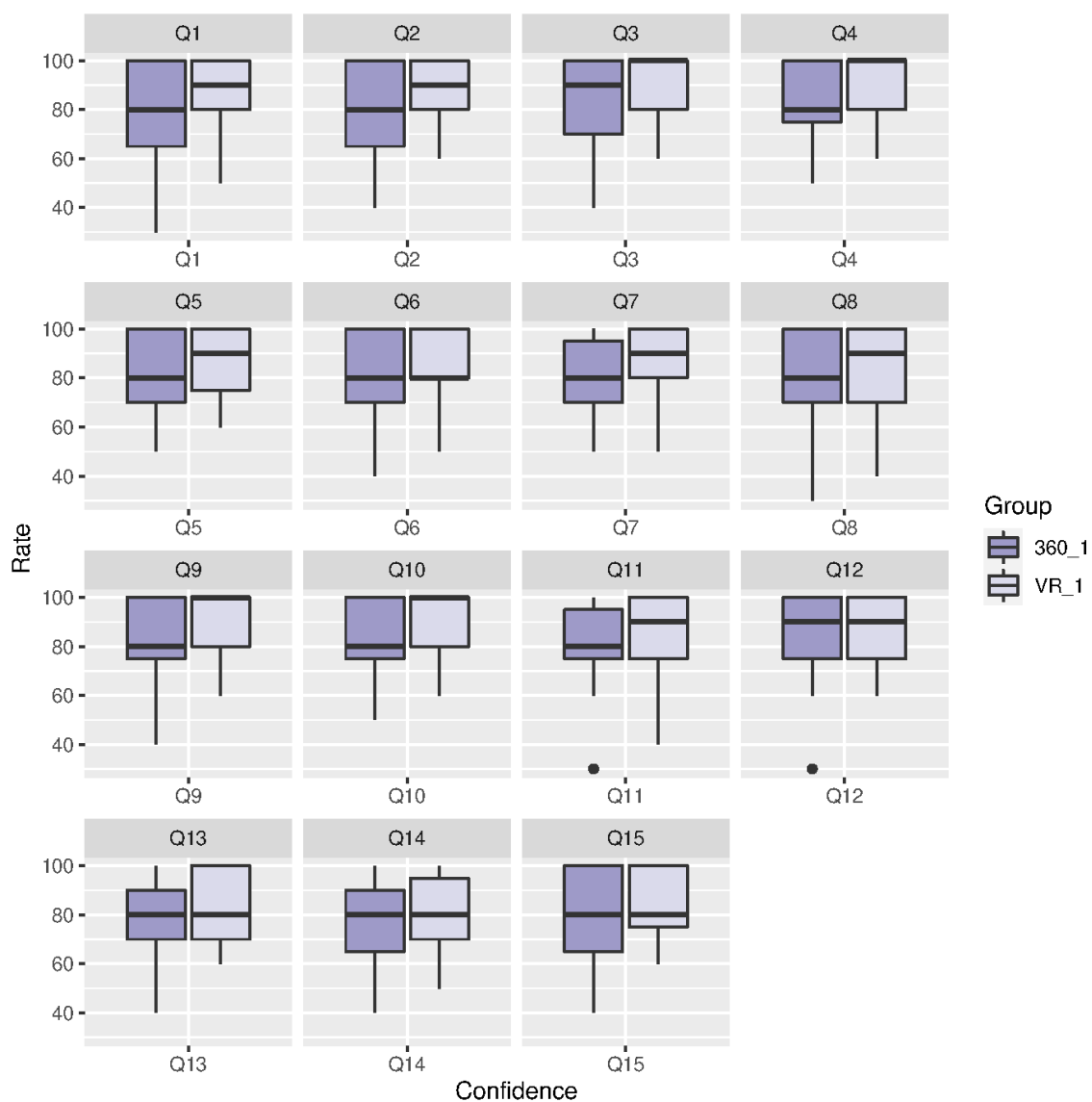


Figure 5.7.2: Confidence ratings from participants after completing training with 360° video vs. VR simulation.

