

EXPLORING TECHNOLOGY TO TRAIN
POSITIVE PRESSURE VENTILATION IN
NEONATAL RESUSCITATION

by

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ABSTRACT

The healthcare industry is always looking for innovative ways to use technology in order to improve the experiences of their professionals and their patients. The improvements are welcomed in a variety of areas, from analyzing relevant health data to establishing new ways of delivering medical education and training. With advancements in Head-worn Display (HWD) technology such as the Microsoft Hololens, we must look into the feasibility of leveraging the technology to aid us in the ongoing challenge of creating these meaningful and educational experiences.

In this thesis, the *bag and mask* step in the Neonatal Resuscitation training is investigated. The bag and mask step is required to provide assisted ventilation through a face-mask [66]. We evaluate the efficiency and performance of using data from devices such as a Phidget sensor for air pressure data [40] and immersive technology such as the Microsoft Hololens to help provide users with useful feedback. Two studies were conducted to evaluate the potential of these technologies as well as the most effective method of delivering the feedback. Between four different stimuli: visual, audio, a combination of visual and audio, and the transition from visual and audio to audio-only, it was found that the visual stimuli resulted in the best performance in the timing of the bag compressions in both our studies with laypeople and medical professionals. Based on the results of the study, we also express the importance of having a proper seal between the mask and the baby in order to achieve the appropriate pressure during manual ventilation.

PUBLICATIONS

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ACRONYMS

API Application Programming Interface

AR Augmented Reality

HWD Head-worn Display

MRTK Mixed Reality Toolkit

NRP Neonatal Resuscitation Program

PPV Positive Pressure Ventilation

VR Virtual Reality

1 INTRODUCTION

This research investigates neonatal resuscitation training, and in particular, the *bag and mask* step of the procedure. The research looks into improving the performance of this intricate and precise procedural task which requires precision, by using various external body or device attached sensors to capture user activity and visually presenting the data on a mixed reality device. The *bag and mask* step of neonatal resuscitation is an important part of the procedure [66]. The steps required to perform the bag and mask procedure need to be followed accurately and efficiently. In this thesis, we explore if there is a significant difference in performance between different stimuli to deliver feedback by using data from a Phidget air pressure sensor [40] that attaches onto the bagging device. Subsequently, we plan to leverage a Augmented Reality (AR) HWD to provide the information to the user and observe the effects of using the HWD.

Procedural tasks such as positive pressure ventilation (Positive Pressure Ventilation (PPV)) (or the bag and mask step) require a set of step by step instructions in general. If the task at hand is complex, the instructions need to be simple in order to reduce the cognitive load. For example, medical procedures often require the task to be completed piecemeal so that the task can be completed successfully and, importantly, in a timely manner. Indeed, various medical procedures often consist of numerous complicated steps and, thus, are challenging. We believe that having

new technology, which allows users to 1) view crucial data, as well as 2) view the feedback of their performance while they are executing this procedural task, will enhance their task performance significantly. By using a modern wearable AR device such as the HoloLens, various types of useful/critical information can be provided consistently across multiple areas in an assistive information space. By leveraging the new HWD's spatial mapping and positional tracking technology, maintaining consistent positioning of the information space layout is achievable. Thus, by providing the user with essential information concerning their task (e.g., instruction) and supplementary data, it is potentially possible to reduce the users' cognitive load to facilitate their performance in-situ.

Based on the standard manual for the Neonatal Resuscitation Program: Textbook of Neonatal Resuscitation (Neonatal Resuscitation Program (NRP)), 7th Edition [66], we have reviewed and identified the essential elements for successful PPV and implemented a tool in order to gauge the performance of both non-healthcare professionals and healthcare professionals. The remainder of this thesis is structured as follows: In Chapter 2, we discuss the NRP, their current tools, and the importance of bag and mask ventilation. Within this chapter, we also provide background on the potential uses of the AR technology being used in this research. Chapter 3 provides an outline of the requirements to consider for the design of the studies and the apparatus used for the studies. In Chapter 4, we describe how we incorporated the requirements identified in Chapter 3 to modify the standard bag and mask, create the study environment, as well as design and implement the application. Chapter 5 and Chapter 6 presents a detailed description of the studies conducted by non-healthcare professionals and healthcare professionals, respectively. Additionally, the two chapters will also provide the analysis of the results. Chapter 7 provides a detailed comparison of the results found in the

previous two chapters as well as an exploration of the differences between the two groups. Finally, the work concludes with the summarized findings of this research, along with discussions of suggestions for future work.

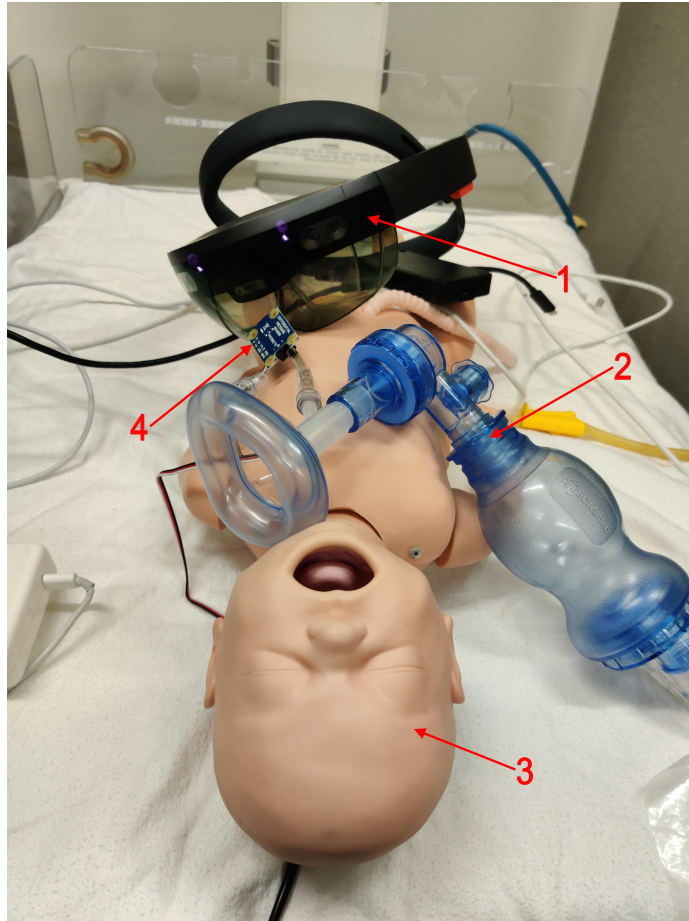


Figure 1.1: Equipment used for the research studies. 1. Hololens, 2. BOMIMed Disposable Ventilator, 3. eNasco Life/Form Newborn Simulator manikin, 4. Phidget gas sensor

2 RELATED LITERATURE

2.1 NEONATAL RESUSCITATION AND CURRENT TOOLS

An estimated 136 million babies born annually, with roughly ten million newborns requiring assistance to breathe, and six million of the affected newborns requiring basic bag and mask resuscitation [44, 51]. The bag and mask step is required to provide assisted ventilation through a face-mask [66]. Due to the importance of the bag and mask step of the procedure, it is critical that this step is performed accurately and efficiently [66]. It is crucial that while performing this step, one is able to deliver compressions at a steady rate and an appropriate pressure. Many adjustments can be made to the bag and mask step to improve its performance [16, 64]. One way to do so is to improve the training aspect of the procedure [72, 80].

Examples of current methodologies for neonatal resuscitation training range from basic scenario training (eg. following stepwise instructions in the textbook on a manikin) [66] to delivery-room simulations with full auditory/visual feedback [33]. Research done by Rubio et al. has also shown that in-situ simulation training can provide positive results in improving technical skills and teamwork in neonatal resuscitation [68]. Vonderer et al. [77] has shown that two minute training with self-inflating bags and the right equipment can improve the performance the bag and mask step, however, equipment measuring airflow such as the Florian

respiratory function monitor is not widely available. In this research, we investigate the use of easily accessible devices such as the Phidget sensors to measure the airflow.

The renewal of the neonatal resuscitation training and certification is required of healthcare professionals every two years, with a goal to ensure a certain standard of care when an infant requires resuscitation [22]. These skills have been shown to degrade within 3–6 months of training. We are unaware of methods that describe motivating frequent and persistent practice of the bag and mask skill. This research will look into using new technology in order to further improve the current training available and potentially provide more frequent training for the bag and mask step of the procedure.

2.2 THE IMPORTANCE OF BAG, MASKS, AND PPV

While the lives of many newborns depend on mechanically assisted ventilation, using mechanical ventilation is challenging, and it could possibly cause long term pulmonary complications such as volutrauma [1, 3, 4, 37, 38, 60]. Such risk associated with the use of mechanical ventilation is even higher in preterm infants. The majority of preterm babies are infants born at less than 28 weeks' gestational age, and are the most vulnerable, requiring PPV in the delivery room [29, 31]. The risk of mechanical ventilation results in a shift for maintaining neonates with more non-invasive ventilation methods such using face masks and a bag for manual compressions during PPV [79]. Weydig et al. suggest that with non-invasive ventilation being the preferred choice for low gestational age infants, the effectiveness of face mask PPV depends on the professional's ability to detect

and overcome mask leaks and airway obstructions [79]. In addition to leaks and obstructions, many factors must be considered throughout the entire [PPV] procedure. For instance, the professional conducting the procedure must be able to deliver the manual compressions at a steady rate, and at the recommended pressure in order to effectively ventilate the infant without causing harm [66]. The ability to actively consider and reflect on these factors properly comes with experience and proper, regular training.

2.3 SITUATED LEARNING

Situated learning is described as learning through scenarios embedded within the social and physical environment where the situation occurs [50, 62]. The concept of situated learning involves learning through activities rather than acquiring information through “discrete packages organized by instructors” [74]. Learning can be described as a matter of creating meaning through activities. By applying the situated learning theory, trainees are not only immersed in the activity, they are also able to reflect on their experience, which in turn, allows trainees to draw from their previous experiences to and refine their knowledge [74]. We investigate using the situated learning theory in order to immerse trainees in manual PPV. By providing feedback in real-time, we hope to allow trainees to actively assess and reflect on their experience with the procedure and solidify their performance. The use of situated learning or learning in-situ varies across disciplines. In Computer Science, the term in-situ, specifically in user interfaces, is primarily defined as continuously providing a user access to relevant information in various locations and contexts [25–28]. In the medical field, in-situ training often takes place on-site

and uses real scenarios in order to train the professionals in question[70, 76]. This research will look at testing different forms of providing feedback to users while they are training in-situ. We provide users with the relevant information of their performance in real-time while using equipment that is commonly used in PPV, however, users will not be trained in real scenarios with real newborns. Thus, for this work, in-situ will be in the context of the definition agreed upon in the field of Computer Science.

2.4 SKILL RETENTION

With regards to skill retention, an important topic of discussion has long been the performance quality of practical skills such as manual ventilation over time. Within neonatal resuscitation, evaluations have shown that although general knowledge can be retained, the proficiency of the skills deteriorate over time indicating that proficiency in knowledge may not be related to the quality of the skill [24, 42, 65, 73]. Simulation training has been shown to improve the performance in neonatal resuscitation by giving healthcare professionals practice with training scenarios that can occur during birth, however, performance still degrades over time without the proper refresher training [13, 59].

