DESIGNING AIRWAY MANAGEMENT EQUIPMENT TO OPTIMISE PARAMEDIC PERFORMANCE

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Contents

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Abstract

Paramedics respond to stressful and unpredictable cardiac arrest emergencies filled with information they need to process. During cardiac arrest resuscitations, Paramedics use various types of Airway Management equipment to provide oxygen to the patient. Airway Management equipment originated from the anaesthesiology department in the hospital. Consequently, the Airway Management equipment was not designed to suit the challenging and unpredictable pre-hospital setting.

By applying a Human-Centred Design and Action Research approach; this research aimed to investigate the factors that impact Paramedic's cognitive load, and to improve the efficiency of using Airway Management equipment during patient resuscitation. Paramedics and paramedicine students were recruited for expert interviews, an ethnographic study, and think-aloud sessions to help gain a better understanding of the Airway Management equipment in the context of a patient resuscitation. The data from these methods were analysed to identify opportunities for design when using the Airway Management equipment.

Three areas for design were identified as the connector pieces of the Airway Management equipment, the tube holder, and the equipment storage. These products were refined with User testing sessions where the intended users provided feedback to improve the usability of each design. As a result each of the three designed components were tailored better to meet their needs when undertaking patient resuscitation.

The findings contribute to an understanding of the benefits of a Human-Centred design approach to designing with paramedics in the pre-hospital setting. Gaining a better understanding of the external factors that impact paramedics during patient resuscitations and feedback from users, helped develop beneficial design solutions. The design outcomes include three product components to support the Airway Management process. These components aim to reduce cognitive load, stress, and improve paramedic performance. This research highlights the opportunities of a Human-Centred design approach and supports further research into the improvement of other medical equipment for use in the pre-hospital setting.

Positioning the Researcher

I have always had an interest in designing medical equipment for healthcare providers.
I began this research with little knowledge about advanced life support, airway management devices and procedures.

My final Undergraduate project involved re-designing Emergency Response Packs (ERP) for first responders in remote Australia. Re-designing ERPs meant I needed to understand what type of equipment would be needed by first responders attending medical emergencies. Although the terrain and environment of remote Australia is vastly different to the urban areas in New Zealand, the pre-hospital setting is essentially the same, as patients required medical care outside a hospital setting. The re-designed ERP focussed on reducing stress experienced by the first responder by introducing a colour coded organisational system that made it easier to access and retrieve the equipment.

My undergraduate project provided me with some medical knowledge that was carried over to this project involving airway management equipment and ideas of how to approach creating a storage solution.

Introduction

Paramedics respond to medical emergencies twenty-four hours a day, seven days a week. Paramedics are healthcare professionals who provide Basic Life Support, and Advanced Life Support (ALS) in the pre-hospital setting (Jennings, 2019). They have enhanced skills that help them rapidly assess, treat, and transport patients to the nearest hospital (Jennings, 2019). They have the necessary skills in ALS such as advanced airway management, defibrillation, and intravenous cannulation as well as patient assessment— pulse oximetry, measuring vital signs and cardiac monitoring (ECG) (Jennings, 2019). During a resuscitation of a cardiac arrest patient, airway management is one important procedure a paramedic performs to maintain a patient's airway which influences patient outcomes. However, the airway management equipment used, originates from the Anaesthesiology department of the hospital (Ostermayer & Gausche-Hill, 2014). Consequently, the airway management equipment was not designed to suit the challenging, unpredictable, pre-hospital environment. Like emergency medicine in the hospital setting, there are few examples of specifically designing medical equipment for paramedics (Privitera, 2013).

CHAPTER ONE

CONTEXTUAL REVIEW

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https://www.aucklandmuseum.com/collection/object/am_humanhistory-object-59698

Figure 1. Asherford Litter Paramedics first mode of transport.

History of Paramedicine In New Zealand

The foundations of the ambulance service were built by people in the community who had an interest in first aid (Jennings, 2019). The St John's Ambulance service is one of the first organisations established in New Zealand (in the late 1800's) (Jennings, 2019). St John Ambulance provided New Zealand communities with first-aid training (Jennings, 2019). Historically, the ambulance service was used as a means of transport for the sick and injured (Jennings, 2019). As such Paramedics facilitated initial treatment of patients and transported them to the hospital (Jennings, 2019). This was based on a system developed by Dr Dominique Jean Larrey in 1792 (Jennings, 2019). Transport has significantly changed over the years from human-powered carts, horse-drawn wagons to motorized vehicles for both land and air (Jennings, 2019). Before 1975, ambulance personnel at St John Ambulance in New Zealand only held basic first aid certificates (Jennings, 2019). It was only after St John reviewed their ambulance service activities that staff were required to have formal qualifications in pre-hospital care (Jennings, 2019).

Throughout New Zealand, emergency care is provided by paid and volunteer ambulance personnel with varying skills and qualifications (Anderson et al., 2018). The practice levels vary from First Responder, Emergency Medical technician (EMT), Paramedic, and Intensive Care Paramedic (ICP) (Anderson et al., 2018). Intensive Care Paramedics (ICPs) have advanced training at a postgraduate level (Jennings, 2019). ICPs provide advanced assessment, treatment, and transport of patients with severe injuries or illnesses (Jennings, 2019). They have the authority to perform more advanced airway procedures and administer a wider range of medications compared with paramedics (Jennings, 2019).

The role of a paramedic has evolved from emergency response to primary healthcare (Jennings, 2019). They are no longer considered “stretcher bearers” (Jennings, 2019 p.27) but are integral parts of the healthcare system (Jennings, 2019). Paramedics have a vital role in improving patient outcomes as they are known as the interface between the community and the hospital (Jennings, 2019).

Existing Paramedic Equipment

The equipment used by Paramedics originates from the hospital setting, and the current designs do not suit the challenging, changing, pre-hospital environment (Privitera, 2013; Pruchnicki & Dekker, 2017). Du Bronson et al. (2019) conducted a scoping review of existing literature and found forty-eight relevant articles related to human factors, ergonomics, and Emergency Medical Service (EMS) equipment. Interestingly, Du Bronson et al. (2019) attribute EMS equipment to stretchers and stretcher accessories. This may be because these were essential items associated with Paramedicine. From the 1800s to the present day, ambulance stretchers have been the most prominent and ergonomically designed equipment Paramedics use (Jennings, 2019). This is because there is a large body of research regarding the physical injuries resulted from patient handling, carrying heavy equipment, and working in cramped spaces (Conrad et al., 2008; Gray & Collie, 2017; Jennings, 2019; Wang et al., 2009). There is some literature on various cognitive aids implemented in the pre-hospital environment (Swinton et al., 2018; Woods et al., 2019) but not much literature exploring ergonomically designed medical equipment that Paramedics use to treat patients.

Du Bronson et al. (2019) addressed the lack of existing papers on EMS equipment interventions and found that eight papers stated that including human factors and ergonomics into the design process would improve patient and Paramedic safety.

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https://www.rnz.co.nz/news/top/323216/st-john-gets-electric-stretchers-as-obese-patients-double

Figure 2. The new ambulances with electric stretchers

Resuscitation and Airway Management Equipment

Paramedics provide Advanced Life Support to unresponsive patients (Considine & Shaban, 2019). During a resuscitation, paramedics follow the protocol of DRSABCDE (Danger and Responsiveness, Send for help, Airway, Breathing, Circulation, Disability and Exposure), (Munroe & Hutchinson, 2019). Airway management is a critical phase of patient resuscitation as a lack of oxygenation can result in the death of the patient (Kovacs & Law, 2008; Considine & Shaban, 2019; Brinton et al., 2019). Airway Management ensures that there is a clear passageway for airflow (Margolis, 2010). Paramedics use Advanced Airway devices to help maintain the patient's airway and ensure it is clear from obstruction (Mongolis, 2004). Airway obstruction can be a result of the patient's tongue or aspiration of foreign material such as blood, vomit, or food (Considine & Shaban, 2019). If the patient is unconscious, the airway takes priority over any injuries— even potential spinal injuries (Considine & Shaban, 2019).