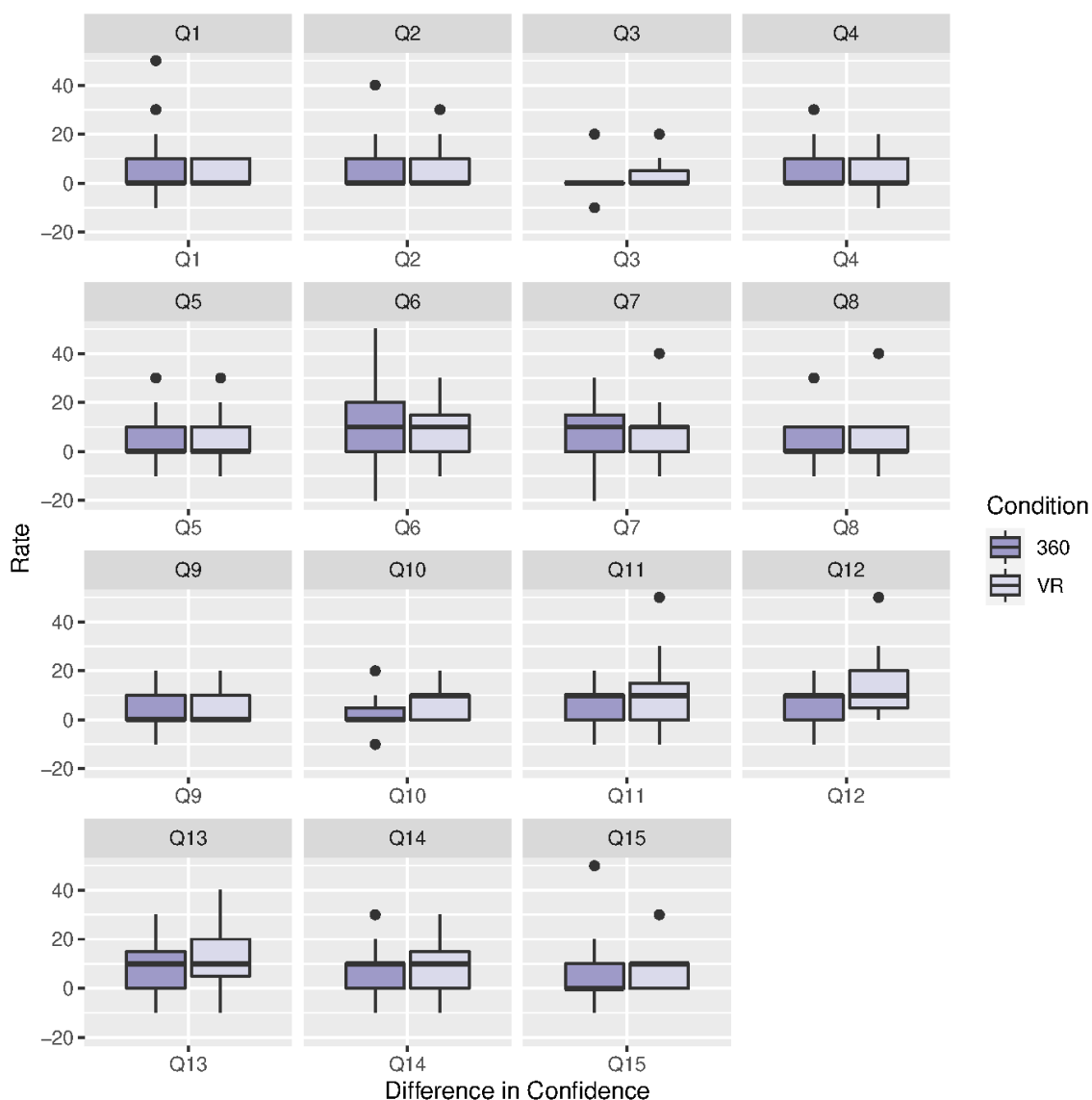


Figure 5.7.3: Difference in Confidence ratings from participants completing training with 360° video vs. VR simulation.

5.8 Instructor Evaluation

The final component of this study was to assess whether the training provided improved performing NRP. This was done, as previously explained in the methodology,

by having NRP instructors evaluate participants performing NRP after either watching the 360° video or completing the VR simulation. The results are summarized in Figure 5.8.1.

As evident, overall, both groups performed well, with a median total score of 12/15. There was no statistical difference in the NRP evaluation between watching 360° video or VR simulation. When looking at specific criteria in the evaluation process, participants completing the VR simulation did better on Q7: *“Provides effective positive pressure ventilation (40-60 bpm) for 30 seconds”*, than participants watching the 360° video (adjusted p-value<0.01). Similarly, participants doing the assessment after completing the VR simulation did better on Q8: *“Re-evaluates heart rate (Heart rate must be > 100 bpm)”*, than participants watching the 360° video (adjusted p-value<0.05).

On the contrary, participants who completed the assessment after watching the 360° video did better on Q5: *“Initiates monitoring (pulse oximeter probe to right wrist or hand +/- ECG)”*, than participants completing the VR simulation (adjusted p-value<0.05).