2.5 AUGMENTED REALITY AS A TOOL

AR systems are defined as systems that enable real time interactions with virtual and real objects that coexist in the same space [6]. AR systems come in many different forms such as head-worn displays, projections, and mobile devices that

allow virtual objects to be viewed within the context of the real world. Unlike Virtual Reality (VR), AR allows for a digital experience in a real environment rather than a fully virtual environment. For decades, researchers have observed the great potential of using AR to enhance certain aspects in fields such as geographic studies [78], data science [82], education [46], and health. In some cases, interactions within an AR environment are more advantageous than those in the VR environment [47]. Bower et al. [11] highlight the usage of mobile phones and tablets to overlay media onto the real world in order to make information available to students when they need it, on the spot. Bower et al. discuss the potential reduction of cognitive overload by providing students real time information. AR has also been used within the healthcare field, specifically the medical field, where it is used for training in various medical tasks and procedures (as described in Section 2.6).

The research uses HWDs such as the Microsoft Hololens [58] (see Figure 2.1), a new headset that enables users to interact with virtual objects in the real world. Combined with the concept of situated learning, where Brown et al. suggest that learning should take place in the context of realistic settings [15], the Hololens may have an effect in providing users with the necessary information required during training in-situ. By providing users with additional information when they perform procedural tasks such as the bag and mask step, they are given the necessary feedback to enable them to adjust their execution in order to potentially improve their performance. This has been shown, in turn, to allow users to learn in an authentic context [19, 55]. In recent years, a plethora of research in AR has become a cycle and blend of outlining potentials, addressing issues at the time, and a survey of the state of AR. Zhong et al. [83] and Boulanger et al. [10] outline the potential in using AR in industrial training. Bower et al. [11] look into applications in education and their potential to improve learning in schools. In the healthcare

industry, researchers such as Barsom et al. [7], Chan et al. [17], Chen et al. [18], and Okamoto et al. [61] evaluated AR's potential in surgery and medical training. However, many of the works outlining potentials do not both develop as well as evaluate the application leading to inconclusive results.

2.6 SIMULATIONS USING AUGMENTED REALITY

In 2016, Barsom et al. [7] detailed the effectiveness of AR applications in medical training. These applications are used to blend virtual and digital elements with a physical environment in order to introduce new educational opportunities for medical professionals. Barsom et al. reviewed seven applications over twenty-six studies and concluded that although these promising applications are generating public as well as scientific interest, they are lacking evidence in the literature that the applications are able to transfer information to the user.

In recent years, researchers have investigated the use of AR in order to improve surgical navigation. Both Okamoto et al. [61] and Chen et al. [18] developed AR-based simulations with the aim to improve the safety and reliability of surgery. Okamoto et al. developed an application for navigational surgery in the abdominal field. Their system leverages a see-through display and a rigid scope that enables the surgeons to obtain a 3D view. Through their study, they were able to identify several problems such as organ deformity, evaluation of utility, portability and cost. In the same year, Chen et al. leveraged a head-worn display and created an application that was tested against actual patient structure data in a real world scenario. They verified and demonstrated that the accuracy of their application was sufficient to meet clinical requirements. However, this is so far only true with

a simulated environment. Within the same area of study, Pratt et al. [67] looked at the use of the HoloLens in order to provide a means of bringing a new level of precision, and planning into reconstructive surgery. Through preliminary studies, the authors were able to demonstrate that using the HWD could help with the precise localization of perforating vessels. Hanna et al. [34] have also showed that the HoloLens has the sufficient power and comfort to be useful in facilitating autopsies, microscopic examinations, and digital pathology. With positive results in previous studies, we hope to leverage the benefits of using AR to provide relevant feedback for users to assess and adjust while performing their task.

2.7 GAMIFICATION OF TRAINING

Serious games or applications that provide a certain level of learning through games are an emerging field of study within the health field. Gamification can be described as a method of applying the typical elements of game playing, such as scoring systems and competitive leaderboards, to other areas [56]. MacKinnon et al. [56] has found that gamification can improve infant CPR performance. Their motivation to explore the use of competition as a gamification technique stems from the lack of methods to "motivate frequent and persistent CPR practice". By using the ventilation and compression scores calculated from a Laerdal Infant QCPR manikin [49], the authors created a leaderboard system to motivate competitive behaviour and motivate frequent use to improve on their performance and achieve a higher score. In this work, we create our own system using a common resuscitator found in healthcare facilities with modifications to detect pressure.



(a) Feiner's window system with an HWDs in 1993 [30]. The large black cube and white triangle are the transmitters for two 3D tracking systems. Tracker receivers are on the head-mounted display, waist, and wrist. (Adopted from [30]. Permission received.)



(b) Microsoft HoloLens - One of the latest HWDs released. It requires no external component and all the sensors are implemented with the device.

Figure 2.1: A comparison of HWDs systems in the 90s vs. today

The use of serious games has also been looked at to teach medical students a variety of situations. For instance, work has been done in areas such as decision making in team situations [12, 36, 75, 81], surgery [20, 21], and various triage assessment scenarios [2, 8, 39, 45, 48]. Bergeron [8] also suggests that serious games can improve skill retention. However, Kaczmarczyk et al. [43] have reported that further empirical research is required to assess the added value of gamifying medical training.

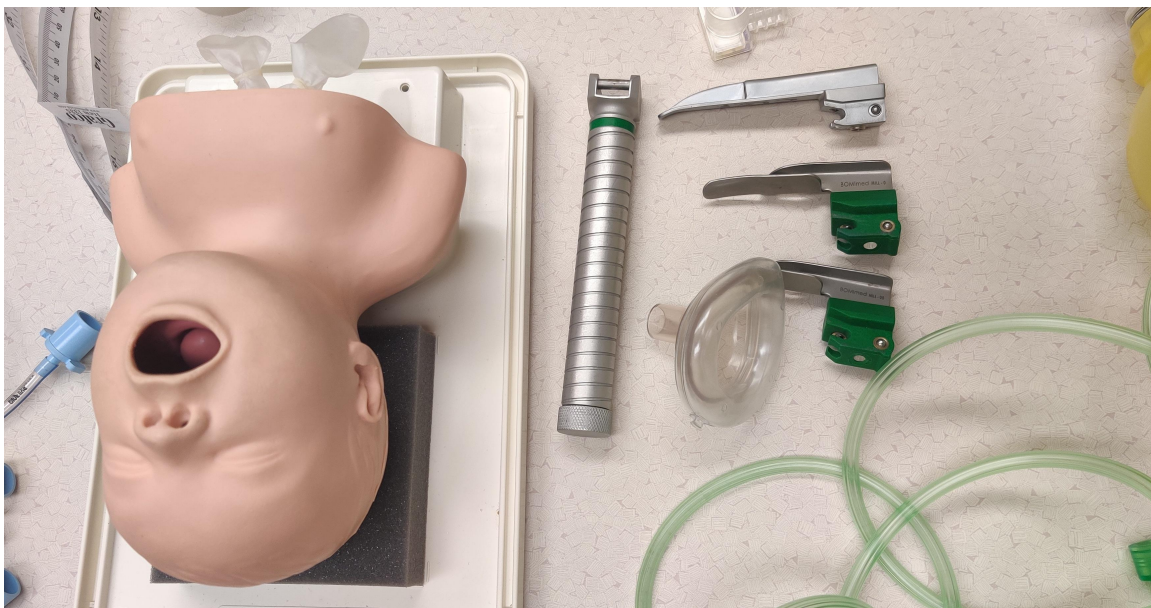


Figure 2.2: Tools for NRP Intubation Training at University of Manitoba

3 CHARACTERISTICS OF PPV FOR STUDY DESIGN

In this chapter, the critical requirements for successful PPV are laid out based on the literature and the Canadian Paediatric Society's standard textbook used for their [NRP](#) [66]. Moreover, this chapter will outline aspects from the textbook used in order to design the studies conducted as well as the equipment used in these studies.

3.1 DEFINING APPLICATION REQUIREMENTS

Based on the literature, we outline aspects of [PPV](#) that define the requirements of the application used for the study. In order to simulate [PPV](#), chapter 4 of the [NRP](#) textbook [66] presents the standards of [PPV](#).

- Positioning: Proper positioning of the baby's head is required for effective mask ventilation. Incorrect positioning will obstruct the airway.
- Mask: There are a variety of mask sizes available. Selecting the correct mask will create a tight seal on the baby's face preventing air leaks.
- Pressure: Achieving the correct pressure is significant during [PPV](#). If the pressure of the compression is low, it may not be enough to inflate the lungs; however, if the pressure is too high, it may burst the lungs of the newborn.

- Timing and Rhythm: The timing of the bag compressions is also important for an effective PPV.

These requirements were the crux of designing and implementing the studies.

3.2 SELECTION OF THE RESUSCITATOR

For this research, we used a RespondPro Manual Resuscitator, a self-inflating bag, manufactured by BOMIMed (see [Figure 3.1](#)). This disposable bag is standard in most hospitals and was used for this study [66]. This bag is made specifically for infants and has a maximum pressure of 40 cmH₂O. Furthermore, the mask selected for this experiment was a teardrop-shaped mask that came with the bag; this fit the manikin used for the studies conducted.

3.3 MODIFICATIONS TO THE RESUSCITATOR

A T-piece was attached to the tube where the mask would be placed before the mask was attached. The t-piece was added in order to attach a small tube with a gas sensor Phidget (P/N 1139 - [Figure 3.2](#)) [40] to the t-piece to measure the compression pressure for the study (see [Figure 1.1](#)). Unnecessary tubing attached to the back to the resuscitator was cut off in order to reduce clutter and interference when being used.



Figure 3.1: Self-inflating bag by BOMIMed

3.4 BABY MANIKIN FOR RESUSCITATING

The manikin used for this research was an older version of the eNasco Life/Form Newborn Simulator manikin ([Figure 3.3](#)). The manikin would be placed on a bed, as described in the textbook during the study. This manikin was not modified; all modifications for measurements in this research were made on the resuscitator.