The airway management equipment used is dependent on the skills and experience of the Paramedic (Considine & Shaban, 2019). Airway management equipment ensures that the patient receives oxygen. During patient resuscitation, an advanced airway device such as a Laryngeal Mask Airway (LMA) (see figure 3) or Endotracheal Tube (ETT) is inserted (see figure 4). This allows Paramedics to use a Bag Ventilation Mask (BVM) to maintain the ventilation rate for the patient (Considine & Shaban, 2019). Maintaining a patient's airway is vital as it impacts the outcome of the patient. Without sufficient oxygen, the patient may suffer neurological deficits (Mongolis,2004). This makes Airway management a time sensitive intervention (Mongolis, 2004). Considine and Shaban (2019) stated that studies suggested that ventilation was less important within the first five

Figure 3. Ambu AuraOnce Laryngeal Mask Airway (LMA)

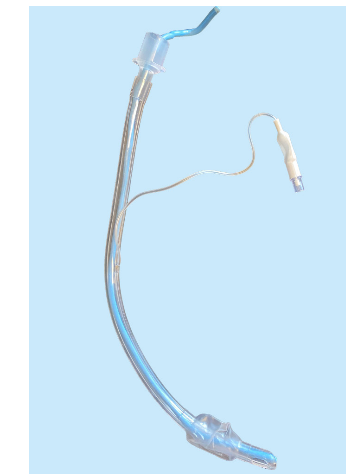

Figure 4.Endotracheal Tube

Endotracheal tube with Stylet.

minutes of a Cardiac arrest, and therefore, uninterrupted chest compressions take priority. This is because in adults, through chest compressions, there is blood circulating the body with some oxygen content (Considine & Shaban, 2019). The airway device is inserted into the patient during the third cycle of CPR (AUT Paramedicine, 2019).

Cardiac arrest is an example of when advanced airway devices are needed. During 2019-2020, New Zealand paramedics treated over 2000 cardiac arrest adult patients per year (Dicker et al., 2021). Of those 2000 patients, only 13% had survived the cardiac arrest event once receiving treatment (Dicker et al., 2021). Cardiac arrest is the most time-critical condition that Paramedics respond to and patient outcomes are reliant on the initiation of CPR and the use of an AED (Dicker et al., 2021). As a result, the average response time for the ambulance service in an urban area is 8 minutes (Dicker et al., 2021). A critical phase of responding to a cardiac arrest is advanced airway management by either using Endotracheal intubation or an LMA device (Dicker et al., 2021).

Airway Management Equipment Origin

Airway Management devices and accessories originate from the Anaesthesiology department in the hospital (Ostermayer & Gausche-Hill, 2014). These devices have been adapted for the pre-hospital setting (Ostermayer & Gausche-Hill, 2014). Anaesthesiology is defined as "the practice of medicine dedicated to the relief of pain and total care of the surgical patient before, during and after surgery" (MacGill, 2017). This is done through using anaesthetic and other medical gases (Bland et al., 2012). Anaesthesiologists also maintain patients' airway through using a variety of airway adjunct's and Supraglottic devices (see figure 3) (Macgill, 2017). This equipment is also used in the pre-hospital environment by Paramedics during emergencies (see figure 5). There are a variety of different Supraglottic devices, but the LMA and ETT are the most common ones used by Paramedics in situations where an advanced airway is required (Jennings, 2019). It is interesting to note that these devices are the same as the airway devices found in the hospital and that they have been designed for a completely different environment (see figure 6). Ostermaver and Gausche-Hill (2014) acknowledged that there are practical and clinical differences to the hospital environment and the pre-hospital setting. Studies on airway devices were mainly focussed on a hospital setting and need to be conducted in the pre-hospital setting (Ostermayer & Gaushe-Hill, 2014). Although, Ostermayer and Gausche-Hill (2019) were referring to further research on neurological outcomes when using the LMA device, it still highlighted that not much research has been done with a focus on the pre-hospital setting.

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https://www.tvnz.co.nz/shows/paramedics

Figure 5. Paramedics in an Ambulance
Note: Australian Paramedic intubating a patient in an ambulance. From Paramedics, 2020

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https://www.commercialprojectawards.co.nz

Figure 6. Operating Theatre

Cognitive Load

The pre-hospital environment is complex and filled with uncertainty. Paramedics frequently provide care and perform life-saving procedures in this environment. A myriad of information is processed by Paramedics during emergencies. This can often result in cognitive overload. For this reason, Paramedicine is considered one of the most cognitively and physically demanding professions in healthcare (Misasi & Keebler, 2017).

Bitan (2020) used a Mass Casualty Incident (MCI) as an example of the impact of stretched resources and external distractions on Paramedics' cognitive load. This extreme, chaotic scenario with many injured demonstrates the influx of information processed. This is done while prioritising medical treatment. Cognitive load refers to an individual's cognitive ability to process, store, and retrieve information (Bitan, 2020). Various factors contribute to Paramedics cognitive load. This includes a time pressure, collecting patient information, forming a diagnosis, calculating drug doses, external noises, and distractions (Palmer, 2017). Working memory (short-term memory) is what an individual is thinking now (Bitan, 2020). It is affected by heavy loads of information (Bitan, 2020). It has a limit to the amount of information an individual can process so the most vital information is prioritised (Schubel et al.,2020). Paramedics form assumptions once they receive a call and must disregard their biases or this could lead to a wrong diagnosis (Palmer, 2017). Through gathering further information from the patient, caregiver, or by-standers they can form a better picture of the factors impacting the patient's need for medical help. An example of understanding cognitive limitations are products called cognitive aids or artefacts. These were designed to reduce cognitive strain during an emergency (Fletcher & Bedwell, 2017). This helps overwhelmed paramedics to follow the correct protocols.

Paramedics use a wide range of technical skills (airway management, administering medicine, wound management etc.) and non-technical skills (Shippey & Rutherford, 2020). Non-technical skills are cognitive or social skills that complement an individual's technical skills (Shippey & Rutherford, 2020). For Paramedics, these are largely based around situational awareness and decision making (Shippey & Rutherford, 2020).

Situational awareness is the process where an individual makes meaning of stimuli inputs (e.g., sounds, images, smells) and uses this information to create an expectation of what will happen next (Shippey & Rutherford, 2020). Paramedics are constantly gathering 'environmental' information at an emergency scene. This includes information regarding the medical history or symptoms/behaviours of patients from the patient themselves or from bystanders (Shippey & Rutherford, 2020). There are phases of situational awareness— Perception, Comprehension and Projection (Shippey & Rutherford, 2020). Shippey and Rutherford (2020) used an example of a Paramedic who is assessing a patient to highlight the stages of situational awareness. In this example, the paramedic noticed a pulse oximeter reading of 89% and used this information to project what may happen to the patient with a low oxygen saturation reading (Shippey & Rutherford, 2020). The paramedic concluded that the patient would be harmed without an intervention of oxygen (Shippey & Rutherford, 2020). Situational awareness is a non-technical cognitive skill that paramedics must use at an emergency scene (Shippey & Rutherford, 2020). Paramedics can gather sensory information, understand it, and decide on the best course of action (Shippey & Rutherford, 2020).

Decision making is a huge part of a Paramedic's role as they work in dynamic environments with variable patient presentations (Shippey & Rutherford, 2020). Decision making is when a Paramedic needs to decide on factors that impact the patient— for example, the best treatment plan (Shippey & Rutherford, 2020).

Situational awareness influences decision making, and both can be further influenced by individuals who are fatigued, overloaded, stressed, and ill (Shippey & Rutherford, 2020). Shippey and Rutherford (2020) suggested that situational awareness and decision making was an important element of Human Factors and Ergonomic discipline as it related to human performance, the cognitive interactions with the environment, work system, patients, and medical equipment. Shippey and Rutherford (2020) stated that the work environment, technology, and processes should be designed to maximise the non-technical skills Paramedics use in the pre-hospital environment.

Stress

Paramedics encounter many stressful challenges during an emergency. Stress is the result of a person's perception of demands and their resources or capability to meet those demands in a particular situation (LeBlanc et al., 2012; Nuamah &Mehta, 2020). In 2018, a study focused on New Zealand Paramedics experiences in Cardiac Arrest Resuscitation identified challenges as clinical, ethical, cognitive, and emotional (Anderson et al., 2018). This revealed factors that impact Paramedics and their decision-making (Anderson et al., 2019). Paramedics make multiple time-critical decisions in temperamental environments without reliable information (Bitan, Moran, & Harris, 2018). Consequently, factors like stress, emotions and personal values affect their clinical decision making and confidence (Anderson et al., 2018). Anderson et al. (2018) revealed that stress can arise from challenges in emergencies. Such as treating a young patient, worrying about having the correct equipment and facing a life and death situation (Anderson et al., 2018). Paramedics juggle many different tasks that add to their cognitive load and their stress levels. Being aware of their vocabulary (Anderson et al., 2018) and maintaining a calm, reassuring composure are some additional tasks (Palmer, 2017). A high cognitive load exacerbates feelings of stress and anxiety (Bitan, 2020). Furthermore, a high level of stress has been linked to decreased performance (Anderson et al., 2018).