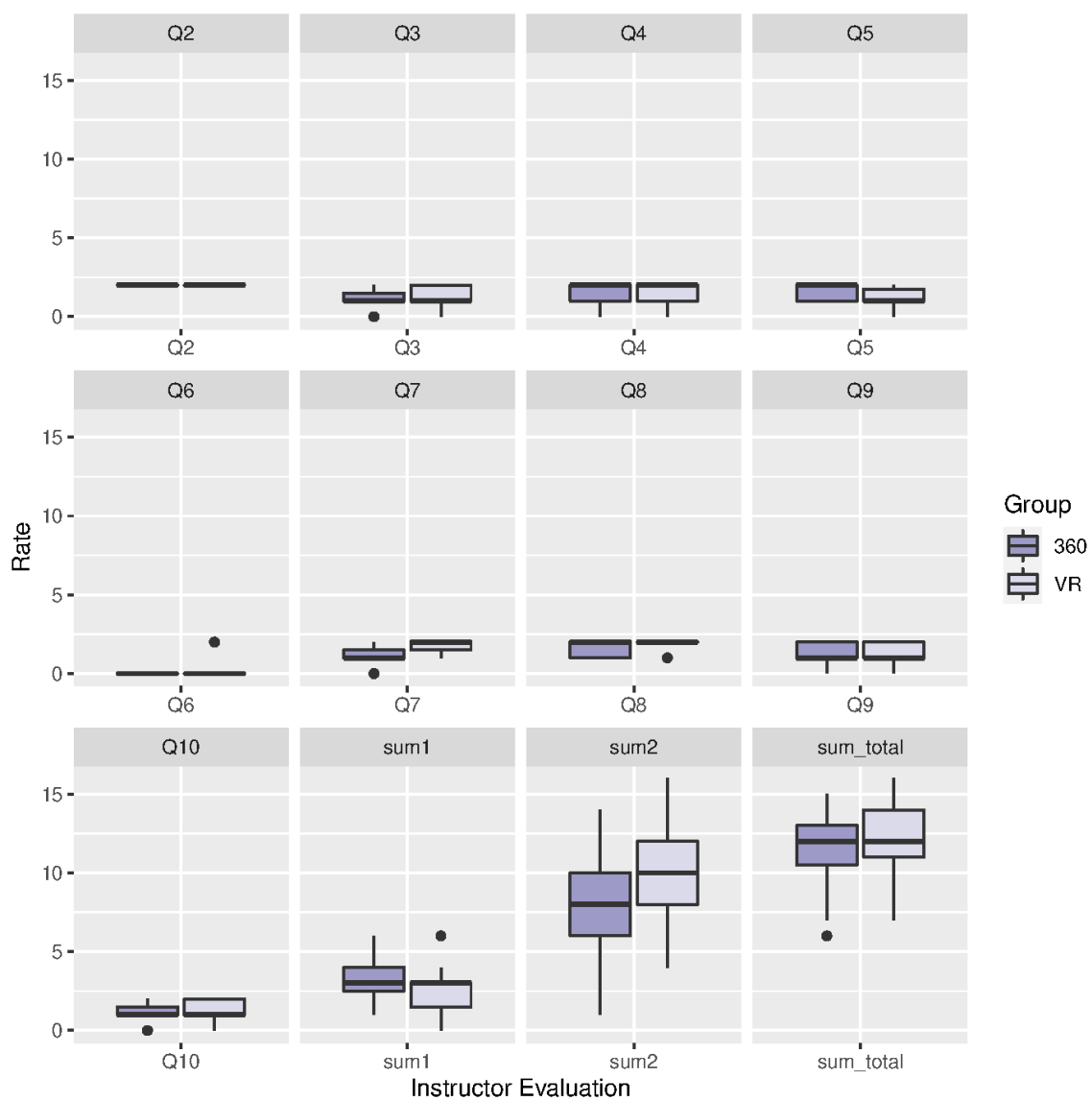


Figure 5.8.1: Instructor evaluation ratings from participants completing training with 360° video vs. VR simulation.

5.9 Qualitative data: participants' comments on the VMAR Technologies

In this study, in addition to quantitative data, we collected qualitative data in the form of comments regarding the participant's opinions on the assigned VR technologies. Participants were asked to comment on what they liked and disliked about each technology, as described in the methodology (Table 4.1.1). The comments for "likes" and "dislikes" were reviewed, and several common themes emerged.

5.9.1 "Likes" for VR Simulation

For "likes", the following themes were evident: 1) good for learning and a safe environment; 2) hands-on and interactive; 3) realistic and immersive; 4) easy to use.

Good for learning and safe environment:

One of the themes that most commonly occurred in participant comments on what they liked about the VR simulation was good for learning and for providing a safe environment. Some of the comments that were provided by participants included the following:

"Very helpful & interactive with learning NRP. Very helpful in keeping content interesting."

"It made it much easier to get my brain thinking about the steps in NRP compared to just reading the algorithm."

"What I liked about this is that I could perform the things that needed to be done myself. It made learning what to do in that situation easier."

“Extremely helpful for training situations. Excellent experience in a controlled environment. Gave me the ability to be a part of an NRP situation without feeling worried about feeling alone (other staff in the video)”. This participant found the VR simulation *“Extremely helpful for training situations”*, in a *“controlled environment”*.

Another participant wrote a similar comment, *“Could be done as a safe learning exercise to run through NRP cases.”*

Some participants found the VR simulation a good refresher of NRP skills. One participant wrote, *“Besides giving me the opportunity to practice PPV technique it was a great refresher for the steps of resuscitation.”*

Similarly, another participant commented, *“A great way to refresh skills that are not always used every day. The virtual reality was very engaging and would be a great supplement to refresh NRP more often than every 2 years.”*

Realistic and immersive:

Participants also liked that VR simulation was realistic and immersive. Some of the comments included the following:

“Interacting with the environment and being a part of the simulation. It was a true 360 environment, felt semi-real, at the end I felt there was a surface I could lay the controllers on after being engaged with the scenario.”

This comment illustrates that the VR simulation was realistic to the point that the participant felt he/she could lay the controllers on the surface depicted in the VR environment.

Another participant wrote, *“I liked the interactiveness and ability to attend to*

different aspects of the scenario. It was really engrossing. The numbers were big enough on the monitor to see easily.”

Other comments were similar, as shown below:

“It was very realistic, and it helped guide me through the appropriate steps.”

“Similar to real setting working in real time.”

“Again you were present in the room and you could complete interventions.”

“Better than just reading the material because you felt part of the experience.”

“Felt that I was there – able to assess the baby & the monitors.”

“I liked how it made the situation feel real.”

“I liked how real everything was. I liked how easy it was to change/troubleshoot the scenario.”

Overall, these comments depict that many participants shared similar views on the VR simulation being realistic and immersive.

Hands-on and interactive:

The third theme that emerged when participants were asked to provide feedback on what they liked about the VR simulation, was that it was hands-on and interactive.

One of the participants wrote the following comment, *“Extremely beneficial review and kept me interested and engaged. I was less distracted in this method and felt like I was learning more because it was hands on”*. The participant found it very beneficial to her learning as it was engaging and hands on.

Some other similar comments included the following:

“I liked that I was involved even though I was being taught. I learn best from hands on experience.”

“Very helpful & interactive with learning NRP. Very helpful in keeping content interesting.”

Another participant wrote that the interaction aspect allowed for critical thinking as well. *“Interactive mannequin made for “as -real” a feedback simulation could be, provide response to an action (or lack of). Therefore, good tool for critical thinking.”*

Easy to use:

Participants also commented that the VR simulation was easy to use. A participant wrote that not only was it easy, but that VR simulation programs can help with barriers to access for skills training.

“Easy to learn how to use VR equipment. If students have access to VR practice programs, they would not have to rely on having access to equipment/staff to practice”.

Other comments included, *“Easy to use and helpful for teaching”* and *“Easy to use and follow”*.

Visual aids:

Lastly, participants liked the visual aids in the VR simulation. Participants like the avatar and the NRP algorithms for reference.

“I liked the avatar to guide NRP. The SPO2 and MRSOPA visible easy to reference. Loved being “immersed” in the role.”

“All the resources were available e.g. NRP algorithm so can see the next steps case-based, interactive.”

5.9.2 “Dislikes” for VR Simulation

We also asked participants to give feedback on aspects they disliked about VR simulation. Four common themes emerged, including: 1) clarity/other visual aspects; 2) bag mask; 3) minimal thinking and lack of teamwork; and lastly, 4) nothing/lack of experience.