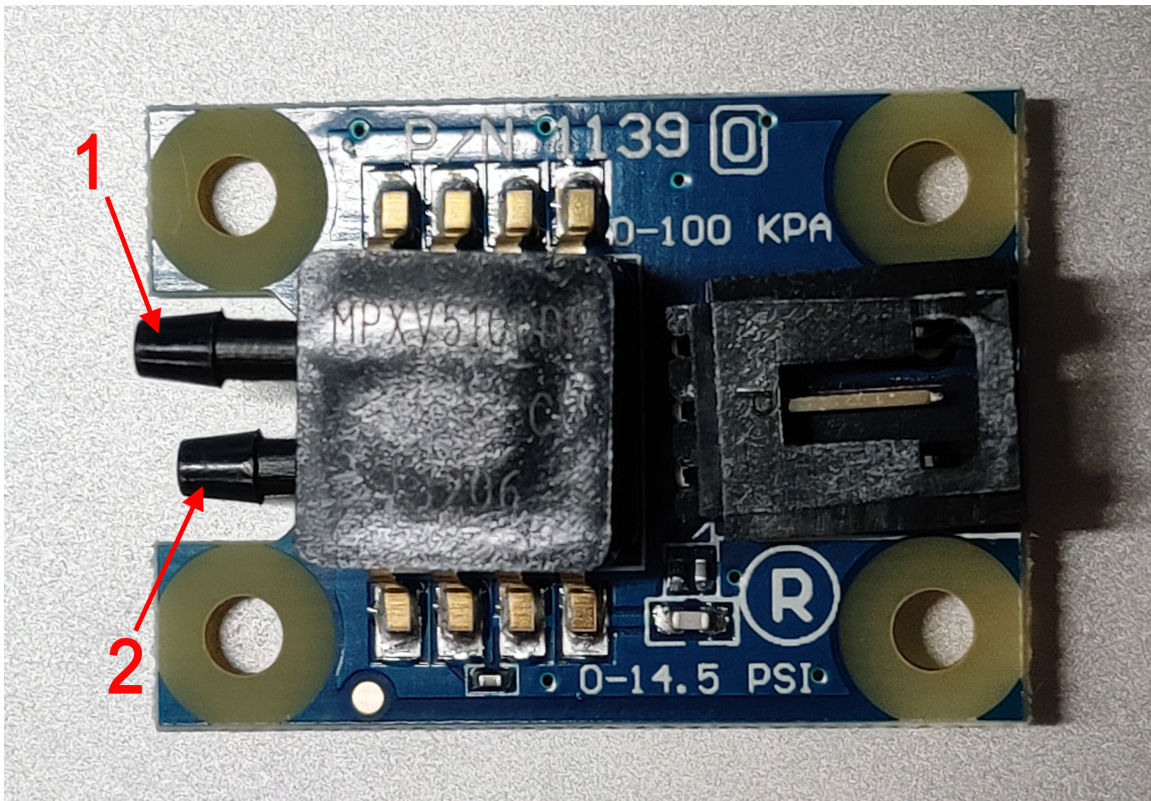


Figure 3.2: Phidget sensor P/N 1139: 0 - 100 kPa gas sensor. The difference in pressure is measured by the tubes labeled 1 and 2

3.5 HEAD-WORN DISPLAY

The potential of [AR HWDs](#) is explored in this research. The motivation to use a [AR](#) device was to create a training simulator that was portable and can be used anywhere. [HWDs](#) can display essential data and information in a virtual space. Moreover, information divided among multiple screens and monitors can be compiled and displayed virtually on the [HWD](#), eliminating the need for those monitors and allowing for portable experiences that still provide the necessary information.

There are many [HWDs](#) to choose from with regards to displaying information; however, the hardware that stood out as the best choice was Microsoft's HoloLens



Figure 3.3: Life/Form Newborn Simulator manikin

[58]. At the start of this research, the first generation Hololens was the best selection in terms of augmented reality experience. The Hololens has one of the largest fields of view available for AR devices; this allows for a larger viewing area to display potential information.

4 DESIGN AND IMPLEMENTATION

With the characteristics and the requirements identified, an application that simulated the compression aspects of the PPV step of neonatal resuscitation was designed and implemented. In this chapter, the application, the environment, and the tools used will be described in full details. This study was run twice using the same apparatus in very similar environments.

4.1 OVERVIEW

The design of this study investigates not only the potential effectiveness of the simulated training but also the most effective method of delivering feedback. In this research, we look into using visual, audio, and the combination of the two stimuli as conditions for delivering necessary information and feedback to the user. The conditions are as follows and fully described in [Section 4.4](#): Visual, Audio, Visual+Audio, Visual+Audio -> Audio. All four conditions were tested in the first study, and the two most interesting and effective conditions were tested in a follow-up study with health professionals such as Neonatologists, Residents, Attendings, Nurses, and Respiratory Therapists. Within all of the conditions, we analyzed variables determined by the characteristics of PPV.

4.2 RESEARCH QUESTIONS

Several research questions were created to drive the focus of the research and explore the value of this training. The questions are as follows:

- RQ1: Is there a difference between learning with visual stimuli versus learning with audio stimuli?
- RQ2: Are participants able to perform the procedure given the specific instructions?
- RQ3: How does one compare the performance of participants?

4.3 CHARACTERISTICS TO IMPLEMENTATION

As noted in [Chapter 2](#), using games for training, specifically medical training, is a relatively new area of research. Mackinnon et al. [56] have found improved performance for infant CPR through the gamification of the procedure.

Our research game's design and implementation took into account the [PPV](#) procedure outlined in the standard manual [66]. These were the characteristics that heavily influenced the overall design [66]:

- Timing: The rate of bag compressions is 40 breaths per minute. Indeed, the PPV procedure and instructions are much more complicated, however, this research focuses on achieving the correct rate during sessions of compressions.
- Pressure: The target pressure for initial PPV is 20 to 25 cmH₂O. Using the Phidget device attached to the ventilator as explained in the previous section,

the device, in Pascals (Pa), can measure the pressure of the airflow coming from the compressions. By converting cmH₂O to Pascals, our target pressure for the implementation was 1961 to 2452 Pa.

In summary, one must achieve the correct timing at the correct pressure with each compression to be effective at PPV.

4.3.1 *Task Implementation*

The task required two applications. The first application captured the data coming from the Phidget and sent it out through a network. The second application was the game created for the Hololens. The game we created for this tool used the data communicated from the Phidget application to play.

The data from the Phidget was captured using the Phidget's C# Application Programming Interface ([API](#)). For both studies conducted, the Phidget attached to the ventilator was connected to a Macbook Pro 15" Late 2016 model via a USB Hub and then sent to the Hololens through a local network. The Phidget data capturing application is also Windows compatible. The server/client implementation was developed using the NetCoreServer library [[71](#)], and the local network consisted of a standalone wireless router that was not connected to the internet. This setup and implementation ensured lower latency and no potential for interference from other devices. Furthermore, the only devices connected to that router were the laptop and the Hololens.

The game was first implemented using Unity 2017.4.12f1 as a desktop application and then ported over to the Hololens using the Mixed Reality Toolkit ([MRTK](#)) developed by Microsoft. No interaction with the Hololens was necessary during

the studies. The application was controlled using the ventilator, minimizing the learning time required for the experimental part of the research. The Hololens allowed us to test all the stimuli we were interested in for this research.

4.4 STIMULI

For this research, we observe the effectiveness of different methods of delivering the feedback required to achieve the objectives. For the first study, we tested four conditions with non-healthcare professionals, and the two most interesting and significant stimuli were chosen and tested with health professionals such as respiratory therapists, nurses, and different types of doctors. The four stimuli presented are the following:

- Visual: Feedback was given via the game's visuals, allowing participants to see the targets and how they can adjust based on the position of the target.
- Audio: Feedback was given via the game's audio, allowing participants to hear sounds signaling when to compress and how they can adjust based on the audio feedback given following a compression. All the audio feedback used came from a collection of royalty-free sounds found on freesounds.org [5].
- Visual and Audio: Participants received both stimuli; they were able to see the game's visual as well as hear the game's audio feedback.
- Visual and Audio -> Audio (VATransition): Participants receive both the audio and the visual feedback; however, midway through the experiment,

the visual feedback was removed, and the participants continued with only the audio stimulus.

4.5 STUDY PROCEDURE

A research assistant conducted both studies. For all studies to be consistent, the research assistant used a script. The script included steps such as reviewing the consent form, the task, and a video tutorial on how to use the ventilator. For the audio conditions, the research assistant running the study played the audio feedback for the participants, explaining the meaning of each sound. Once the experiment was complete, the research assistant administered Ishihara's colour vision deficiency test [41] and a questionnaire. Finally, the participant was debriefed and thanked for their time. This research (HS20973: J2017062) was approved by the Joint-Faculty Research Ethics Board.

5 STUDY 1 - LAYPEOPLE

In this chapter, we discuss the application of the study methodology from the previous chapter in detail. This study consisted of all four conditions described in the last section: Visual, Audio, Visual+Audio, and VATransition. We conducted the experiment with non-healthcare professionals from the non-medical campus of the University of Manitoba.

5.1 ENVIRONMENT

In an attempt to maintain a higher level of mundane realism, the Dräger Air-Shields IICS-90 [23], a type of bed warmer currently used in actual settings, was used in this study. The functions of this warmer included: a heater, extra lighting, and the ability to increase or decrease the height of the bed. Space dividers were placed on each side of the bed to avoid any distractions in the area and allow the participant to focus on the task at hand. The GoPro was attached to one of the warmer's removable panels (i.e., left panel in [Figure 5.1](#)). Furthermore, as described in [Chapter 4](#), a standalone wireless router was used on a local network to ensure the least amount of interference when the devices were communicating.



Figure 5.1: Study 1 - Experimental Setting

5.2 PARTICIPANTS

Forty-one participants (fifteen females) were recruited through posters posted around the University of Manitoba Fort Garry campus. One participant (female) began but was not able to complete the study. Subjects' ages ranged from 18 to 49 years old ($M = 25.43$, $SD = 6.70$). Experience with medical procedures was not necessary to participate in this study. A tutorial given by a professional was shown before the study. Furthermore, experience with HWDs was not necessary; the participants controlled what they saw on the HWD with the ventilator. Each session took up to 45 minutes, and participants were given a \$15 gift card for their time.

5.3 TASK AND STIMULI

5.3.1 *Task*

The task consisted of twenty trials of twenty compressions, each where the participant had to attempt to squeeze the ventilator with the correct timing at the right pressure. The implementation based the timing of the compressions on the rhythm taught in the textbook [66]: "...*breath, two, three, breath, two, three,...*", therefore, each compression is approximately 2.5 seconds apart. Additionally, twenty compressions were given per trial to simulate 40-60 breaths per minute. Participants were also required to take a one minute break after every five trials for a total of three breaks altogether. These breaks allowed the participants to rest their hands as the task can cause fatigue. The task is the same through all the conditions. All participants were required to stand during the trials, however, they were able to sit down during their one minute rest period. Before each trial, a menu screen (Figure 5.2) is displayed with potentially useful information such as a reminder of the target values, the current trial, and the summary of the last trial. Moreover, a cooldown timer is given to time the participants' breaks.

5.3.2 *Stimuli*

There were two stimuli used across four different conditions in this study.



Figure 5.2: The menu screen shown prior to every trial. Compressing the ventilator controls the application.

5.3.2.1 Visual Stimuli

Participants who had the visual stimuli (visual, visual+audio, VATransition), saw a two-dimensional 8-bit fox run across a platform (see [Figure 5.3](#)). Every 2.5 seconds, a target in the form of a wooden crate spawned, and the objective was to compress the ventilator to make the fox jump and hit the target.