Interestingly, in 2012, a study conducted with Canadian Paramedics revealed that when exposed to a highly stressful environment, stress only impacted their ability to recall the patient case details from the emergency. As they tended to reported details that were not present at the scene (Le Blanc et al., 2012). This could be because Paramedics already have access to cognitive aids (e.g., a checklist). These alleviate stress and cognitive strain (Palmer, 2017).

Cognitive Aids

Cognitive aids are tools that are designed to optimise the intended user's performance by lessening the cognitive strain experienced when performing tasks such as collecting, storing, and retrieving information (Fletcher & Bedwell, 2017). Cognitive aids can vary from Checklists, Alarms, Physical Tools, Mnemonic Devices, Cues and Decision Support Systems (Fletcher & Bedwell, 2017). Each cognitive aid aims to reduce human error and optimise the performance of the user (Fletcher & Bedwell, 2017).

MOPed

An example of a useful cognitive aid was the Medic One Paediatric (MOPed) cards that were trialled in the United States of America (Woods et al., 2019). Paediatric patient resuscitations are much more complex and less frequent than adult resuscitations (Woods et al., 2019). The factors that make paediatric resuscitations complex are drug dose calculations, sizing, selection of equipment and an emotional component experienced by Paramedics (Woods et al., 2019;

Anderson et al., 2018). These factors result in a high cognitive load for Paramedics and may contribute to human error and potentially poor patient outcomes (Woods et al., 2019). The MOPed cards are used as a colour coded guide to help Paramedics calculate drug doses for paediatric patients (Woods et al., 2019). They were designed using the Paediatric Advanced Life Support protocol (Airway, Breathing, Circulation and Disability) for critically ill children (Woods et al., 2019). 97% of participants in this study reported using MOPed cards as their primary reference when attending Paediatric resuscitation cases (Woods et al., 2019). This cognitive aid was useful because it reduced the burden of calculating complex drug doses for highly stressful paediatric resuscitation cases (Woods et al., 2019). This example highlighted the importance of gaining a better understanding of factors that may impact Paramedics cognitive load. Furthermore, it helps guide where in the resuscitation process a cognitive aid is needed (Woods et al., 2019). The result of MOPed emphasises the importance of how simple design can be beneficial (Woods et al., 2019).

Triage tags

Many emergency cases in pre-hospital care are time-critical with patient conditions requiring immediate treatment. The design of equipment that is easy to use is vital to help optimise performance and impact patient diagnosis and stabilisation. During a Mass Casualty Incident, Bitan (2020) focuses on triage tags used by Paramedics (see figure above). Bitan (2020) proposes three pillars of design in this context—environment, human operator, and equipment. He emphasised the importance of designers understanding the factors that impact Paramedics in uncertain environments so that the design of equipment is resilient and reliable (Bitan, 2020). He illustrated that the simplicity of material and design for this artefact made it reliable and easy to use (Bitan, 2020). It was a cognitive aid designed to help Paramedics alleviate their cognitive strain by prompting

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https://doi.org/ 10.1136/bmjoq-2018-000534

Figure 7. MOPed

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Figure 8. Triage Tags used in an MCI

them to follow protocols (Bitan, 2020). The location and factors present at each emergency scene vary so the environment could not be changed. However, by having studied Paramedics' behaviour, equipment was designed to assist them with patients in those situations (Bitan, 2020).

SCRAM and Pre-filled syringes

Airway management procedures that are performed outside an operating theatre are correlated with an increase in patient morbidity and mortality rates (Schyma et al, 2020). In an emergency, Schyma et al. (2020) state that factors that impact a healthcare professionals' ability to perform in a stressful situation is equipment that can be challenging to find, different, or inadequate. Schyma et al. (2020) highlight that improving a healthcare professional's work-flow, improves performance. Swinton et al. (2018) state "the primary purpose of an ambulance service is to provide rapid access to emergency care" (p.3). To manage the critically ill, Pre-hospital Emergency Anaesthesia (PHEA) with oral tracheal intubation is the preferred technique of choice for Paramedics in Scotland (Swinton et al., 2018). Swinton et al. (2018) suggest that this life saving intervention has significant risks caused by prolonged on-scene times theorised it can be reduced by having appropriate preparation.

The adult SCRAM (Structured CRitical Airway Management) bag— created to test this theory— contains Airway management equipment with 'shadow templates' to act a cognitive aid for Paramedics (Swinton et al., 2018). The equipment was optimally organised and prepared for paramedics to use for administering drugs and advanced airway procedures (Swinton et al., 2018). This cognitive aid was tested with paramedics in a pre-hospital high-fidelity simulation (Swinton et al., 2018). Swinton et al. (2018) found that the paramedics had a reduction in the time it takes to perform the procedure, errors during the procedure, and a

reduction in cognitive load of the paramedics. This study also highlighted human error regarding drug labels which was reduced by using pre-drawn, labelled syringes (figure 8) (Swinton et al., 2018). Swinton et al. (2018) believed there is a relationship between work-flow and cognitive load and can be influenced by storage and presentation of equipment. Swinton et al. (2018) proposed that by designing storage and the presentation of equipment to reflect the series of steps required to carry out a procedure it then becomes a useful tool for reducing cognitive burden. It was acknowledged that this study was conducted in a simulated setting and that the results may not replicate true clinical practice (Swinton et al., 2018).

The SCRAM bag was explored using experienced paramedics and was then trialled with fifty experienced Anaesthetists (Schyma et al., 2020). The use of the 'shadow template' (silhouette of the equipment) was meant to act as a cognitive aid to visually prompt health clinicians to ensure the equipment was prepared in advance (Schyma et al., 2020). Schyma et al. (2020) believe this 'shadow template' gives the SCRAM bag an advantage over resuscitation trolleys in the hospital because of its low error rates. Through their investigation, Schyma et al. (2020) found that the equipment was checked more thoroughly and attributed this to participants having a reduced cognitive load because of using the cognitive aid.

Cognitive aids can be useful in the complex pre-hospital environment, however; it may lead to complacency which may result in more errors (Fletcher & Bedwell, 2017). The design of a cognitive aid needs to aid the Paramedic when using it but also not become something that is relied on too often. There needs to be a balance of being helpful while not replacement for remembering procedures and protocols (Fletcher & Bedwell, 2017).

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https://doi.org/10.1186/s13049-018-0549-3

Figure 9. SCRAM Bag

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Figure 10. Pre-prepared syringes

Human Error

In healthcare when a mistake is made or something goes wrong, the human at the centre of it is blamed, when in fact the system should be at fault (Rutherford, 2020; Simmons & Graves, 2008). In the hospital environment, there have been several 'Human Errors' that have occurred with the misconnections of central Intravenous Catheters, Nasogastric Feeding Tubes, Peritoneal Dialysis Catheters, Tracheostomy inflation Cuff Tubes, and Automatic Blood Pressure Cuff Tubes (Simmons & Graves, 2008). The error was the result of two products both using a lure tip and small-bore connector (Simmons & Graves, 2008) (see figure 11). When a healthcare clinician makes an error, it is called a 'cognitive slip' (Simmons & Graves, 2008). When this occurs, the healthcare clinician is unaware of their mistake of connecting the wrong tubing as they are in 'automatic' mode, and they are functioning at a level where the error is undetectable (Simmons & Graves, 2008). These errors are discovered by someone else (Simmons & Graves, 2008). These 'cognitive slips' occur when healthcare clinicians perform common tasks that are repeated often without failure (Simmons & Graves, 2008). Design needs to be able to anticipate human error and this can only be done by looking at the system (Simmons & Graves, 2008). Simmons and Graves (2008) suggested that the incompatible systems should not be able to connect and should be re-designed to prevent this mistake from happening which will create a safety net. Health care is mistakenly designed on the assumption that human performance is perfect (Simmons & Graves, 2008). This, however, is not the case as humans can make mistakes due to external factors (staffing shortages, fatigue, stress, interruptions during tasks) that are not considered when using the design (Simmons & Graves, 2008). This relates to this research project as it further emphasises the need for the process of resuscitation to be examined to determine the different factors that influence Paramedics. Poorly designed products can have grave consequences in healthcare (Simmons & Graves, 2008). It is not just the patient that is affected, the healthcare provider is also affected. Design should be beneficial, and not be easily misused.