Clarity/other visual aspects:

One feature that was a common dislike was the visuals. One participant wrote that *“Clairness of some of the visuals, specifically the charts could be improved”*. Participants wrote similar comments:

“Resolution of graphics was grainy if not tilting my head to look directly at the resource.”

“Difficult to get head gear in a stable position to keep words clear in simulation. Easily became blurred for me.”

Two participants wrote, *“Foggy glasses”*.

“Blurry at times, not sure if it was because I was wearing glasses with headset. No clock was present for timing”. This participant also commented on the baby being not ideal: *“The baby’s eyes were a bit scary, typically a hypnotic newborn wouldn’t be alert.”*

Bag mask:

One specific visual aspect that participants did not like/would like to see improvements in the VR simulation was the bag mask. Generally, the feedback was that the bag was not realistic.

“The bag of the bag mask valve, bag valve mask did not feel the same as a real one as it was just a trigger.”

“Using the controller to mimic the mask and bag have a different feel than in reality.”

Some participants commented that the skills required for bag mask were not utilized.

“Felt like missed out on the muscle memory of using actual bag/mask.”

“Fine skills such as mask readjustment was not able to be performed (they were automated by computer); technical skills challenging to simulate virtually.”

Lastly, some participants gave feedback on proper bag inflation:

“Unable to assess if PPV is effective (example – proper bag inflation or holding mask effectively on pt face.”

“I questioned the use of the self-inflating versus the flow inflating bag (for CPAP). Also, the ability to “sense or feel” the correct amount of pressure to use for lung inflation.”

Minimal thinking and lack of teamwork:

Some participants gave feedback on the VR simulation requiring minimal thinking. One participant wrote, *“Took away the thinking so it was happening before you had a change to think it. Might be better if you do same simulation more than once.”* Two other similar comments were provided, *“minimal thinking because the avatar told me what to do”* and *“Gave away answers easily”*.

Participants also commented on lack of teamwork, and interaction with other people in the VR simulation. Comments included, *“In this particular scenario – not interacting with other person – more so bystander”*, and *“Lack of teamwork skills”*.

Nothing, lack of experience:

Lastly, some participants wrote “*nothing*” for dislikes/improvements, for VR simulation. For example, participants wrote, “*Nothing, might take some getting used to but easy once you get the hang of it*” and “*Nothing. I would’ve liked a CPR scenario!*”.

Others also included the lack of experience, and they would have better learning if more experienced in VR technology. Example, one participant wrote, “*My being unfamiliar with VR. More practice would help this*”.

Other three participants wrote:

“I didn’t like that I could hear but not see my real surroundings, but I am sure I could get used to it.”

“It took a few moments to become familiar with its function.”

“I found getting used to the virtual room distracting to the information being given.”

5.9.3 “Likes” for 360° Video

When examining the comments participants provided for what they “liked” about the 360° video, several common themes emerged, including: 1) good refresher; 2) real-life representation; 3) ability to observe NRP; 4) 360° view; and lastly, 4) easy to follow and immersive.

Good refresher:

One of the most common comments on what participants liked about the 360° video was that it was a good refresher. Comments included, “*Visual, auditory & case – loved learning good refresher of NRP*”, “*Helpful to refresh NRP learning*”, “*It was*

a very effective way of review skills of NRP”, and “It was a good refresher”.

One participant commented that seeing a successful NRP was a good refresher, *“Real voices, familiar scenery/equipment. Watching successful progression for learning was a good refresher”*. Another participant wrote that the 360° video would be useful for debriefing, *“I liked seeing the video after I did they practice SIM exercise. It would be a good way to debrief after training to watch a video of it being done”*. Lastly, a participant wrote that watching the 360° video would be helpful in becoming more confident performing NRP, *“I would do the same scenario multiple times to become confident at it”*.

Real-life representation:

Another aspect that participants liked about the 360° video was the real-life representation. Particularly, participants liked the realistic view and real people. One participant wrote, *“Nice to have a realistic view – feel a part of it”*, and another wrote *“I liked being with real people”*.

Participants also liked the seeing NRP being performed in a familiar environment. Comments included: *“I liked the 360° video. It had more of the resuscitation details than the VR headset and was filmed in a familiar environment with familiar equipment.”*

“I felt like it was a more real experience than when done in a lab setting. It made me feel like it was a real-life situation and not a scenario made up by the instructor.”

“It was like you were present in the room & you could see all interventions being done.”

In addition to the use of real people, another participant liked the visuals of correct ventilation, *“Once again immersed in the NRP resus. Loved the use of real people.*

Like the visual of good/correct pressure for ventilation from the RT and where to increase on the T-piece”.

Ability to observe NRP:

Participants also liked having the ability to observe NRP without actively being engaged in performing themselves. This allowed them to focus on NRP without being concerned about their own skills.

“I was able to watch & observe the lesson first. Paid attention to both aspects (roles) without worrying/concentration on my skills alone.”

“I liked being able to see real people perform NRP. I was not distracted trying to use the equipment & was able to focus on what was happening.”

“I liked that I could get to see what was/needs to be done instead of just being told. I find that I am a visual learning so I feel this would help my learning.”

“Was able to observe resuscitation which outside of NPP recertifications is not something I usually get to do.”

“Watching others perform the task properly. Easy to use.”

360° view:

Another aspect that participants liked was the 360° view. They liked *“being able to look around the room. See the whole set up scenario”* and found it *“more up close & personal feeling than just watching a video”*.

One participant wrote, *“I liked that I could easily attend to different aspects of the video. It held my attention easily compared to watching videos on my laptop”*, and another wrote that they liked *“being able to interact with the video”*. Participants also

commented on liking that the 360° video *“Gave you the experience of being in the room during NRP and it felt as though you are a participant.”* Another participant wrote similar comment, *“the perception that you are there during the resuscitation rather than just watching it.”*

Easy to follow and immersive:

Lastly, participants commented that the 360° video was easy to use, and was immersive. Comments included, *“Quick and clear instructions”*, *“Easy to use; clear video & sound. Good vantage point”*, and two participants wrote *“immersive”*.