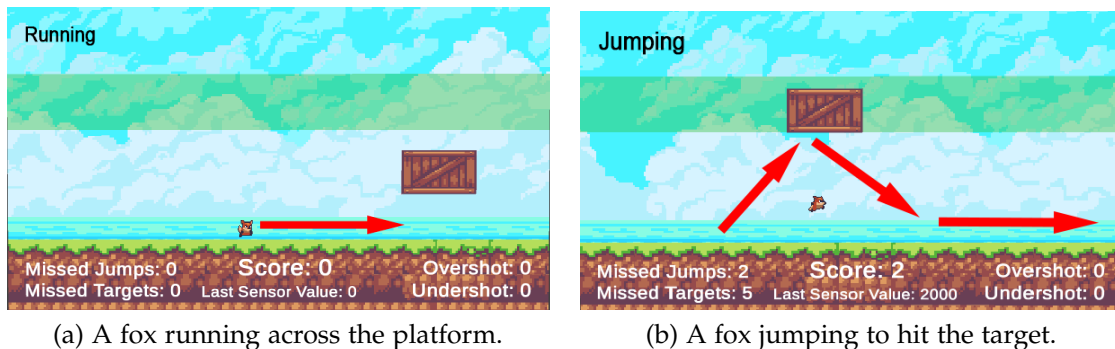


Figure 5.3: Basic movement concepts of the application

The height of the target depended on the amount of pressure exerted on the ventilator. A green area was shown in the game to identify the target range of the pressure. Anything over or under the green space was an over-shot or an under-shot, respectively. Participants saw a scoreboard that gave the score, the number of over-shots, the number of under-shots, missed targets, and the previous compression's pressure. The scoreboard allowed the participants to adjust continuously based on their performance (Figure 5.4).

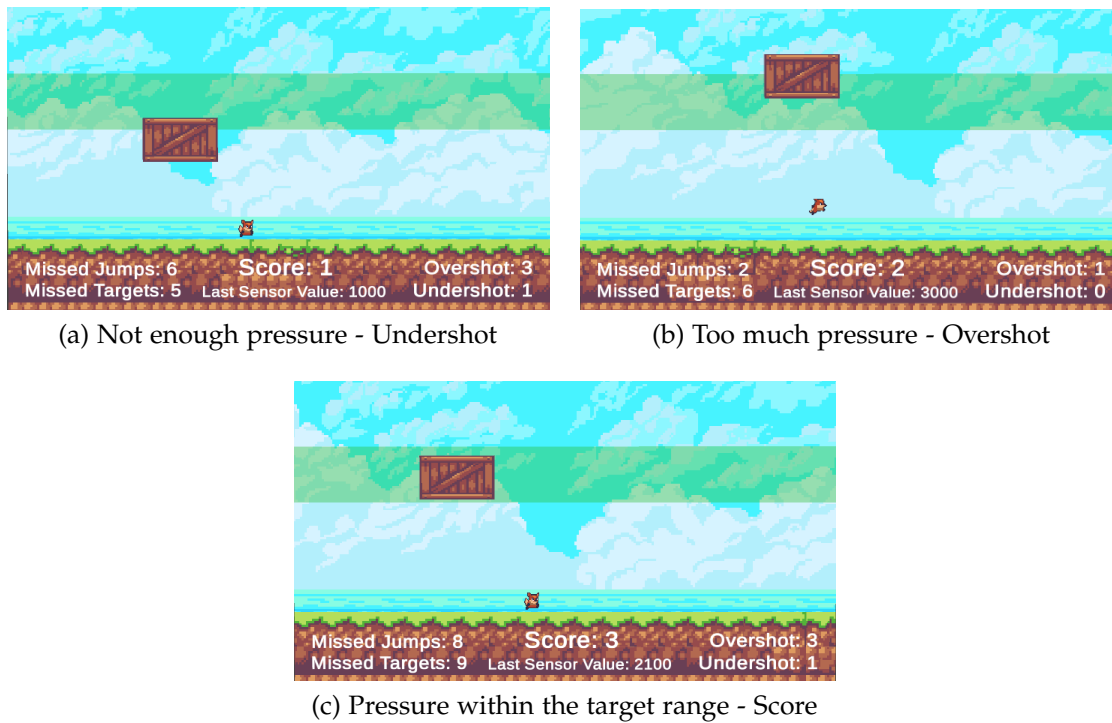


Figure 5.4: Possible outcomes when compression timing is correct

5.3.2.2 Audio Stimuli

The audio stimuli consisted of the same task; however, the participants did not have any visual feedback other than the information shown on the scoreboard. All of the mechanics of the visual stimuli were also associated with audio feedback. The



Figure 5.5: The audio stimuli: a score board view with sound cues playing through the HoloLens.

game visuals were running in the background, however, the visual was blocked by a mask (see [Figure 5.5](#)) for the audio and the VATransition condition. [Table 5.1](#) outlines the cues and signals used for the game.

These audio cues were chosen based on discussions with advisors for this application. The sounds had to be carefully selected to be effective. When the participant scores, the tone must sound rewarding. However, negative tones must sound like alerts to inform the participant to make adjustments. Neutral tones such as the jump signal must be clear and not rush the participant into compressing the bag. Before the experiment, participants were able to hear and familiarize themselves with the sounds through a simple soundboard web application ([Figure 5.6](#)).

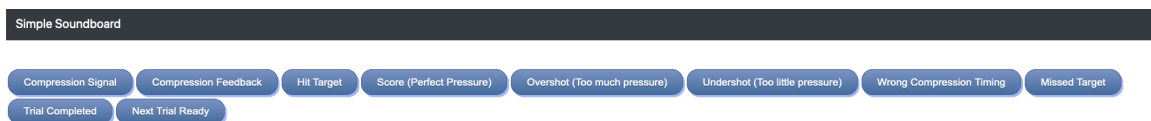


Figure 5.6: The simple soundboard used to play tones for participants

SOUND	DESCRIPTION
Compression Signal [52]	The signal played right before a compression.
Overshot Feedback [69]	The sound played when a participant delivers too much pressure
Undershot Feedback [57]	The sound played when a participant delivers too little pressure
Score [53]	The sound played when the participant achieves the correct pressure and hit the target.
Missed Target [85]	When the target leaves the game, this sound is played.
Missed Compression [85]	Plays when the participant compresses the ventilator and does not hit anything.
Target Hit [84]	Sound plays when the compression timing is correct, followed by the feedback
Trial Completed Sound [54]	Plays when the trial is completed.

Table 5.1: Sound files used for stimuli

5.3.2.3 Visual and Audio / VATransition

The rest of the conditions were a combination of the two stimuli. In the Visual and Audio condition, participants were exposed to both the visual aspect of the game and the associated audio. VATransition took the combination one step further by masking the game after the first half of the study, leaving only the audio feedback. Participants had exposure to both stimuli at the beginning, and then they had to rely on just the audio cues for the second half of the study.

For this study, we looked at all stimuli and their combinations for our conditions. Before each study, the participants were able to adjust the height of the warmer to a comfortable level. This experimental design can be summarized as:

10 participants per condition x
 4 conditions (Visual, Audio, Visual+Audio, VATransition) x
 20 trials per condition x
 20 compressions
 = 16000 total compressions.

5.3.3 *Instructional Video - PPV*

Once the participants claimed they understood the task at hand, the research assistant played the instructional video [Figure 5.7](#) for PPV. The video played featured an experienced respiratory therapist from the Health Sciences Centre in Winnipeg performing the procedure. The videos were recorded using a 48-megapixel camera on the OnePlus 7 Pro smartphone [\[63\]](#) and then cut together using Adobe Premiere CS6. The video's instructional voice-over, based on the Neonatal Resuscitation Program training sessions, was recorded using a Bluemic Snowball [\[9\]](#).

5.3.4 *Experimental Environment*

The subsequent chapters ([Chapter 5](#), [Chapter 6](#)) describe the experimental space in more detail as the environments themselves have some differences. However, the apparatus used, specifically the application and technology used, were the same.

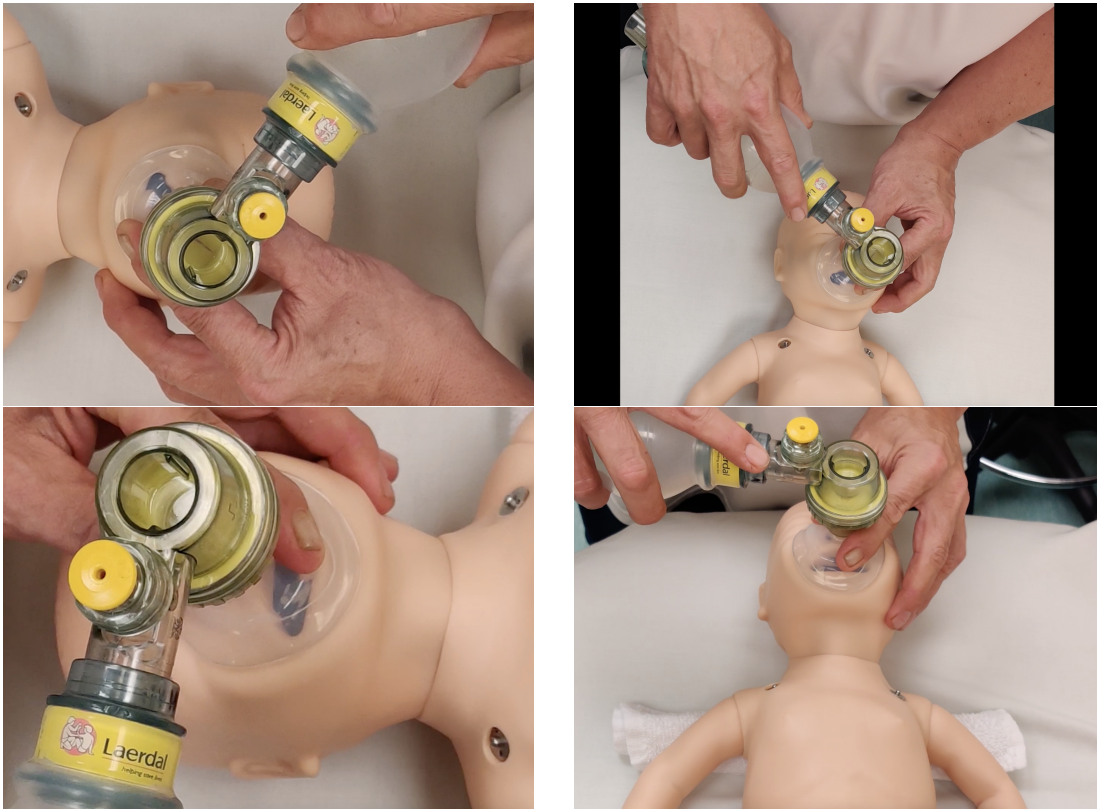


Figure 5.7: Frames from the instructional video of the demonstration done by an experienced respiratory therapist.

Both studies were recorded using a GoPro Hero 3+ [32] mounted on a modified stand that was attached to an infant bed warmer that kept the camera constantly charged. The recordings captured featured the participant performing the PPV procedure without any identifying features of the participant (see Figure 5.8). Moreover, both studies used the same setup as described in Section 4.3.

5.3.5 Post-Study

Upon completion of the study, each participant was asked to take an online version of Ishihara's colour vision deficiency test [41]. The research assistant also

administered a general questionnaire, which included general demographics as well as a combination of questions from the System Usability Scale [14] and the NASA Task Load Index [35] about the overall system. The Ishihara test provided insight on a potential usability issue while using the Hololens, rather than diagnose the participant. The participant was then debriefed, thanked, and given a \$15 gift card for their time.