Rutherford (2020) demonstrates how easy it is for a patient to receive the wrong medication due to a variety of ampoules of medication (Naloxone, Adrenaline and Chlorphenamine) having a similar packaging design and all three medications being a clear liquid (see figure12). Rutherford (2020) proposed that human error is a result of a poorly designed system. To overcome this, a 'Systems Thinking' approach must be implemented as this is useful in strengthening the system and preventing 'Human Error' (Rutherford, 2020). This also emphasized the fact that many types of medical equipment had similar designs in both the product itself and packaging. Jeffcott (2020) stated that people usually "make mistakes because the systems, tasks and products that they work with are not designed to fit their needs and goals" (p.84). Effective design results in products that are easy to use and difficult to make errors (Jeffcott, 2020). Don Norman's (1989, as cited in Jeffcott, 2020) principle of "if the system lets you make the error, it is badly designed. And if the system induces you to make the error, then it is really badly designed" (p.86) emphasized the importance of incorporating human centred design, human factors and ergonomics into the design process to reduce human error.

Human Factors and Ergonomics (HF/E) and Human Centred Design

Human centred design is an approach that can be used to help improve patient care and medical devices clinicians use. Human centred design allows designers

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Figure 11. Leur Connectors/ Small Bore Connectors

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Figure 12. Similarities in drug packaging

to create and develop tools and systems with a better understanding of the user's limitations and strengths (Jeffcott, 2020). There are many examples of successful design solutions that have improved patient care and optimised the performance of healthcare clinicians. These designs include medical devices, storage solutions, and equipment preparation. Human Factors and Ergonomics is about designing systems and tools around the person using it (Jeffcott, 2020).

Incision and Drain Packing Device

Mary Beth Privitera (2015) is an American Industrial Designer that specialises in designing medical devices for clinicians. Privitera (2015) and her team developed an Incision and Drain Packing Device for draining abscesses in Emergency Medicine (see figure 1). They gained valuable insights from the tactile feedback from using gloves and designed a medical device that optimised clinicians performance while being comfortable to use (see figure 13). Privitera (2013) spent time in the University of Cincinnati's Department of Emergency Medicine and noticed that most of the medical tools used originated from different departments within the hospital. Emergency medicine clinicians adapt these tools to suit their situation (Privitera, 2013). Privitera (2013) used the example of how a Laryngoscope was designed in the 1940s for Anaesthesiologists to place breathing tubes into anaesthetised patients. She emphasised that it was designed for a well-lit operating room with an unconscious patient whereas this may not be suitable for a clinician to use on a helicopter with a combative patient who is drunk and vomiting (Privitera, 2013). Privitera (2013) underlines the fact that no-one has been designing specifically for emergency medicine. Emergency medicine is similar to the pre-hospital setting, as it is also unpredictable, chaotic, and time sensitive (Privitera, 2013). This highlighted a gap for equipment design in both pre-hospital care and emergency medicine. Paramedics also use much of the same equipment hospital clinicians use. Emergency medicine

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Figure 13. Third generation design.
Note: Third generation Incision and Drain Packing Device.
From *Contextual Inquiry for Medial Device Design* (1st ed.,p.258) by M.B., Privitera, 2015, Copyright 2015 by Gubser et al.

is fundamentally the same as pre-hospital care—it is the environment that is different. Pre-hospital care is evolving unlike the hospital environment which is described as "static design" (Pruchnicki & Dekker, 2017 p.217). Furthermore, this presented an opportunity to design medical equipment explicitly for pre-hospital care.

Newly Designed Paramedic Bags

Bitan is a human factor and ergonomics expert who has contributed to various designs within the pre-hospital setting (Bitan et al., 2015; Bitan et al., 2016;

Bitan et al., 2019a, 2019b). As a result, Bitan et al. (2019a) have created slimmer Paramedic Response bags (see figure 14). These bags have removable pockets which are labelled and readable in low-light as well as a colour coded system to distinguish the Airway bags (blue) and Circulation bags (red) (Bitan et al., 2019a). The Paramedic Response bags were tested by active Paramedics in Toronto, Canada (Bitan et al., 2019a). A high-fidelity simulation was used and resulted in 35% of Paramedics preferring to carry this new design compared with their current bags (Bitan et al., 2019a). Bitan et al. (2019a) attributed their success in the design to a user centric approach. They believed that incorporating the bags into Paramedics training sessions helped them accept the design as it made it evident that it had been designed to consider the work environment (Bitan at al., 2019a). Bitan et al. (2019a), also hypothesized that the methodical organisational system, in the newly designed paramedic response bags, would have a positive impact on patient outcomes as it could reduce human error (i.e., grabbing the wrong equipment or wrong medication).

Ambulance Pods

Prior to 2005, in the UK the NHS ambulance service had over 40 different designs of emergency ambulances (Hignett, 2017). The variation in location of the equipment in each vehicle presented an increased risk to patient safety (Hignett, 2017). In 2005, the UK Department of Health identified the demand for pre-hospital care was increasing and the role of the ambulance service was changing which resulted in standardising the design of ambulances (Hignett, 2017). Paramedics were observed as part of the Human Factors and Ergonomics research and their clinical tasks helped highlight the problems with the design of the ambulance (Hignett, 2017). They found that the ambulance was only involved

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Figure 14. Paramedic Response bags

Note: Newly designed paramedic response bags tested with Canadian Paramedics. From "Working with paramedics on implementing human factors improvements to their response bags", by Y. Bitan, G. Philip, & T. Uukkivi, 2015, *International Symposium on Human Factors and Ergonomics in Health Care: Improving the Outcomes,* 4(1), p.181. Copyright 2015 by Human Factors and Ergonomics Society.

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Figure 15.Smart Pods

Note: Newly designed standardized paramedic bags. From *Design for health* (1ed., p.166), by S. Hignett, 2017, Taylor & Francis Group. Copyright 2017 by S. Hignett.

in a small percentage of emergency calls as most pre-hospital care is delivered where the patient is located (home, street, shopping centre etc.) (Hignett, 2017). Consequently, this led to the Smart Pods project which explored equipment and consumables used for care wherever the patient is located (Hignett, 2017) (see figure 15). Through an audit of equipment, the Smart Pods project found that the wide range of products used by Paramedics ranged from individually purchased equipment to adapted bags and systems to reduce the quantity of equipment taken to the location of the patient (Hignett, 2017). Data collection from workshops with clinicians led to standardisation of equipment contents and layout influenced by clinical presentations—for example, cardiac, breathing difficulties. This led to user testing the Smart Pod prototypes with Paramedics using emergency scenarios (Hignett, 2017). After several user testing sessions, the Smart Pod evolved into design that had a small footprint and improved access to equipment (Hignett, 2017). The final prototype also included visible fonts to communicate the contents of the Pod, and this was achieved by using colour and luminous materials (Hignett, 2017). They also created a sterile work surface (Hignett, 2017). These changes resulted in positive feedback from Paramedics during the user trials (Hignett, 2017). Designers need to have a good understanding of how people behave during emergencies so that design can effectively provide support while avoiding unwanted side effects (Hignett, 2017).

Pit Crew Approach

A growing body of literature around the importance of uninterrupted chest compressions to improve patient outcomes prompted a better approach to resuscitating cardiac arrest patients (Misasi & Keebler, 2017; Considine & Shaban, 2019). A human factors approach led to the creation of the ‘pit crew’ formation which is also known as high-performance cardiopulmonary resuscitation (CPR) (Misasi & Keebler, 2017) (see figure 16). This was created through observing the

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Figure 16. Pitt Crew Approach

Note: Pitt Crew Approach By P. Misasi & J. Keebler. Copyright 2017 by P.Misasi & J. Keebler.

human factors element present within a cardiac arrest resuscitation some of which included teamwork, cognitive artefacts, situation awareness, task switching and decision making under stress (Misasi & Keebler, 2017). Misasi and Keebler (2017) noted that these human factors elements are all psychological constructs and do not have any foundation in medicine. Each paramedic within the 'pit crew' formation has a specific role and responsibilities during the resuscitation of the patient (Misasi & Keebler, 2017). The 'pit crew' approach was a systemic change to the way high-performance CPR was administered and was achieved through gaining a better understanding of how paramedics work in field resuscitations (Misasi & Keebler, 2017).

Conclusion

Paramedics work in an unpredictable pre-hospital setting. There are many factors that impact Paramedics during emergencies, such as gathering information, situational awareness, decision making, stress and a time pressure. On one hand, there were many thoughtful design solutions, in the context of healthcare, that have been created with the user at the centre of the process. In contrast, there were also many poorly designed products and equipment that have influenced patient outcomes. In some cases, these have been re-designed after mistakes highlighted the issues with the design. Airway management equipment is an important part of a Paramedic's skill set and kit. It was designed for Anaesthesiology department use (controlled settings) and revealed an opportunity for design to be used to explore the factors that impact Paramedics who use this equipment in the pre-hospital environment. Introducing design in this context needs to reduce cognitive strain and stress. As an Industrial designer I identified an opportunity to explore how this equipment could be better adapted to the complex pre-hospital environment.