5.9.4 “Dislikes” for 360° Video

Participants were also asked to give feedback on aspects they disliked about the 360° video. Four common themes emerged, including: 1) not interactive and not hands-on; 2) visual aspects; 3) foggy glasses; and lastly, 4) nothing/lack of experience.

Not interactive and not hands-on:

Over one third of the patients commented that they disliked that the 360° video was not interactive and not hands-on. Some of the comments included:

“Not at all interactive so less immersive”,

“Not hands on”,

“Lack of interaction”,

“Unable to interact. No “hands on”. No visual monitor for heart rate of SpO2”

“No participation”.

Participants also commented that by simply watching 360° video they did feel

involved in making decisions in NRP. One participant wrote *“I did not feel involved, but it was helpful”*, while other added *“I wasn’t a participant or involving in making the decisions of the simulated resuscitation.”*

Some of the other comments included:

“Lost the tactile component of practice vs. real life practice sessions or VR headset with controls”.

“Not hands on. The participant cannot do things themselves.”

“There was no interact with the environment”.

“This form was not as interactive or engaging and more so felt like watching a video”.

Visuals:

Some participants commented that they did not like the visuals in 360° video. Particularly, the resolution could have been better. Some of the comments included:

“The visuals – could be more clear (better pixels?).”

“Sometimes picture not clear.”

“The videos appeared to be low resolution – I wanted to read the numbers on the monitor, but it was too blurry.”

Foggy glasses:

Few participants also disliked that the glasses were foggy. Comments included, *“Foggy glasses”*, *“Ø – except mask steaming up the visual a bit”* and *“Hard for learners with glasses since the set up can get foggy”*.

Nothing/lack of experience:

Lastly, some participants commented that there was nothing that they disliked about the 360° video. They also commented that they did not have much experience using VR headset and as such it took some getting used to. Some of the comments included:

“Nothing. It would take a little getting used to”

“First experience? same. Bit difficult at first.”

“It takes a little getting used to.”

“N/A, no dislikes with same”

“No dislikes”

Chapter 6

Discussion

Recently virtual reality technology has gained significant attention for its use in education. It has been explored in many different fields, including medicine [80], due to the virtual learning environment providing many possible teaching scenarios and content. It has been shown to improve learners' ability to analyze problems and develop new concepts [2]. Additionally, learners perceive learning to be more engaging and enjoyable with the incorporation of VR technologies. Similarly, VR technologies in education reported higher satisfaction and perceived usefulness [21], [22].

The goal of this study was to assess whether VR simulation may be used for neonatal resuscitation training purposes, as well as to compare it to watching NRP training via 360° video. To be able to analyze the data statistically, we recruited 30 participants and randomly divided them between two groups; VR simulation and 360° video. As stated in the results, the overall distribution of participants was almost equal in several aspects, including profession, experience, and time since the last NRP training.

Most participants were nurses, had about 0-5 years of experience as an NRP

provider, and had completed NRP training within the last year. There was no statistical difference between the group assignment and the demographic variables, which implies that the groups could be compared without the concern of confounding variables. When assessing and comparing the two groups, we looked at several aspects, including ease of use, presence, usefulness, motion sickness, confidence in NRP skills and instructor evaluations of NRP skills.

6.1 Ease of Use

In our study, participants rated 360° video and VR simulation as moderately easy to use. Both of the groups used VR headsets, and as such, it is not surprising that participants rated them similarly. VR simulation used controllers to represent the oxygen mask in the virtual reality scenario.

The ease of use was evidenced in the comments participants wrote as well. For VR simulation, comments included, *“Easy to learn how to use VR equipment. If students have access to VR practice programs, they would not have to rely on having access to equipment/staff to practice”*, *“Easy to use and helpful for teaching,”* and *“Easy to use and follow.”* Similar comments were provided for 360° video, *“Quick and clear instructions,”* and *“Easy to use; clear video & sound. Good vantage point”*. Regardless of being a 360° video or a VR simulation, people may use VR technology to either develop or freshen up skills.

6.2 Presence

Our study showed that participants felt more presence with VR simulation than with 360° video. Participants rated the VR simulation higher on the visual and auditory aspects of the environment, which plays an essential role in feeling present. Similarly, being able to actively survey or search the environment, vision, closely examine objects, and examine objects from multiple viewpoints were also rated higher. These also contribute to the feeling of being present in the learning environment. The study also showed that participants felt more immersed in the VR simulation than 360° video. Higher ratings were reported for being involved in the virtual environment experience and completely engaged in the experience for VR simulation compared to the 360° video. Similarly, overall, participants reported higher ratings for being involved in the experiment task to the extent that they lost track of time and had moments during the virtual environment experience where they felt completely focused on the task environment while completing the VR simulation. Participants responded that they were not distracted by the events occurring outside the VR environment and that the controllers and visual displays in the VR simulation were also not distracting.

When asked what participants liked about the VR simulation, about 30% responded that it was realistic and immersive. These qualities contribute to the sense of presence in the VR environment. An example of such comments included, *“Interacting with the environment and being a part of the simulation. It was a true 360 environment, felt semi-real; in the end, I felt there was a surface I could lay the controllers on after being engaged with the scenario.”* The participant was so immersed and felt present in the VR simulation that they thought they could lay the controllers on the surface depicted in the VR environment.

Participants also commented that they liked the fact that the 360° video was very realistic and they could view the environment from different aspects. Examples include, *“I liked that I could easily attend to different aspects of the video. It held my attention easily compared to watching videos on my laptop”*, and *“I felt like it was a more real experience than when done in a lab setting. It made me feel like it was a real-life situation and not a scenario made up by the instructor”*.