5.4 RESULTS

In this section, the results are organized by; 1) compression timing, 2) pressure performance, and 3) score. Out of the twenty trials, trials 1 to 10 were removed from the analysis. The exclusion was due to participants in the VATransition condition having both stimuli in the first half of the study, with one stimulus being removed for the second half. At the 11th trial, the game masked the visual stimuli, thus, leaving only the audio stimuli.

5.4.1 *Compression Timing*

First, the compression timing component of the participants' performance was investigated. Prior to the statistical analysis, we created a visualization of the data to observe potential trends (see [Figure 5.9](#)).

Some interesting observations derived from the visualizations include:

- Although the audio condition resulted in, on average, the poorest performance as seen in [Figure 5.10](#), we can observe a potential learning effect as the performance is seen to improve as the study continues.

- A drop in performance can be observed in the VATransition (see [Figure 5.13](#)) condition at trial 11. This drop was expected as the Visual stimuli are removed, leaving the participants to rely on the Audio stimuli for the feedback. Interestingly, the performance improves up to the 16th trial and degrades during the remaining trials.
- Both Visual ([Figure 5.11](#)) and Visual+Audio ([Figure 5.12](#)) conditions have similar results, as participants also seem to perform better than during the Audio and the VATransition conditions.

These observations were investigated further by conducting a Kruskal-Wallis test and a Mann-Whitney U test with the application of the Holm-Bonferroni method to accommodate for potential Type 1 errors.

The Kruskal-Wallis Test found a condition effect: $\chi^2(\text{Visual+Audio}) = 11.64, p = 0.009$, with a mean rank accuracy scores of 29.35, 23.30, 16.25, and 13.10 for the Visual, Visual and Audio, Audio, and VATransition conditions, respectively. Subsequently, Mann-Whitney U tests were conducted to identify where the difference occurred. The Holm-Bonferroni method was applied to control for the probability of false rejections when analyzing multiple comparisons. As the alternative to Bonferroni's correction, where a consistent threshold is applied, Holm-Bonferroni's method progressively adapts the threshold in which hypotheses are rejected based on the ranks of the mean scores of the comparisons.

These tests found that the Visual condition was significantly better than both the Audio and the VATransition conditions. Between the Visual and the Audio condition, the test found the following effect: $U = 15.00, p = .007$, (Visual mean rank: 14.00, Audio mean rank: = 7.00) — Holm-Bonferroni $\alpha = .00831$. In the case of Visual and VATransition, the tests found the following effect: $U = 16.00, p = .009$,

(Visual Mean rank: 14.00, VATransition Mean rank: = 7.00) — Holm-Bonferroni α = .01. There were no other significant effects found.

5.4.2 *Pressure Performance*

Next, pressure accuracy was investigated as part of the participants' performance. This analysis examined the number of compressions with the correct pressures, regardless of the exact timing. A graphical representation was created and no interesting observations or trends with regards to pressure accuracy were found.

This component was normally distributed with homogeneity; therefore, ANOVA was conducted. No effect was found across all conditions.

5.4.3 *Score*

Finally, the score component was investigated. Participants received a point towards their score if their pressure was correct *and* their timing was correct. A visualization of the scores ([Figure 5.15](#)) across all conditions shows us similar trends as those observed in the results of the compression timing. The Audio condition improved over time (first row), whereas the VATransition condition appeared to decline (second row).

The Kruskal-Wallis Test found a significant effect: $\chi^2(\text{Visual+Audio}) = 10.61$, $p = 0.014$. Mann-Whitney U tests were further conducted to follow up. Two significant effects emerged. The first, between the Visual (mean rank = 13.80) and the VATransition condition (mean rank = 7.20), the test found $p = 0.006$ — Holm-Bonferroni $\alpha = 0.01$. The second, between the Visual+Audio condition (mean

rank = 14.00) and the VATransition condition (mean rank = 7.00), the test found $p = 0.006$,— Holm-Bonferroni $\alpha = 0.008$. This means that both the Visual and the Visual+Audio conditions performed better than the VATransition in terms of score. No other effects were found.

5.4.4 *Pressure Accuracy vs. Compression Timing*

To investigate the results further, a Wilcoxon Signed Ranks Test was conducted to investigate which task between achieving the correct pressure or the correct timing was more challenging to control. With $Z = -5.44$, $p < 0.001$, the medians for pressure and time were calculated at 0.13 and 0.62 respectively, therefore, it can be concluded that controlling the pressure was significantly more difficult than controlling the timing.

5.4.5 *Discussion*

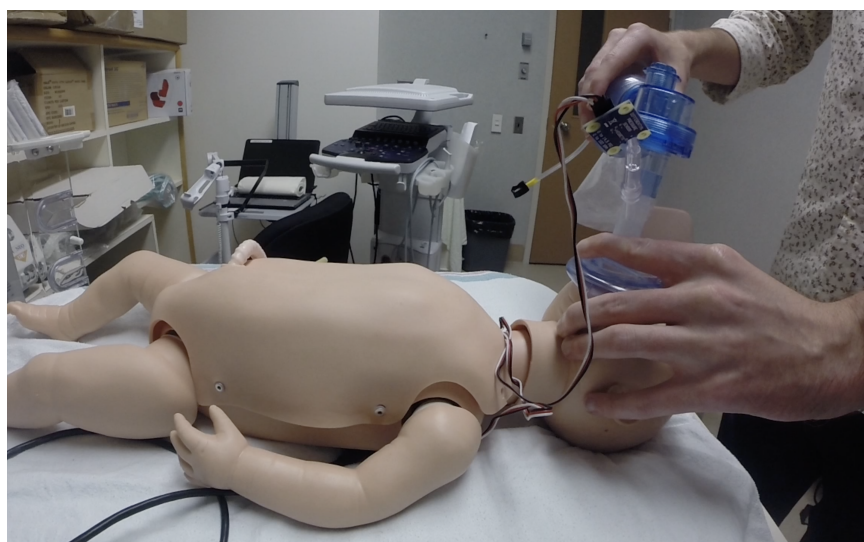
The lack of condition effect in pressure accuracy was surprising. Thus, an investigation was conducted to look for potential causes. Upon analyzing the data, there were many missing values found. The missing data occurred when no pressure value was recorded. Out of the 16000 total compressions, 3303 values were missing (20.64%). No pressure values are recorded when the Phidget sensor does not capture any pressure when the bag is compressed.

5.4.5.1 *Proper Mask Seal*

Indeed, the results of this study present us with the issue of having the proper seal. One of the core characteristics of PPV outlined in [Chapter 3](#) is having the appropriate mask as well as ensuring a secure and reliable seal between the face of the baby and the mask. For all of the participants in this study, this was their first time exposed to performing PPV on a baby; thus, they may not have the necessary experience to know when there is a leak in their seal. Due to the potential lack of awareness with regards to mask leaks, we planned a study with health professionals to validate the results of the first study. Furthermore, we compared both the laypeople and expert groups.



(a) Example of the environment at the University of Manitoba - Fort Garry Campus.



(b) Example of the environment at the Health Sciences Centre - Neonatal Intensive Care Unit

Figure 5.8: Frames from the GoPro recordings.

Average Target Hits vs. Trial Number By Condition (Ft. Garry)

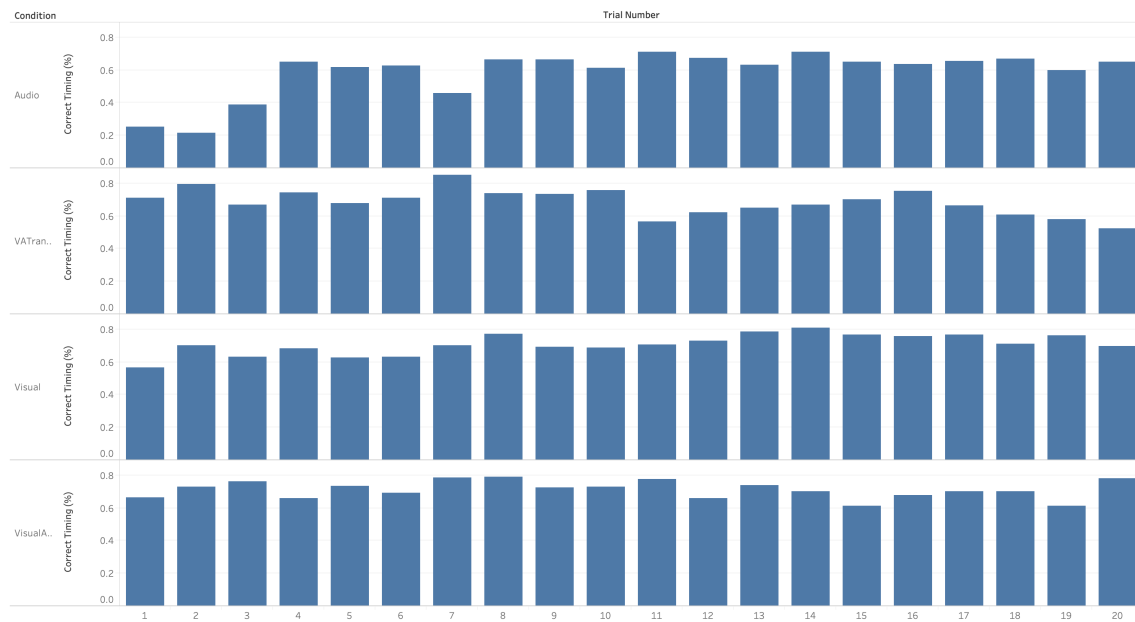


Figure 5.9: Overview of Compression Timing Accuracy in Each Condition

Average Target Hits vs. Trial Number By Condition (Ft. Garry)