Research Question

Paramedics experience a cognitive overload and stress when responding to emergencies. Patient resuscitations are time-critical and require Paramedics to use various types of medical equipment to maintain a patient's airway. How might Human-Centred design be used to improve airway management equipment to optimise Paramedic performance, while reducing cognitive strain during patient resuscitation?

Aims

From the literature I reviewed, I formed aims for this project. These included:
To explore the factors that impact Paramedic how paramedics work during a Cardiac Arrest resuscitation.

To create a design solution that is alleviates Paramedic stress and reduces cognitive load during patient resuscitation.

To design a solution that makes Airway Management equipment easy to find and retrieve in an emergency.

CHAPTER TWO

METHODOLOGY

Action Research

Action Research (AR) is often used in research that aims to solve a real-world problem (Gray & Malins, 2016). The aim of this methodology is to improve procedures within a specific context (Gray & Malins, 2016; Gray, 2018). With AR , there are three fundamental conditions that must be met which includes changing a social practice within the subject area, the collaboration between the researcher and participants, and an iterative cycle (planning, acting, observing, and reflecting) (Swann, 2002; Rowe, 2020).

This research project focussed on changing how airway management equipment is used by paramedics through collaborating with potential users to create design solutions that were catered to their needs. Design concepts are rarely solved in the first ideation (Swann, 2002). It goes through a cyclic process of iterations that are refined with feedback and input from potential users (Swann, 2002).

It was crucial to collaborate with participants who had knowledge of the pre-hospital setting and the airway management process as their experience informed and further developed the design concepts so that the design was better tailored to their needs. AR enabled me to consider human factors and ergonomics, external factors, and usability of the airway management equipment so that the design could be optimised for the user.
I used action research to improve how airway management equipment is used and accessed by paramedics. I worked with paramedics and paramedicine students to identify areas for design, and then later in the design process, refined the design concepts I presented to them.

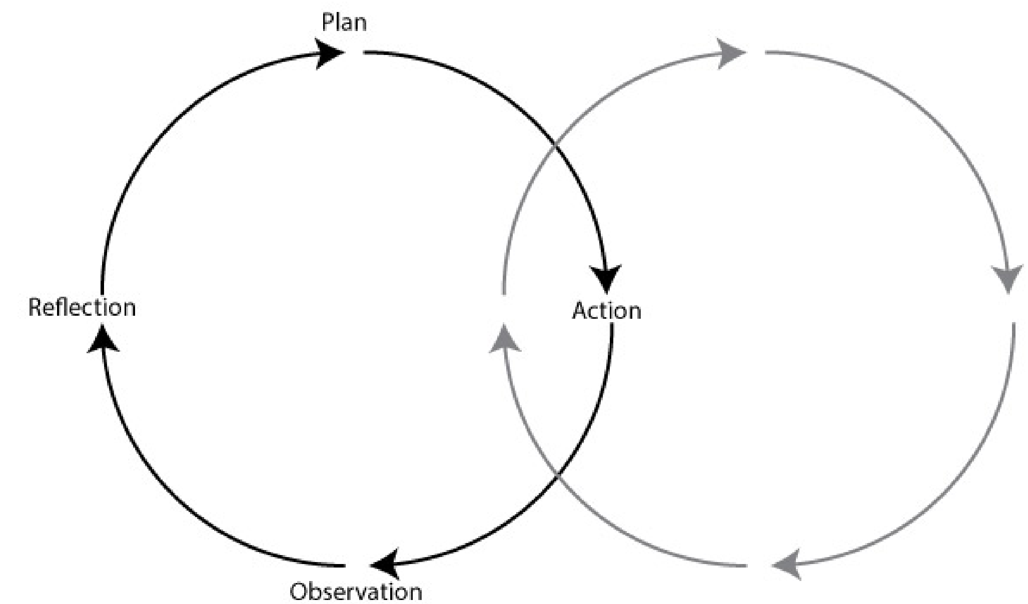

Figure 17. Action Research Cycle. Adapted from (Gray, 2018).

Human-Centred Design

Human-Centred design (HCD) or User centred design is an approach to help ensure that the design of a product or service has a focus on the user, the context, and the aim (Jeffcott, 2020). The design process should "start with a full understanding of user requirements to help them to achieve their goals" (Jeffcott, 2020, p.98). Involving end-users (paramedics) during the design process ensured that their experience using products/ equipment was improved (Friess, 2010). There are two common themes associated with HCD — conducting research with the intended user and using the findings of that research to inform the design solution (Friess, 2010).

I conducted my research with Paramedics to gain an understanding of their needs in the pre-hospital setting. Expert interviews, an ethnographic study (simulations), think-aloud sessions, and role-playing allowed me to better understand paramedics and the airway management equipment they use.
During the user testing phase of my research, I asked participants to 'test' each concept in the context of a patient resuscitation. Their feedback helped inform the subsequent design concepts because I gained a better understanding of how they would use the concepts in the context of an emergency. Asking questions and video recording their interactions with the designs allowed me to highlight how the designs would be used and how it could be improved for paramedics. The participants were able to draw from their experiences to give feedback on each concept.
HCD allowed me to refine the design concepts so that it was better tailored to the pre-hospital setting and the paramedic using it.

Ethical considerations

Using an AR and HCD approach meant that human participation was necessary to ensure that the design outcomes were tailored to the paramedic's needs and requirements in the pre-hospital setting (Harte et al., 2017). Paramedicine students, paramedics and an anaesthetist participated in interviews. Only the paramedicine students and paramedic were able to give expert feedback on prototypes as they work and use airway management equipment in the pre-hospital setting.
As I am a designer and not a medical professional, an HCD and action research approach allowed me to understand how paramedics perform airway management procedures and approach medical emergencies.

A detailed research plan was submitted to the AUT Ethics Committee (AUTEC) to gain approval to research and work with participants. This was approved and was received under the number (20/277). The three ethical principles— Partnership, Participation and Protection— were the foundation for the research plan submitted for the ethics application. Participants gave their informed consent before deciding to participate into each stage of research.

Initially postgraduate paramedicine students were going to be the main group of participants for the whole research process, however; the ethics process was quite long and as a result the postgraduate students had finished their studies before the application from AUTEC was approved. Therefore, the participant group was changed to third year paramedicine students who were still on campus. However, the third-year students were still challenging to recruit as it was near the end of the semester during their examination period.