Even though participants commented that they liked both the VR simulation and 360° video for NRP, the apparent difference was in the comments regarding the hands-on aspect. Hands-on features play an essential role in immersion and feeling of presence. Participants positively commented on the hands-on component of the VR simulation. One of the participants wrote the following comment, *“Extremely beneficial review and kept me interested and engaged. I was less distracted in this method and felt like I was learning more because it was hands-on”*. Another participant wrote, *“I liked that I was involved even though I was being taught. I learn best from hands-on experience”*. Evidently, the hands-on feature contributed to being engaged, less distracted, and learning neonatal resuscitation.

On the other hand, participants did not like that the 360° video was not interactive and hands-on. Some of the comments included, *“Not at all interactive, so less immersive,” “Not hands-on,” “Unable to interact. No “hands-on.” No visual monitor for a heart rate or SpO2”*. One participant even stated that the lack of a hands-on component is what they disliked compared to VR simulation with controllers. The participant wrote that she did not like the *“Lost the tactile component of practice vs. real-life practice sessions or VR headset with controls.”*

The feeling of immersion and presence plays a vital role in learning [80]. Studies have compared 360° video to traditional two-dimensional movies and demonstrated

360° video to be immersive and improve learning [81], [82]. A recent study involving fourth-year medical students reported 360° video with an immersive headset to be more engaging than 2D format on a laptop computer. Students watched videos of anatomy lab exercises and rated them as more practical and interesting than traditional 2D-video [82]. However, learning outcomes were not assessed in this study, which makes it hard to determine the overall value and effectiveness of 360° video. Similarly, they did not compare 360° video to other VR technologies.

A recent study by Lerner et al. assessed the training effectiveness of the EPIC-SAVE (Enhanced Paramedic Vocational Training with Serious Games and Virtual Environments) project, where a highly immersive room-scaled multi-user 3-dimensional VR simulation environment was developed [80]. The VR simulation in this study involved an emergency scenario with anaphylaxis grade III with shock, swelling of the upper and lower respiratory tract, and skin symptoms in a 5-year-old girl (virtual patient) visiting an indoor family amusement park with her grandfather (virtual agent). The study involved 18 emergency physicians who positively rated the VR simulation for training effectiveness and quality of training execution. The VR simulation training was rated as an effective educational approach, and there was a strong, significant correlation between experiencing the presence and assessing training effectiveness [80]. As such, given that VR simulation was rated higher for the feeling of immersion and presence, it was also equally rated to be more effective for learning than the 360° video.

6.3 Usefulness

VR technology has been used in various settings, with one of the major uses in medical education [16]. This is due to the ability of the VR environment to provide opportunities for learning, such as learning various surgical skills using surgical simulations via robotics and VR system [23], without negative real-world consequences. VR environments remove the risks associated with learning on actual patients while providing various possible clinical case scenarios where users can train [23].

Additionally, a recent systematic review shows that VR-based HMDs are perceived as salient, motivating, and engaging [83]. HMD-based interventions are found to be effective, with results showing that they are at least comparable to traditional methods of medical education, with the added benefit of increasing students' motivation for learning.

For that reason, we assessed the usefulness of VR technologies in NRP training. Participants in our study perceived VR technology to be helpful in NRP training. Participants rated usefulness high for both VR simulation and 360° video. Overall, the VR simulation was rated higher than 360° video for its usefulness for learning. Mainly, it was rated higher for questions assessing whether using virtual reality would improve participants' learning performance and if it would enhance their learning effectiveness.

Participants commented that the VR simulation was good for their learning as it provided a safe learning environment. One participant wrote, *“Extremely helpful for training situations. Excellent experience in a controlled environment. Gave me the ability to be a part of an NRP situation without feeling worried about feeling alone (other staff in the video)”*.

Some participants wrote that VR simulation was a good refresher for their NRP skills. Comments included, *“besides giving me the opportunity to practice PPV technique, it was a great refresher for the steps of resuscitation,”* and *“a great way to refresh skills that are not always used every day. The virtual reality was very engaging and would be a great supplement to refresh NRP more often than every 2 years.”*

Participants also wrote that they found 360° video of NRP useful, particularly the ability to observe NRP without actively being engaged in performing themselves. One participant wrote, *“I was able to watch & observe the lesson first. Paid attention to both aspects (roles) without worrying/concentration on my skills alone”*, and another similarly wrote, *“I liked that I could get to see what was/needs to be done instead of just being told. I find that I am a visual learner so I feel this would help my learning”*. Observing NRP being done from a 360° view allowed users to correctly see how to do a successful neonatal resuscitation without worrying about being involved. This, too, provided a safe place to learn without the added pressure of worrying about one’s own skills and performance in a high-stress situation. Moreover, like VR simulation, participants found the 360° video to be a good refresher for NRP skills. Some comments were *“Helpful to refresh NRP learning”* and *“Real voices, familiar scenery/equipment. Watching successful progression for learning was a good refresher”*.

Overall, both VR simulation and 360° video were perceived as useful for neonatal resuscitation training by the healthcare professionals in our study. When assessing ratings from all the participants combined, VR simulation was rated higher than 360° video. This could have been because while in simulation, participants were going through the NRP algorithm themselves, actively participating, in contrast to 360° video, where they watched it being performed by others. Both allowed participants

to review the steps involved, and it may be beneficial to have them as an adjunct to one another to increase their usefulness in skill training and as a refresher course.

6.4 Motion Sickness

Even though VR technologies have been shown to be helpful in NRP training, it is essential to assess if there are any associated adverse effects before being incorporated into training healthcare professionals. Simulator sickness is a syndrome similar to motion sickness, which may be experienced during simulator or another VR exposure [84]. Simulator sickness can be measured using subjective and objective methods, the most popular self-report method being the Simulator Sickness Questionnaire. An adapted version of this questionnaire was also used in our study [84].

In this study, we assessed several symptoms that may result from VR use, including discomfort, fatigue, headache, eye strain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, and blurred vision. Participants in our study reported minimal sickness after using the assigned VR technology. The average rating was 1, “None,” for both VR simulation and 360° video.