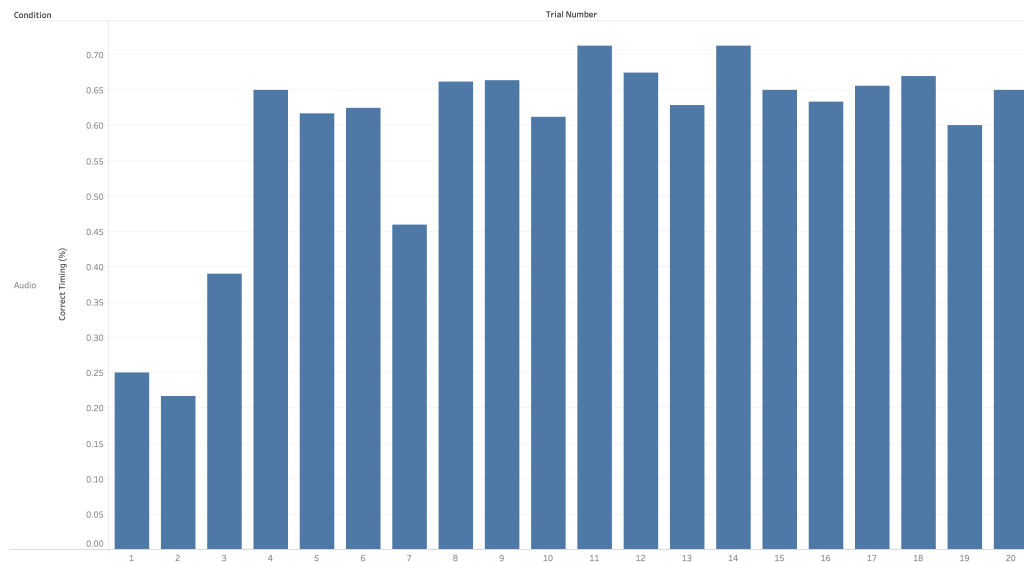


Figure 5.10: Results of Compression Timing - Audio Condition

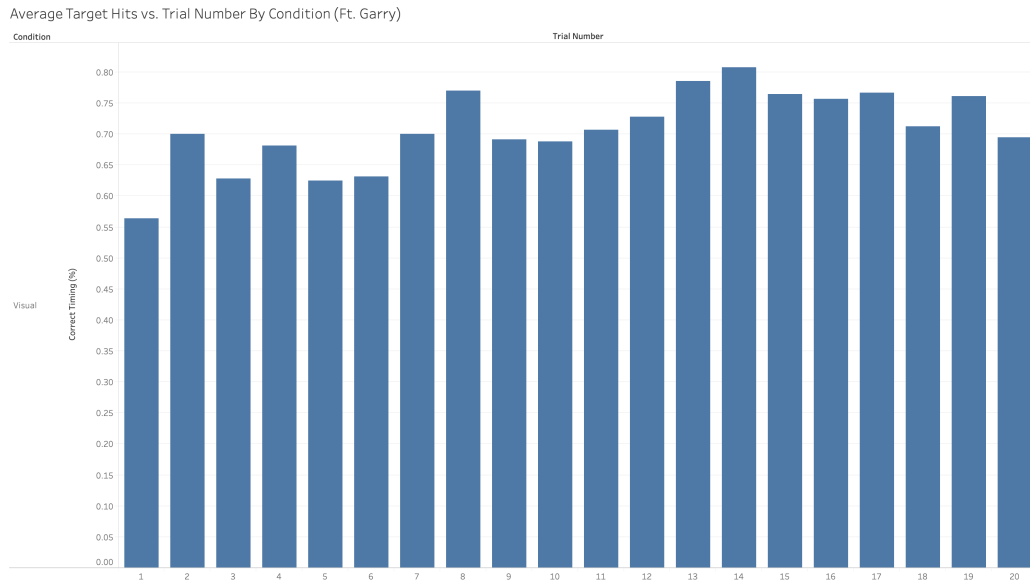


Figure 5.11: Results of Compression Timing - Visual Condition

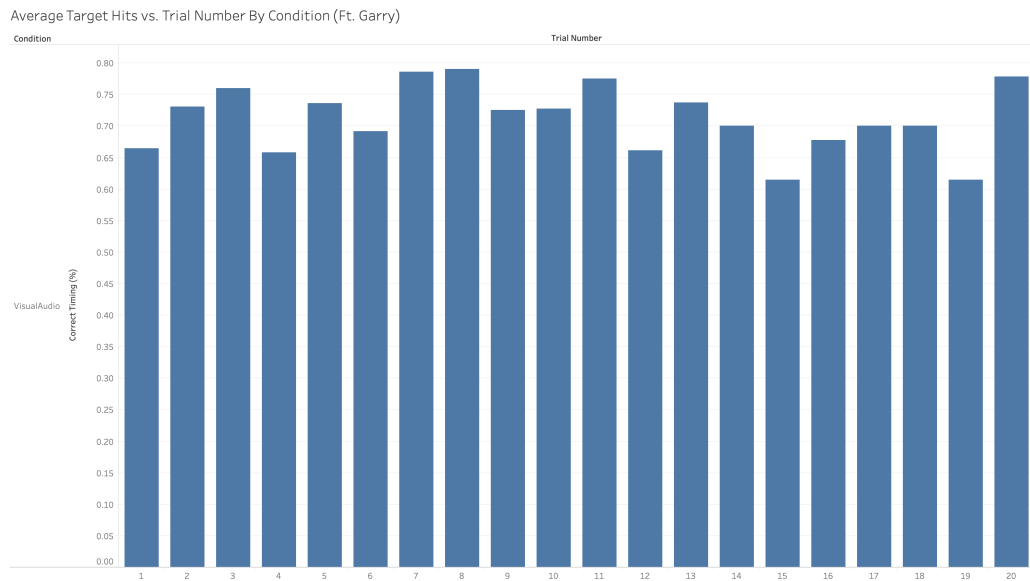


Figure 5.12: Results of Compression Timing - Visual+Audio Condition

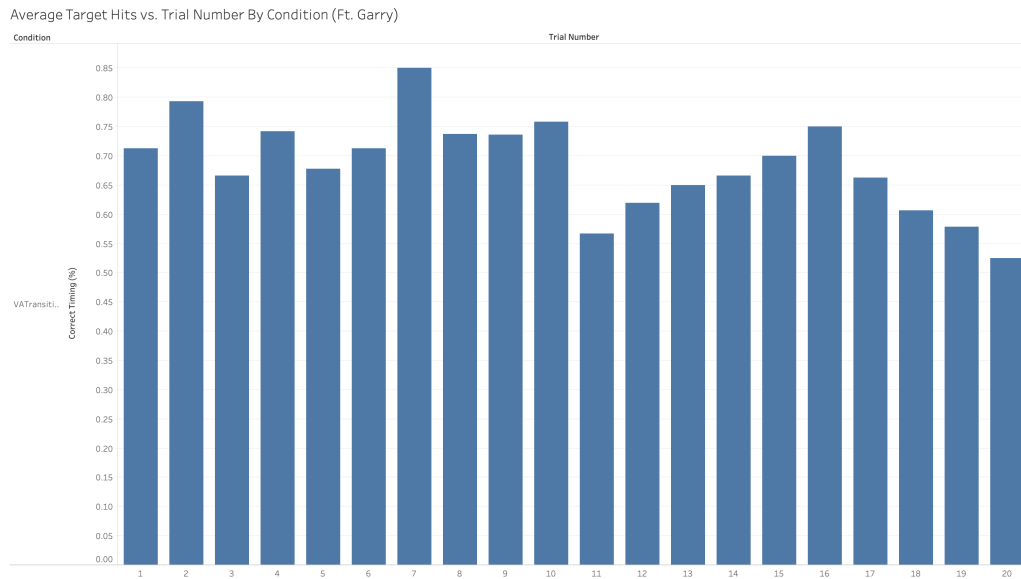


Figure 5.13: Results of Compression Timing - VATransition Condition

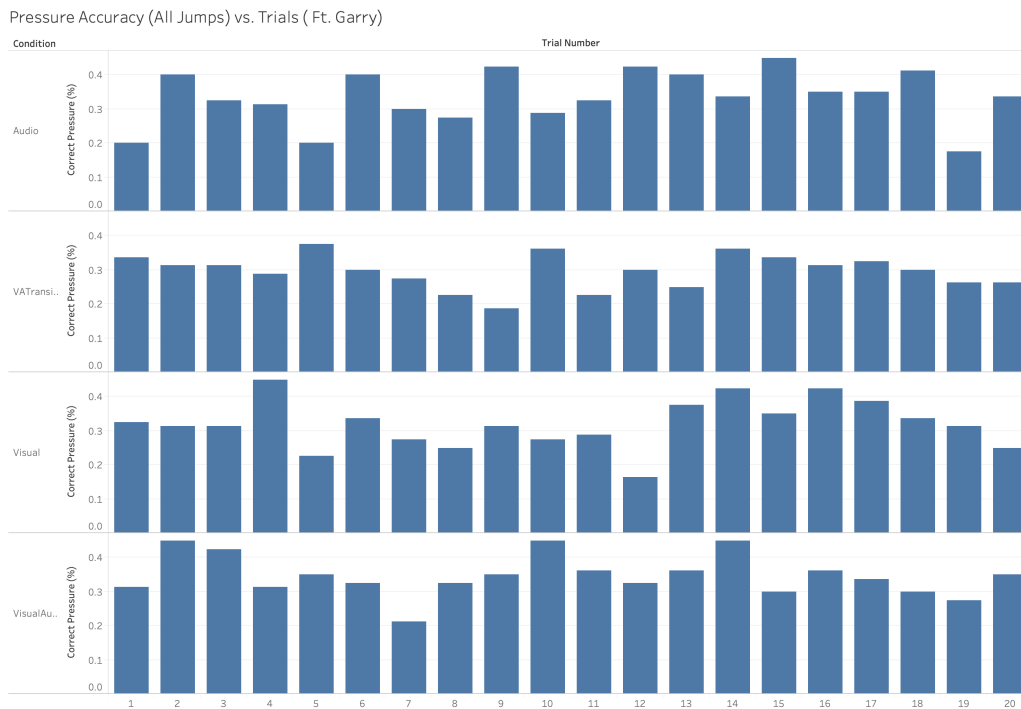


Figure 5.14: Overview of Pressure Accuracy - All Conditions

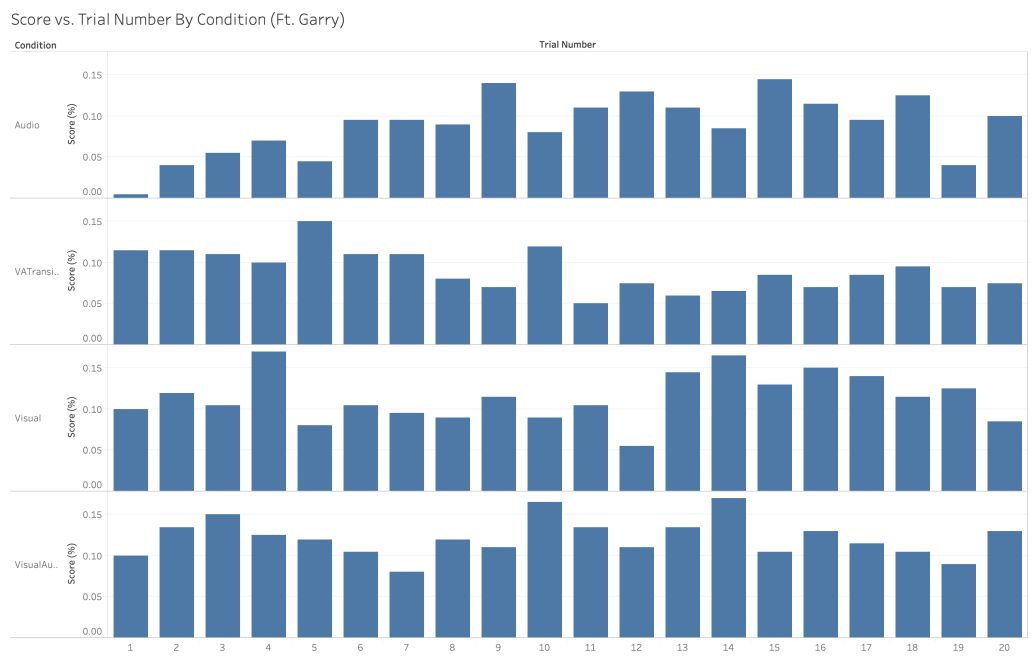


Figure 5.15: Overview of Score - All Conditions

6 STUDY 2 - HEALTHCARE PROFESSIONALS

This chapter describes a follow-up study conducted with professionals within the medical field. For this study, we used the same methodology as the first study, however, only two conditions were selected. Based on the results of the previous research, the Visual only condition and the Audio only conditions were chosen for this study. The Visual+Audio condition did not reveal to be significantly better than the Visual only condition, which yielded the best results; therefore, we assumed that the participants focused on the visual aspect of the condition. Moreover, VATransition was excluded for the same reason, without the visual aspect of the game; our visualization ([Figure 5.13](#)) suggested that participants' performance deteriorated with regards to compression timing.