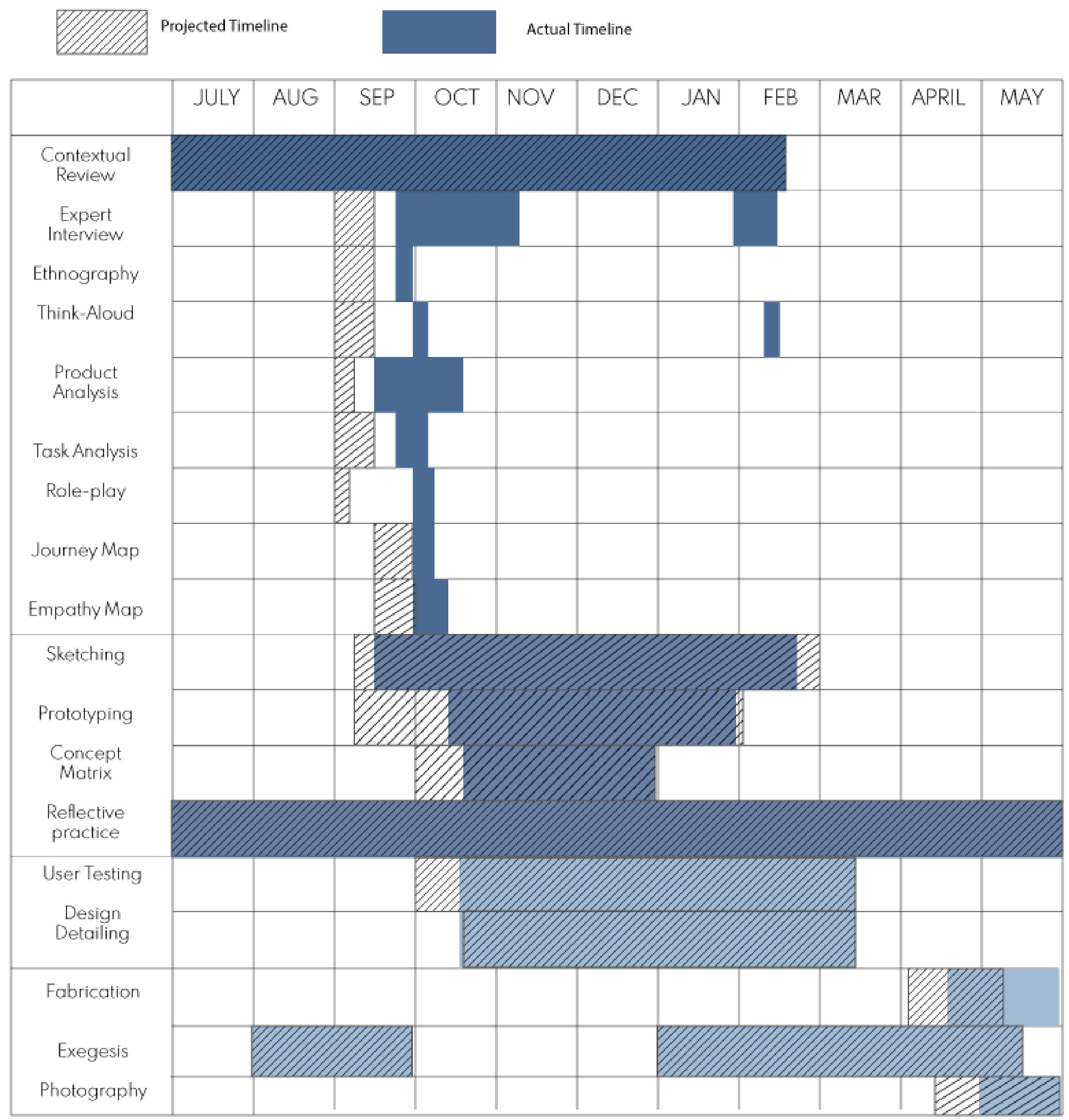

Figure 18. Project Timeline

RESEARCH METHODS

Contextual Review

A contextual review examines existing literature around issues (Gray & Malins, 2016). This method allows researchers to survey the research area to evaluate and analyse what other researchers have done in this area of interest. One issue with this method is that it is only useful if there is existing literature on the focus area for this research project.

The use of, or focus on, industrial design in the pre-hospital environment was limited. I used examples of design in healthcare in areas like the pre-hospital environment. As well as some pre-hospital design examples, I used examples of design interventions in emergency medicine in the hospital. I primarily used Google scholar, and the AUT library database to access sites such as Australasian Journal of Paramedicine, BJM Journals, Clinical key, CINAHL Complete, Taylor and Francis online, to find information about design and Paramedicine. Some of the key words used were 'Pre-hospital care, Out-of-Hospital, Paramedicine, Design, Industrial Design, and Healthcare'. I selected articles that contained those keywords as this was the area of interest. I used a combination of these words in my searches.

Assumption Mapping

Assumption mapping is when a designer notes down their preconceived ideas or assumptions of the design project (Schoups, 2017). It allows them to set aside their assumptions and move the design project forward because assumptions may get in the way of insights or breakthroughs in the research (Schoups, 2017).

Before I started researching, I mapped all my assumptions about Paramedicine. Mapping my assumptions allowed me to learn new information and gain valuable insights into how Paramedics work at an emergency. I found that this was a useful tool to help guide me to fill in gaps in knowledge that I had.

Role-Play

Role-playing is an effective method to gain a better understanding of the intended user's experience (Milton & Rogers, 2013). By simulating the experience of using Airway management equipment in certain situations, I was able to empathize with the user and gain insights into these tasks (Milton & Rogers, 2013).

AUT trains New Zealand paramedics using a high-fidelity simulation room equipped with training manikins that simulate real patients. The paramedic kits used are the same kits St John currently uses, stocked, and set up with the same equipment.

I conducted a role-play of using the Airway Management equipment in an educational classroom (not a high-fidelity simulation room) with a training manikin at AUT's South Campus. After studying the Airway Management procedures, I was able to insert a Laryngeal Mask Airway (LMA) device into a manikin and from this task I gained valuable insights. I then proceeded to attach the accessories to the Laryngeal Mask Airway— the Filter, Cobb's Connector, and Bag Valve Mask. This was done near the end of the semester, which meant that the Paramedicine lecturers were busy with exams, so I did not have any guidance from the lectures. Consequently, I had conducted this role-play alone and had to rely on a YouTube tutorial of how to insert an LMA as a point of reference to know if it was done correctly. I also relied on my memory from observing simulations of participants performing the airway management procedure and the 'Think-Aloud' session I conducted with participants prior to doing the Role-play.

By conducting role-play sessions, I gained a better understanding of how the airway management equipment is accessed, laid out and assembled. Watching simulations allowed me to observe how the procedure was carried out but by performing the procedure myself, I could experience and empathise with Paramedics in an emergency. I had access to the equipment but using it in the context of a 'patient' (a training manikin) it gave me a different perspective and highlighted issues with the equipment. A role-play helped me to empathize with users and gain insights to inform a beneficial design solution (Privitera, 2015a). I conducted this role-play by myself and did not have a 'partner' to simulate a real emergency.

During the user testing sessions, I asked participants to imagine they were in an emergency needing to insert an airway device into the patient. I asked them to 'role-play' this situation which allowed them to think and use the airway management equipment in the context of an emergency which helped them think about usability issues or improvements to the designs.

Expert Interviews

Expert interviews are used to gain insights about an identified research topic and to elicit rich data on people's views and behaviours (Gray & Malins, 2016; Gray, 2018). The core of interviewing is to gain an understanding of lived experience of people and the significance they give to that experience (Gray, 2018).

Expert interviews can be used flexibly throughout a design process to obtain information about expert's experiences with existing solutions, feedback on prototypes, and it was an opportunity for participants to share their thoughts and opinions (Milton & Rodgers, 2013). During the interview, I used a narrative inquiry approach to allow participants to describe their experiences and tell their story (Privitera & Culverhouse, 2019).

Recruitment began with advertising a poster to invite third-year paramedicine students to participate which was uploaded to Blackboard as well as posted around AUT South campus. The third-year paramedicine students who responded were either in their fifth or sixth semester of study and had recently learned how to use the advanced airway management equipment (Laryngeal Mask Airway).

I conducted five initial interviews with paramedicine students , an experienced paramedic, and an anaesthetist. Each participant was regarded as an expert of their own experiences (Sanders & Stappers, 2008). Each interview was audio recorded and transcribed afterwards.

A semi-structured approach was taken with all interviews as this allowed me to explore different topics while guided by key questions of interest (see below) (Privitera, 2015a; Gray, 2018). I was able to 'probe' participant's answers by asking them to expand on their answer.

The anaesthetist was recruited through purposeful sampling. The interview with the anaesthetist was to gain more information about the purpose of each piece of equipment as airway management equipment originates from Anaesthesiology. Anaesthetists frequently use airway management equipment in the hospital as they administer anaesthesia to patients before surgery and use airway devices. The emergency department call an anaesthetist when they need to intubate a patient. The line of questioning with the anaesthetist was different as the questions were directed toward the purpose of the airway devices as well as the differences between the hospital environment and pre-hospital environment.

For example I asked:

'What is the purpose of each piece of equipment? For example, the Filter, $ETCO_2$, the Catheter mount/ Cobb's connector, and BVM?'

'Are these pieces of equipment used in the hospital environment? '

'To your knowledge, is there much of a difference of the order of the equipment between Paramedics and anaesthetists?'

I used a narrative inquiry approach when interviewing the paramedicine students and the experienced paramedic. A narrative inquiry approach involved using detailed 'stories' of experience to elicit a response from the participant (Privitera, 2015a). For example, I asked the participants to 'think back to a specific time where an Airway Management procedure didn't go as planned by them or a colleague'. This allowed the participant to share their experience with the equipment. It also highlighted different challenges within pre-hospital care and the airway management equipment.

The advantage of asking a participant if they had heard of a colleague experiencing any difficulties was that they could share that story if they did not have one of their own due to lack of experience.

Critical Artefact

Critical Artefact/Cultural Probe is one method that was beneficial to use during the interview as this elicited a response from the target user (Milton & Rodgers, 2013). A cultural probe was used as part of the pre-design research phase as it focused on that broader context of experience (Sanders & Stappers, 2015).
As part of the interviewing process, I used a critical artefact with the Paramedicine students and experienced Paramedic (figure 19-21).