Six participants reported having slight eye strain, difficulty focusing and blurred vision. The individuals who reported these symptoms almost all wore prescription eyeglasses and were also in the older age group. The VR headset was possibly not appropriately positioned over their eyeglasses, which could have impacted their view in the VR environment. This is evident in some of the comments that the participants wrote. For VR simulation, one participant noted, *“difficult to get headgear in a stable position to keep words clear in simulation. Easily became blurred for me.”* The participant did not like that the headgear wasn’t stable, and the VR simulation was

blurry for them. Before starting the simulation, participants were asked if the VR environment seemed clear after putting on the VR headset and if it was tight enough. However, as evidenced by this comment, the VR headset was not fastened enough, which caused the environment to appear blurry, which could cause eye strain. A few other participants also wrote *“Foggy glasses,”* and one wrote, *“Blurry at times, not sure if it was because I was wearing glasses with headset.”* For 360° video, participants also commented about the *“Foggy glasses”* and that it was *“hard for learners with glasses since the setup can get foggy.”*

Another reason for some participants having slight eye strain, difficulty focusing, and blurred vision could be that participants wore a mask as per pandemic hospital policy. The mask sometimes caused the VR headset to fog up, particularly if not properly tightened or if the participant also wore eyeglasses. One participant wrote that the *“mask was steaming up the visual a bit.”*

Nonetheless, our study showed that both groups reported minimal motion sickness. In fact VR technologies could be implemented to train most health professionals for neonatal resuscitation without the concern for negatively impacting their health or worrying that they will not be able to complete the training due to motion sickness.

6.5 Confidence in Neonatal Resuscitation Skills and Instruction Evaluation

Our study results suggest VR technology is easy to use, useful for learning, and with minimal motion sickness, making it an excellent educational tool. However, another factor that is also important to assess is if the training translates into skill improvement. Our study showed that participants had slightly higher confidence in

“demonstrating correct mask placement” and *“re-evaluating newborn response after 30 seconds of effective PPV (HR and spontaneous respirations)”* after completing the VR simulation than after watching the 360° video. This could be because VR simulation had a hands-on component that enabled the participant to practice and remember the correct mask placement. Similarly, the VR simulation reminded participants to evaluate the newborn response after 30 seconds of effective PPV. There were no other differences found in other aspects of NRP skills.

Apart from that, participants found the training useful, and one participant commented that the 360° video helped them become more confident performing NRP. The participant wrote, *“I would do the same scenario multiple times to become confident at it.”*

For our study, in addition to having feedback from the participants regarding their confidence in NRP after completing the sessions, we also had NRP instructors evaluate their skills. Our study showed that overall, there was no statistical difference in the NRP evaluation between the two groups, with both groups scoring well. It is difficult to determine the impact of either training on the participants’ neonatal resuscitation skills since our study did not evaluate their baseline skills. It is very likely that the participants already excel in neonatal resuscitation, given that majority of them completed NRP within a year. As such, the VR simulation and 360° video were simply a refresher course for them. It would have been interesting to evaluate participants before and after completing VR training and assess for improvement.

Regardless, our study showed that when looking at specific contents of neonatal resuscitation skills, participants who completed the VR simulation did better “providing effective positive pressure ventilation for 30 seconds” than participants who watched the 360° video. Similarly, participants who completed the VR simulation

did better with “re-evaluating heart rate (Heart rate must be > 100 bpm)”. This correlates with the reported increase in confidence ratings from the participants, who reported higher confidence with these components, as mentioned above.

On the other hand, participants who completed the 360° video before being evaluated performed better on “initiating monitoring (pulse oximeter probe to the right wrist or hand +/- ECG).” Though the VR simulation was hands-on and required the participants to place the oxygen mask and be involved in the simulation, this part was carried out by the avatar in the VR environment. In 360° video, this part may have been more noticeable, contributing to participants performing better in this area.

Another study by Zackoff et al. (2019) assessed whether exposure to an immersive virtual reality curriculum on pediatric respiratory distress improves medical students’ recognition of impending respiratory failure [85]. All students received the standard training on respiratory distress through didactics and high-fidelity mannequin simulation. The intervention group had an additional 30-minute immersive virtual reality curriculum, experienced through an OculusRift headset, with three simulations of an infant with 1) no distress, 2) respiratory distress, and 3) impending respiratory failure. The study assessed if there was any improvement in learning via a free response clinical assessment of video vignettes at the end of the pediatric rotation, which physician experts scored. Their study also demonstrated VR to be helpful in skill amelioration. The study showed that exposure to an immersive VR curriculum improved objective competence in assessing respiratory distress and recognizing the need to escalate care for patients with signs of impending respiratory failure [85].

Moreover, a study by Putnam et al. (2021) assessed the usability and feasibility of combined interactive instructional videos and a novel virtual reality trainer for healthcare professionals. It also evaluated the impact of this combination on learners’

knowledge of critical airway events in children. Like our study, participants included medical students, residents, faculty, and advanced practice nurses, and the study compared VR trainers (HoloLens technology) simulating a pediatric critical airway event with interactive instructional pediatric airway videos. Participants completed pre- and post-test for pediatric airway emergency management and a survey of their perceptions of the videos and VR trainer [86]. Like our study, both interventions were well received, and positive perceptions also included realism, interactivity, and an active learning environment. Additionally, participants had slight to significant improvement in knowledge following the interventions.

Participants also reported preferring to have video and VR trainers included for future training in pediatric airway events, with or without didactic lectures [86]. Some participants in our study also preferred the combination of 360° video and VR simulation as an adjunct to NRP. The interactive videos in Putnam et al.'s study provided narration, realistic images, and audio. Several participants commented on the realism of the sounds associated with airway compromise (e.g., stridor and wheeze) to the extent that they evoked a degree of anxiety commensurate with the real event. This is similar to the 360° video in our study, which takes place in a familiar environment, allowing participants to see how to perform neonatal resuscitation successfully.