6.1 ENVIRONMENT

The environment (see [Figure 6.1](#)) was constructed as similar to the first study as possible. Although the room the experiment was held in and the bed warmer that participants used was different, the apparatus used was the same as the first study. No changes to the equipment were made between the first and the second study. The study was conducted in the Attending's office within the secure NICU at the Health Sciences Centre. The router used in the first study was brought, and a local

network was set up in the office. Furthermore, the bed warmer used in this study was a GE Giraffe Omnibed, which has the same functionality as the previous bed and does not change the task or the feel of the experiment. Finally, the same GoPro was set up the same way as the previous study.

6.2 PARTICIPANTS

Twenty participants (ten females) were health professionals recruited by word of mouth and a poster placed outside of the experimental area. Due to potential emergencies, and the unpredictable nature of hospitals in general, participants came and took part in the study on a walk-in basis, rather than being scheduled. The participants ages ranged from 22-57 years old ($M = 39.65$, $SD = 11.25$). The participants were nurses, respiratory therapists, and doctors who have been trained and have experience in performing neonatal resuscitation. As with the first study, experience with HWDs was not necessary, each session took a maximum of 45 minutes, and participants were given a \$15 gift card for their time.

6.3 TASK AND STIMULI

There were no changes to the task between the first study and second study. Healthcare professionals followed the exact same procedure as the participants in the first study, including the video tutorial on PPV. This experimental design can be summarized as:

10 participants per condition x
2 conditions (Visual, Audio) x

20 trials per condition x
 20 compressions
 = 8000 total compressions.

6.4 RESULTS

The results were organized by compression timing, pressure performance, and score. For consistency, out of the twenty trials, trials 11 to 20 were used in the analysis, and the first ten trials were removed. This exclusion was done in order to compare results between the non-healthcare professionals and the healthcare professionals in the next chapter. The majority of variables were normally distributed, and thus, parametric analyses were selected throughout, unless otherwise specified. In this analysis, we conducted ANOVAs for compression timing, pressure performance, and the score between the two conditions tested.

6.4.1 *Compression Timing*

First, with a comparison of both conditions in [Figure 6.2](#), one can see a noticeable difference in the timing performance between audio and visual. The Visual condition performs better on average than the Audio condition in every trial. Furthermore, there was a significant effect found between the Visual ($M = 0.711$ with an $SD = .15$) and Audio ($M = 0.477$ with an $SD = .16$) conditions. The visual condition induced superior performance ($F(1, 19) = 10.84, p = .004$).

6.4.2 *Pressure Performance*

No effect was found between the conditions for pressure performance ($p = 0.143$). This finding is consistent with the first study. A visualization of [Figure 6.3](#) also shows that both conditions performed similarly, and no interesting trends were derived.

6.4.3 *Score*

Finally, we looked into the scores between the two conditions. Scores consist of the responses where both the timing and the pressure were correct. When analyzed, the comparison between the Visual and Audio conditions lacked significant effect. This result is also consistent with the first study. However, a glance at the visualization in [Figure 6.4](#) shows that the Audio condition may have a potential learning effect. It was also interesting to see low scores within the health professionals. Further discussions on these outcomes as a whole will be described in detail in [Chapter 7](#).



Figure 6.1: Study 2 - Experimental Setting

Correct Timing vs. Trial Number (HSC)

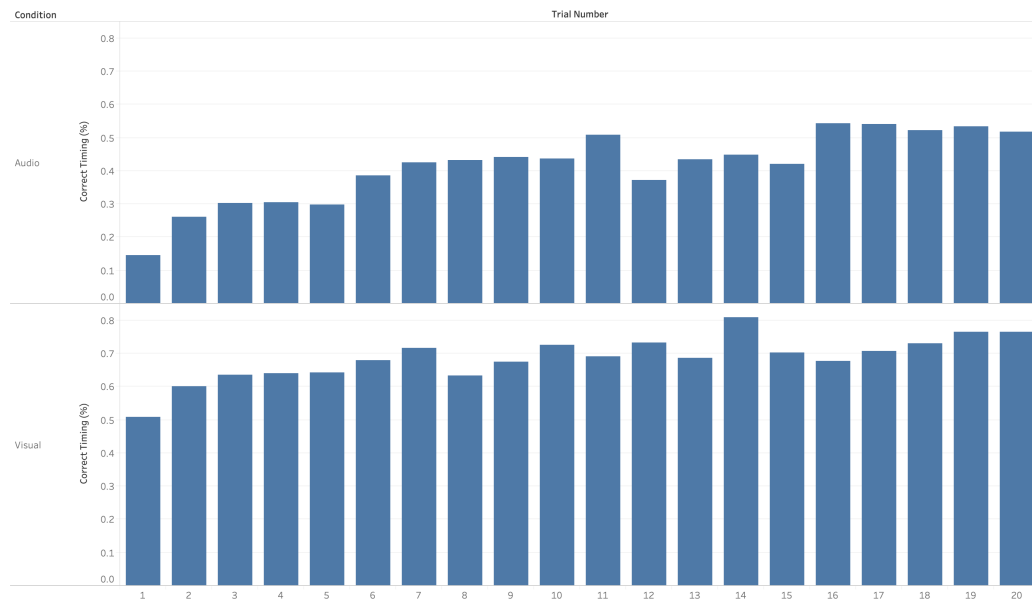


Figure 6.2: Overview of Compression Time - Medical Professionals

Pressure Performance vs. Trials - Audio (HSC)

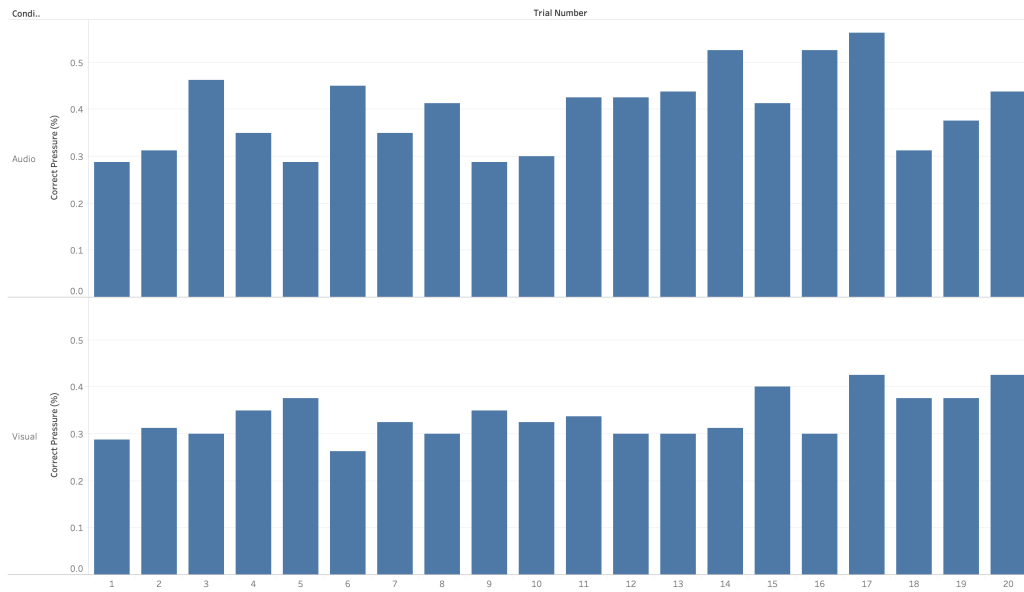


Figure 6.3: Overview of Pressure Accuracy - Medical Professionals

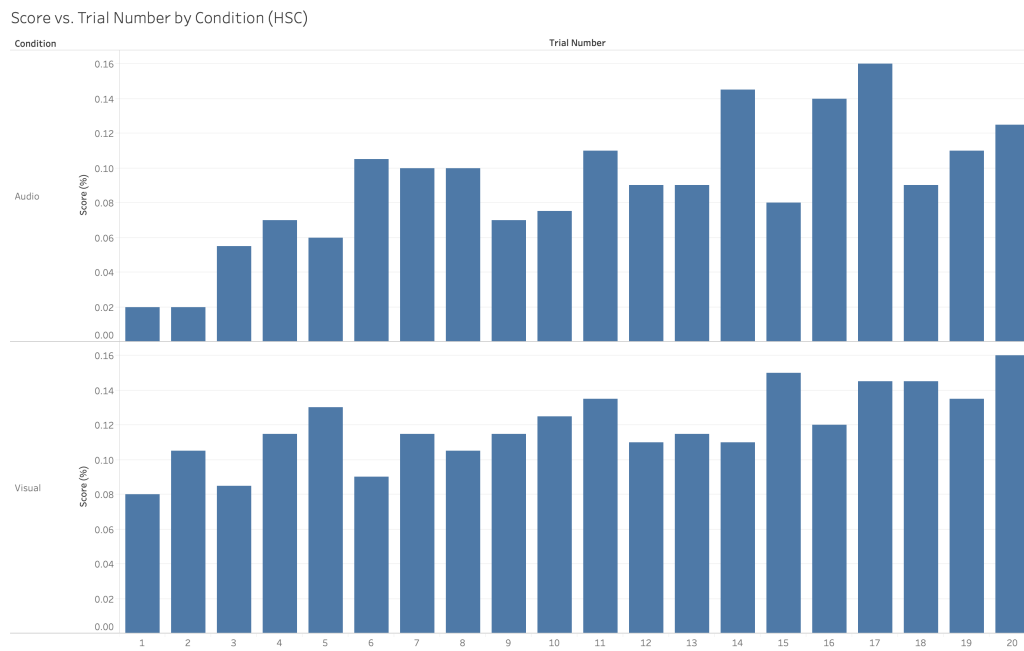


Figure 6.4: Overview of Score - Medical Professionals

7 DISCUSSION

This chapter will compare the results of the first study conducted with laypeople and the second study conducted with healthcare professionals. We observe and discuss the performance, similarities, and differences between the two groups. Furthermore, we will address potential causes of the comparison results. In this analysis, the compression timing, pressure accuracy, score, and missing data will be compared between the laypeople and the health professionals. The expected outcome of this comparison is that health professionals will perform better than laypeople.

7.1 LAYPEOPLE VS. HEALTH PROFESSIONALS

Interestingly enough, no significant effect was found; laypeople and health professionals did not differ in all three categories (see [Table 7.1](#)).