I read out an emergency scenario that accompanied the critical artefact and asked questions afterwards to record their responses. Participants were asked to imagine they were in an emergency and they were the paramedic that needed to insert the airway device. I would give them the critical artefact and ask them how they would feel using that piece of equipment. This helped me gain insights into how Paramedics may think in an emergency. It also helped identify opportunities for design with the airway management equipment.

Figure 19. Critical artefact LMA with hourglass attached

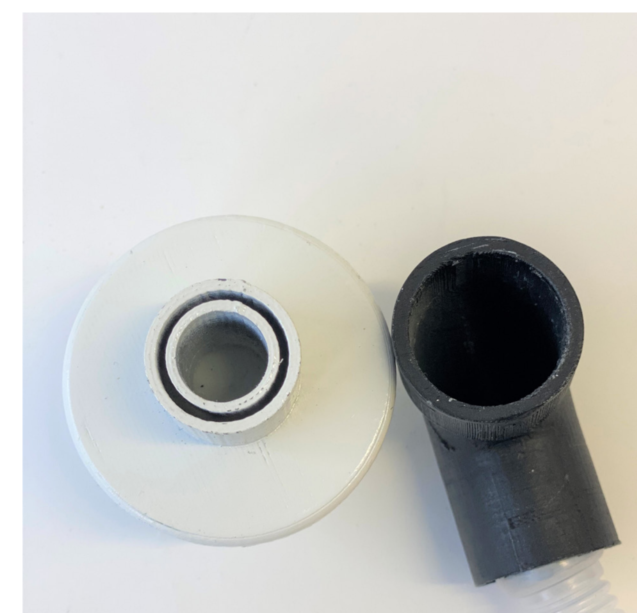

Figure 21.Critical Artefact large connector pieces.

Figure 20.Critical artefact exaggerated Cobb's connector length

Market Analysis

Market analysis involved surveying what products are currently available on the market (Milton & Rodgers, 2013). I researched what Filters, and $ETCO_2$ devices, Airway Management storage and Tube holders that are currently available. I then analysed each image and noted the differences and similarities. This was a useful method as I could find out about similar products used overseas. It also helped highlight how ergonomics in the pre-hospital environment could be better improved.

Product autopsy

Product autopsy is a method that allows a designer to gain a better understanding of design decisions that were made for existing solutions (Milton & Rodgers, 2013). I conducted a Product Autopsy on the existing Airway Management equipment that AUT's Paramedicine Department provides for their Paramedicine students.

I photographed the pieces of airway management equipment paramedics may use during a resuscitation. I carefully inspected each piece of equipment and analysed the photos to highlight how each piece of equipment functions. The airway management equipment I analysed ranged from the airway devices (basic devices, advanced airway devices), airway equipment accessories (filter, Cobb's connector, $ETCO_2$ device, PEEP valve, tube holder), and ventilation equipment (bag valve mask device, oxygen tubing).

Analysing the equipment allowed me think about how my design could be manufactured. I was also able to investigate the ergonomics of each piece of equipment. Design is not just about aesthetic, it is also about user experience and usability (Milton & Rogers, 2013)

OBSERVATION METHODS

Ethnographic Study

Conducting an ethnographic study is a method that studies the target user in their environment (Milton & Rodgers, 2013). An ethnographic study was a useful method as it helped to determine how Paramedics react to emergencies and investigate how a high cognitive load affects their ability to use airway management equipment. The information gathered from this study helped highlight specific use patterns of equipment and behaviour (Privitera, 2015b). It was also an excellent way to collaborate with users (Privitera, 2015b).

It would have been beneficial to see a real-world emergency to gain a better understanding of the factors that influence Paramedics. Riding along with Paramedics on an ambulance would be ideal, however it would be unethical as it would be challenging to gain informed consent from patients (Söderholm et al., 2019). It would also be time consuming waiting for the right call (cardiac arrest) (Söderholm et al., 2019) .

I observed two simulations of a Cardiac Arrest with two paramedicine students. This simulation is routinely used as practice for the students. Each simulation lasted 15 minutes and at the end of the simulation, the patient (training manikin) had a Return of Spontaneous Circulation (ROSC) which meant that their heart started beating on its own. Both participants had the opportunity to perform an Advanced Airway Management procedure on a training manikin during the simulation. The simulation was conducted by an AUT lecturer who controlled the manikin's vital signs from an observation room (figure 22). I reviewed the video recordings for details I may have missed. It also helped me understand the protocols involved with Airway Management. During the simulations, I was also able to ask the AUT lecturer about certain behaviours and procedures.

Figure 22.Simulation suite at AUT South Campus where paramedicine students train for patient resuscitations with a high fidelity training manikin.

While it might be expected that following a HCD approach, the patient would be the focus of the research. In this case the patient is unconscious and is unaware of any airway management intervention. As such, the HCD focus was on Paramedics. Furthermore, the ethical constraints would have made it challenging to identify and recruit former patient as participants if they were to be part of this research.

Think-aloud session

A think-aloud session is when the researcher asks the participant to verbalize their actions when performing a task (Privitera, 2015a). The purpose of this method is to reveal aspects of their behaviour or opinions that may be challenging to recognise through observation alone (Privitera, 2015a).

This was an essential method as the video recorded cardiac arrest simulation, I conducted as part of the ethnographic study, was a fast-paced scenario which did not allow for questions to be asked by the researcher. The think-aloud session allowed participants to verbalise their actions in a slower paced setting. I scheduled four 'think-aloud' sessions with four participants. Three participants were third year Paramedicine students, and one participant was an experienced Paramedic. Each session, the participant was asked to verbalise their actions when inserting an LMA device into a patient (training manikin). I video recorded these sessions and took screen shots of the video to conduct a Task Analysis on it.

ANALYSIS METHODS

Task Analysis

Task analysis is a research method used to identify how a primary user performs specific procedures and how the environment might influence their actions (French, Taylor, & Lemke, 2019). Conducting a task analysis through observing the cardiac arrest simulations helped identify how Paramedics operate and highlighted errors which revealed opportunities for design (Bitan, 2020).
I am a designer who does not have any medical training or knowledge. This method allowed me to gain a better understanding of how the equipment was used. I analysed screen shots of the simulation video I recorded. This allowed me to better understand paramedic's behaviour during a Cardiac Arrest. By using a task analysis, I was able to break down the movement and behaviour of participants when using the airway management equipment.

I conducted a Task Analysis on recorded simulations and the think-aloud session. This was done by annotating the screen shots of each video and breaking down how the airway management equipment was accessed, prepared, and how paramedics communicated with each other. I was able to highlight differences between the different simulations and the think-aloud sessions. The Cardiac Arrest simulations, although not a real emergency, showed a glimpse into what the pre-hospital setting might look like during an emergency. The task analysis also gave me the opportunity to map the different factors that impact Paramedics in the pre-hospital environment.

I also conducted a Task Analysis on a YouTube video created by the AUT paramedicine department about High-Performance CPR, prior to conducting the simulations with participants. I used screen shots from the video and focused on the Airway Management segments of the video. This allowed me to see how more experienced experts approach the airway management process. I then compared this to my simulations and think-aloud session, as I found differences with each approach. The limitation with using a video online was that it mainly focused on CPR and the camera angle was not focused on the head of the patient where the Airway Management procedure was performed. So, it was difficult to see how equipment was prepared or attached to the LMA.

Journey Mapping

A journey map allows designers to understand a user's experience of a product or service (Kushniruk & Parush, 2020).

I created a visual map of the journey a New Zealand Paramedic may take when they respond to a cardiac arrest and commence Advanced Life Support (ALS).

This was done after I conducted interviews with Paramedicine students and the experienced Paramedic. I also gathered information from YouTube videos about High Performance CPR, and from documentary TV shows such as Rapid Response (2010), Paramedics (2018), and Ambulance Australia (2018).

I needed to understand how Paramedics work on a typical shift to create a map of their journey.

I initially used post-it notes to label each stage of their journey— from receiving the call, to commencing CPR and then eventually achieving Return to Spontaneous Circulation (ROSC) (patient's pulse returns). This allowed me to visualize the whole resuscitation process. I did not map other potential paramedics on scene because this would complicate the map and the other paramedics on scene may be assigned different tasks and may not be involved in the Airway Management task.

Empathy Mapping

Empathy allows designers to gain an insight into a person's needs (Siricharoen, 2020). Empathy mapping is a tool that allows the designer to consider what a person is thinking and feeling (Siricharoen, 2020). After the interviews I conducted with the Paramedicine students I created an Empathy map which consisted of what paramedics think and feel during an emergency. This allowed me to gain an insight into what Paramedics experience when they respond to an emergency. As I have never experienced providing Advanced Life Support in an emergency context, this helped me gain some insight into how Paramedics react, think, and feel.