These two studies explored the usability of VR training and assessed the educational outcomes associated with incorporating VR technologies in medical education. Both showed positive feedback and outcome with its use, as our study. One of our study's advantages was the neonatal resuscitation evaluation of the participants by actual NRP instructors. This allowed evaluations to be the same as if they completed standard NRP without using VR technologies.

Overall, our study and others show that VR technologies can improve NRP skills.

Our study also showed that VR simulation increases user confidence with more hands-on skills compared to the 360° video.

Chapter 7

Conclusion

One of the main goals of the study was to compare the effectiveness of VR using HMDs with the 360° videos training and evaluate the sense of presence, immersion, and impactful experiential learning afforded by VR. We explored NRP providers' perceptions, experiences, and satisfaction and compared the effect of VR simulation and 360° video on learning outcomes.

Our study showed both VR technologies, 360° video and VR simulation, to be easy to use by healthcare professionals. Participants had an increased feeling of presence with VR simulation overall than with 360° video. They rated the VR simulation higher on the visual and auditory aspects of the environment, being able to actively survey or search the environment, vision and closely examine objects from multiple viewpoints. Participants felt more immersed and involved in the VR simulation than in the 360° video. It was essential to assess immersion and presence since they have been shown to be more engaging and improve learning [80]. Our study showed that healthcare professionals found both VR technologies useful in NRP. They particularly reported the VR simulation to be more helpful in improving their learning performance and

enhancing their learning effectiveness.

After completing the assigned technology, we also assessed the difference in confidence in NRP skills. Participants who completed the VR simulation reported higher confidence in *“demonstrating correct mask placement”* and *“re-evaluating newborn response after 30 seconds of effective PPV (HR and spontaneous respirations)”* than participants who watched the 360° video. VR simulation was more hands-on, allowing participants to practice and pay attention to proper mask placement. Similarly, the avatar in the VR simulation prompted them to check for the newborn’s response after 30 seconds of effective PPV. The 360° video showed healthcare professionals performing NRP without highlighting specific steps. From the NRP evaluators perspective, there was no difference in other NRP skills.

Interestingly, the skills participants reported being more confident were the aspects they performed better when assessed by the NRP evaluators. Participants who completed the VR simulation did better on *“providing effective positive pressure ventilation for 30 seconds”* and *“re-evaluating heart rate (Heart rate must be > 100 bpm)”* than participants who watched the 360° video. Participants who watched the 360° video before being evaluated performed better on *“initiating monitoring (pulse oximeter probe to the right wrist or hand +/- ECG)”*.

Overall, both VR technologies are easy to use, VR simulation has a better feeling of presence, and participants rated it more useful for their learning than 360° video. Though VR technologies did not drastically improve participant confidence and neonatal resuscitation skills, they could still be applied in medical education as another modality for teaching. Particularly, since only minor motion sickness was reported, there is no associated harm in incorporating VR technology in NRP.

7.1 Limitations and Areas to improve

In our study, NRP providers included registered nurses, pediatric residents, respiratory therapists, respiratory therapy students, pediatricians, clinical associates, medical students, obstetric residents and licensed practical nurses. However, most participants were nurses, and our sample size was small, with only 30 participants. As such, our findings cannot be generalized to all healthcare providers. Moreover, most participants had completed NRP in the last year, so their skills were still sharp. Having participants only recently trained within the last year could have probably diminished the learning outcomes of VR simulation and 360° video. If the participants had completed NRP over 2-5 years, it would have been a better assessment of the VR technologies for NRP training, refresher or booster course. This is because after 2-5 years, participants' skills may have been diminished, and there would have been more room for improvement from VR NRP training.

Another limitation of our study was that there were features of VR simulation and 360° video that participants did not like, which affected their NRP training potential. For example, for VR simulation, the bag mask could have been better rendered with maybe haptic feedback to make it more realistic, particularly since participants commented that it lacked real-life sensation. Similarly, the baby we used in our study was not ideal, and one participant wrote, *“the baby’s eyes were a bit scary. Typically, a hypnotic newborn wouldn’t be alert.”* This could have distracted participants, which may have affected the feeling of immersion and presence. If the VR environment is optimized and made more realistic, it would increase immersion, presence, and, most likely, its power as a learning tool. Similarly, 360° video was limited to one location, and participants could not see NRP from other points in the room. The feeling of immersion and presence might have been better if participants

could switch positions to see them perform NRP from different angles.

Lastly, another major limitation in the study was the mandatory use of masks due to COVID-19 pandemic regulations. Some participants reported foggy glasses, especially those wearing eyeglasses, which may be related to wearing masks to some extent. Foggy glasses could have affected participants' experience as it could have distracted them.

However, the study was well designed and executed regardless of the limitations. It showcased the potential of VR technologies in medicine, specifically in NRP training.

7.2 Future Directions

Our study demonstrated that VR technologies are helpful for NRP training of healthcare professionals. VR simulation and 360° video were perceived as valuable, with overall higher ratings for VR simulation. We did not assess whether the combination of both technologies was effective. However, one participant commented that watching the 360° video after the VR simulation was an effective way of debriefing. *“I liked seeing the video after I did the practice SIM exercise. It would be a good way to debrief after training to watch a video of it being done”*. It would be beneficial to assess if incorporating both technologies would be helpful in NRP training, particularly with healthcare professionals working in remote or rural areas where in-person training may be difficult to access. VR NRP training via VR simulation and 360° video could be offered as an adjunct to the in-person training as an additional resource for healthcare providers.

Besides NRP training, VR simulation can be adapted to other training and scenarios, such as cardiopulmonary resuscitation (CPR) training and advanced cardiovascular life support training (ACLS). For our study, we built the VR environment, comprising the room, the characters, the medical equipment and other medical aspects. The scenario and simulation can be easily modified for training CPR and ACLS in pediatric groups. Similarly, changing the baby to an adult can also be used for adult CPR and ACLS training. After modification of the VR environment, its effectiveness can be assessed in another future study involving healthcare professionals. This research shows that there is vast potential with VR technology, and how it can have a beneficial role and impact on healthcare education.

Chapter 8

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