	SCORE	COMPRESSION TIMING	PRESSURE ACCURACY
Visual	$p = 0.635$	$p = 0.462$	$p = 0.631$
Audio	$p = 0.509$	$p = 0.321$	$p = 0.119$

Table 7.1: The p-values of the comparisons between laypeople vs. professionals

One interesting outcome, however, comes from the number of missing values. The frequency of missing data (i.e., participants not responding or the response was not entered due to air leak) was explored across both the Visual and Audio conditions. A significant effect emerged between the Audio condition of both studies, $F(1, 19) = 4.28$, $(p) = 0.05$. Laypeople failed to respond more often ($M = 37.80$, $SD = 13.31$) than experts did ($M = 23.10$, $SD = 16.43$). No effect was found between participants in the Visual condition ($p = 0.54$).

The effect found in the Audio condition can potentially point towards two causes:

- Laypeople missed jumping more often than experts did.
- Laypeople were not able to use the mask properly and consistently. Thus, their response was often not recorded in the system. The potential cause of the lack of response could be the concentration of listening to the auditory signal to compress rather than concentrating on the mask seal. Moreover, health professionals have formal training on adjusting seal when they feel a lack of response, which may have contributed to the performance between the two groups.

7.2 DISCUSSION

In order to improve upon the simulation used for the study, qualitative feedback was obtained through questionnaires. Moreover, the feedback or comments the participants had after experiencing the experiment were also recorded. Some healthcare professionals also expressed comments during the experiment, that feedback was recorded by the GoPro.

7.2.1 *Hololens*

Many participants in both studies found the Hololens quite heavy and cumbersome by the end of the experiment. Furthermore, some reported that they felt eye-strain afterward. Even in a cool temperature-regulated room, participants were often very sweaty after the study. The cause of the sweating could be do to a number of potential factors. The heaviness of the HWD and the warmth that accumulates from continuous use of the Hololens can contribute to heat, causing the participant to sweat. The Hololens is useful in many ways, but it may not be ready for use for extended periods.

7.2.2 *Audio Condition*

Some participants exposed to the Audio condition expressed that the auditory signals were confusing at the beginning, however, they got used to it by the end of the study. This can be observed in both the first study and second study where both groups were able to hit more targets, on average, by the end of the experiment (see [Figure 5.10](#) and [Figure 6.2](#)). More research into the best auditory cues is required to limit confusion. Furthermore, as shown visually in the previous chapters ([Figure 5.10](#), [Figure 6.2](#)), different auditory signals may potentially improve learning. The Audio condition in both studies, for most of the variables analyzed, had a potential learning effect.

7.2.3 *Mask Seal*

As far as we know, there has not been research in providing precise feedback in simulation training for precise mask seal control and effective PPV. At the training sessions for the Neonatal Resuscitation Program, PPV was a relatively small, yet essential, part of the training. Although important, precise feedback about mask seal and compressions was not given as part of the training; possibly due to time restrictions required in order to accommodate skills training for the overall neonatal resuscitation procedure. The only feedback the trainees received was the chest rise of the advance newborn manikin used for the simulation. There are, however, many potential problems that may cause an ineffective seal in this study. Investigations in the first study have shown that the apparatus, when perfectly sealed, can pick up the slightest of compressions. Thus, there are several possible reasons why a participant's seal may have been ineffective.

7.2.4 *Baby Manikin*

As mentioned in the previous section, precise seal and compressions are not measured in during the core training. As long as the chest of the manikin rises when the trainee compresses the bag, for that simulation, the PPV is considered effective. Furthermore, several experts have expressed that the manikin was not realistic due to the hardness of the plastic composing the manikin's face. Therefore, this manikin may not be suitable for a precise seal. The manikin used in the studies was also a relatively older model of the manikin, making it potentially more difficult to hold a proper seal. (Figure 7.1) During both studies, participants

had difficulty maintaining their seal, which led to using force to create a seal on the manikin. The amount of pressure required to maintain the seal was unnecessary and would absolutely do harm to a newborn in a real-life situation.

7.2.5 *Bag and Mask*

Many health professionals have expressed that both the bag and mask were different from what they usually use at that specific hospital. The health professionals were given the resuscitator described in [Chapter 3](#); however, numerous participants expressed that "Jackson-Rees bags" were preferred (described in the standard textbook [66]). Some participants have also requested a performance test between the two types of bags in future work.

The mask was also a topic of discussion among each participant. A number of the participants either did not like the disposable plastic teardrop-shaped mask or rarely use that type of mask. A round and reusable silicone mask was preferred, and through observations the reason is apparent. As mentioned in the previous section, participants had to use an excessive amount of force and pressure in order to maintain a proper seal ([Figure 7.2](#)). The excessive force led to a total of six masks breaking [Figure 7.3](#). Three broke during the first study, and another three broke in the second study. The destruction of masks can potentially be avoided if a proper seal can be obtained using an acceptable amount of force.

7.2.6 *Fatigue*

Finally, with the amount of force required to maintain the seal in addition to the heaviness of the Hololens, fatigue is a potential factor in maintaining consistent compressions. Even with the participants' required rest breaks every five trials, participants often expressed their hands were 'cramping up' by the end of the trial.



Figure 7.1: Possible leak areas when performing PPV with the manikin

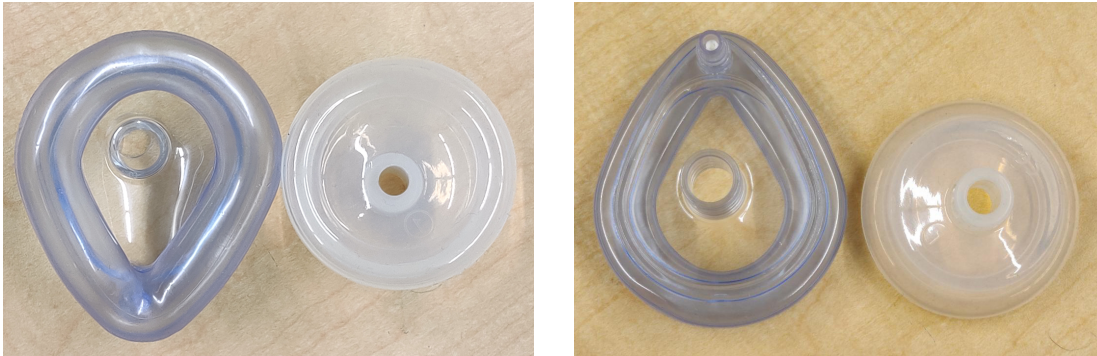


Figure 7.2: Comparison of the teardrop-shaped mask vs. the round mask



Figure 7.3: Masks damaged due to excessive force

8 SUMMARY AND FUTURE WORK

Neonatal resuscitation is a crucial procedure for millions of newborns each year. The process is composed of many intricate steps that require precision and care from the healthcare professionals. One step that requires a considerable amount of practice to carry out effectively is positive pressure ventilation. In this thesis, we studied the effect of using different technologies such as augmented reality devices and a simple gas pressure sensor to help with training by delivering feedback to professionals seeking to practice. Through gamification of the PPV step, the audio stimulus, visual stimulus, and different combinations of the two stimuli, were compared in an attempt to discover the best form of delivering the feedback. For this research, our main findings come two-fold. First, our results demonstrates that visual feedback performs significantly better than conditions with audio-only feedback in multiple components of the procedure. Second, our findings suggest that between the tasks of maintaining the correct pressure or precisely timed compressions, maintaining the pressure was significantly more difficult to control. The results of both studies conducted show that a visual stimulus is significantly better for compression timing. Both the laypeople and experts exposed to the visual stimulus were able to hit more targets than the participants exposed to the audio stimulus. The difficulty however, lies within achieving the correct pressure. Both studies show inconsistencies in pressure accuracy as well

as cases of unresponsiveness due to a lack of pressure captured by the Phidget pressure sensor. This issue is caused by leaks between the face-mask and the manikin's face. The leaks and the unresponsiveness of the device demonstrate the importance of having a proper seal when one is masking the newborn. The studies suggest that laypeople had a more difficult time maintaining the seal than the experts. A comparison demonstrated that laypeople failed to respond more than the experts did in both the Visual and the Audio condition, however, only the comparisons between the Audio conditions of both groups had a significant effect. The qualitative feedback suggest that the Hololens may not be ready for use in training for extended periods. The hardware is innovative, however, participants expressed a lack of comfortability with the Hololens. With the mask seal being one of the priorities in PPV, we are currently investigating designs that are able to provide feedback regarding the mask seal in combination with the input from the compressions. This implementation would allow users to observe when they need to adjust the mask in addition to when they should change the amount force applied of their compressions.

8.1 CONTRIBUTION

This study looks into developing tools to deliver feedback for a specific step of the Neonatal Resuscitation Program training. Furthermore, these tools have the potential to be used frequently for training to maintain an important skill required of the procedure. Currently, refresher training for the procedure is required every two years; however, the lack of skill retention is a concern. Although textbook knowledge is often better retained, studies have shown that skill performance in

neonatal resuscitation deteriorates over time [13, 24, 65]. Many researchers have suggested frequent refresher training to improve the performance and the quality of the skills used in this procedure. This research contributes to the ongoing investigation in designing innovative ways to help maintain the performance and quality of skills. By developing a training device that assesses one's PPV performance in real-time, one may be able to use the device frequently to maintain the quality of their ventilation in PPV.

8.2 LIMITATIONS

Mask leakage with this apparatus was a challenging issue. This problem is seen in the form of missing data caused by unresponsive compressions. The leaks caused participants to be rough with the apparatus and the baby manikin by exerting an unnecessary amount of force to maintain a proper seal. This issue was very prominent in both studies. However, to preserve consistency and reproduce the study for validation, there were no changes to the apparatus between the first study with the laypeople and the second study with the health professionals. This limitation is an important focus for future work with this tool and will be addressed to provide a better training experience.

8.3 FUTURE WORK

The next step in this research is to tackle the design challenges that involve measuring both the seal and the pressure exerted through compressions. Furthermore, the Hololens may not be ready for extended use; thus, moving feedback delivery to

another device such as a smartwatch should be investigated as well. Investigations regarding skill retention after using the tool is also required. If the tool is successful in helping healthcare professionals retain their practical skills in PPV, this tool could also be a catalyst in developing tools for different steps in NRP training. The most intriguing outcome for future work in this area is the potential use of everyday training.

8.4 FINAL WORD

Many health professionals require neonatal resuscitation training. One may be well-versed in the knowledge of the procedure, however, the performance of skills may deteriorate over time. One skill that requires more attention is PPV; as there are many factors involved to the performance of effective ventilation. This research provides a catalyst in investigating the use of different technologies to provide feedback on the user's performance. The tool created has demonstrated that users achieve better performance in certain areas with a visual stimulus versus an audio stimulus. Furthermore, both studies demonstrated the importance of a proper mask seal. Further design is required to create a device that assesses the mask seal and the pressure from the compressions. It is our hope that tools such as this one can help contribute to the improvement of neonatal resuscitation training. Furthermore, we hope to provide users with an accessible and exciting way of frequently practicing PPV such that one may maintain or improve their performance of the skill.

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