Thematic Analysis

Thematic analysis is a systematic approach in analysing qualitative data by identifying common themes or patterns (Mills et al., 2012). The process of analysis consisted of reviewing the interview transcripts, task analysis of the think aloud session, and user feedback sessions to identify common themes. I coded the data and categorised it into themes which allowed me to see what issues there are with the airway management equipment and process.

IDEATION METHODS

Sketching

Sketching enables designers to give form to distinctive design solutions (Milton & Rogers, 2013). This method is usually used at the start of the design process to help a design quickly visualise an idea and help give freedom to explore different possibilities of an idea (Milton & Rogers, 2013). Thematic sketches are used to explore how a design may work (Milton & Rogers, 2013). They help communicates a product's form, characteristics, and aesthetic (Milton & Rogers, 2013). This method was extremely useful as I could quickly communicate potential design solutions and visualise my ideas.

I used a mixture of analogue sketching (pen and paper) and digital sketching (on an iPad or computer) to work out design details and to visualise what potential concepts may look like. This low-cost method was also an excellent way to communicate my thinking.

Prototyping

Prototyping is an essential problem-solving method that allows a designer to create physical models to test their ideas (Hallgrimsson, 2012). Prototypes evolve over the course of the design process and usually start out as low fidelity models that act as initial three-dimensional sketches (Hallgrimsson, 2012). During the design process these evolves into high-fidelity models that better communicate the purpose of the design (Hallgrimson, 2012). It is a useful method that helps bring ideas to life and demonstrate size, proportion, and usability (Milton & Rogers, 2013). Physical prototypes can answer questions that might be difficult to achieve with sketching and CAD models (Hallgrimsson, 2013). Like sketching, prototyping is an iterative process which involves making multiple models until the product meets the brief and serves its purpose (Hallgrimson, 2012).

I used a mixture of making processes and materials to create prototypes of my concepts. For low fidelity prototypes I used cardboard, foam board, clay and blue/gold foam. When I needed to present concepts to participants, I used high fidelity concepts that were 3D printed and made from soft materials (canvas, cotton). This was also a quick way to prototype these designs to communicate the form and intended function.

EVALUATION METHODS

User testing/feedback

User testing involves taking a prototype of a design concept and inviting end-users to test it to provide feedback (Milton & Rogers, 2013). I conducted four user testing sessions with seven participants that each lasted approximately 15 minutes. I video recorded each session to review later to identify the interactions with the designs. I also asked questions in relation to each concept. I conducted three user testing sessions with two, third year paramedicine students. I developed the designs further and incorporated any suggestions for improvement in the next design.

I conducted two user feedback session with experienced paramedics. This was conducted at a Central Auckland Ambulance Station. I was able to gain valuable feedback from the paramedic participants as they could draw from their experience working with airway management equipment.

I also conducted three user testing sessions with three postgraduate paramedicine students. The user testing sessions with the third-year students and postgraduate students occurred in educational classrooms at AUT's South Campus.
The participants were asked to imagine that they were in an emergency and that they needed to set up the equipment for an airway device insertion and use each concept. This allowed me to see how they would interact with the products in an emergency. During some use feedback sessions, a training manikin was used in place of a 'patient' and in other feedback sessions I used a 3D printed head as I could not gain access to the training manikins used by AUT.

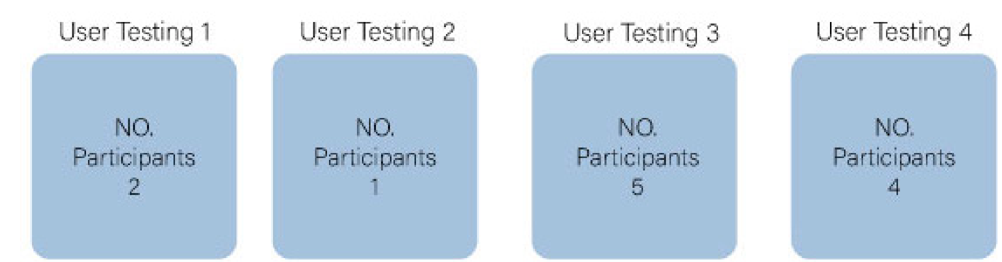

Figure 23. Diagram of number of participants per user testing session.

The participant numbers and experience varied with each user testing session (figure 23). This meant there was not consistency in the number of participants per session who provided feedback.

Concept Matrix

A concept matrix was a valuable tool that helped me evaluate my concepts against the criteria I set up for myself (Milton & Rodgers, 2013). I created a checklist of the requirements each design needed to meet. I then evaluated the concepts against the checklist by adding a plus sign (+ better than), minus sign (- worse than) , or equal sign (= equal to). I totalled the number of plus signs and chose the concept which had the high number. This helped guide me into deciding which concept I should develop further. This was helpful as I could evaluate which concept would be more useful for the end-user. I then took the concepts that better matched the requirements and developed them for the user. Afterwards I set up user-feedback sessions with participants to test these ideas and gain further feedback.

Reflective Practice

Reflective practice is a framework for inquiry that combines research and practice as well as through action (Gray & Malins, 2016). Reflective practice helps encourage different ways of reflection (Gray & Malins, 2016). For my research project, I reflected throughout the different phases of my research.

Reflection was a useful tool to document what tactics worked well in this research and what did not work well. Consequently, this helped me apply what I learned from previous decisions to adjust my approach to the research when necessary. This was a form of Reflective practice called 'Reflection-in-action' which involved thinking about what I was doing and reforming action while I was doing it (Gray & Malins, 2016).

After each stage of research, I would reflect on what I had learned, what challenges I faced and how I overcame those challenges. This was an important tool as it allowed me to think more deeply about my research and assess what I had learned from each research method.

CHAPTER THREE

DOCUMENTATION OF RESEARCH

Assumption Map

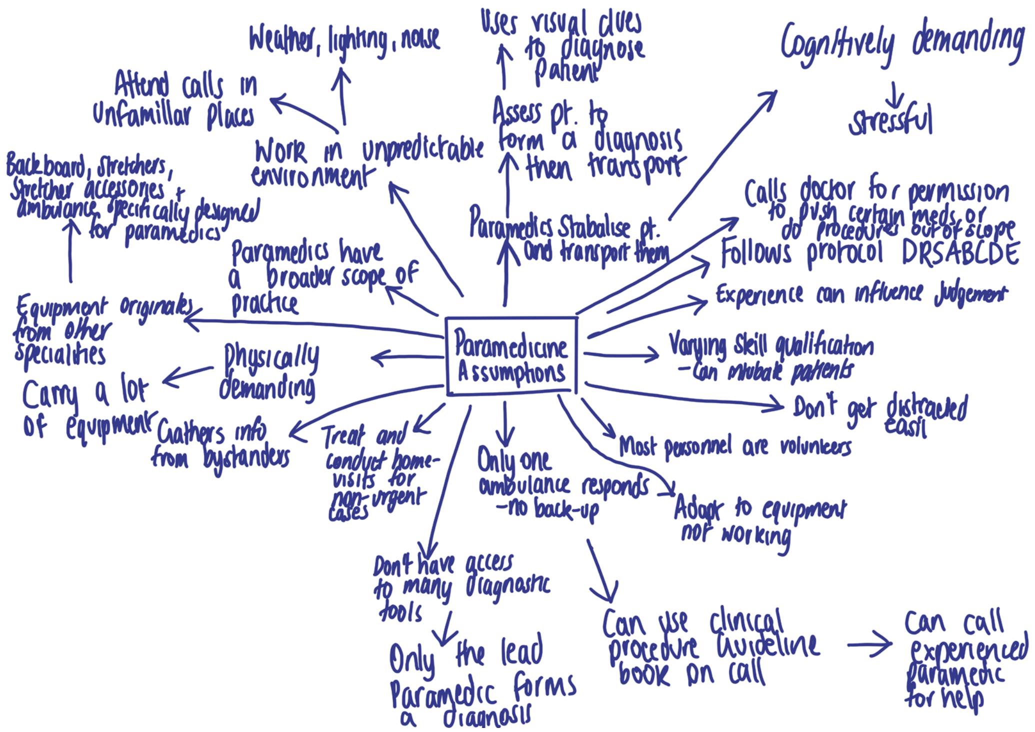

Figure 24. Assumption Map of my assumptions regarding paramedicine and the role/scope of practice of a paramedic.

At the beginning of my research journey, I wrote down my assumptions about Paramedicine and the airway management process.

I found that through the research journey, some of my assumptions were wrong. For example, I thought paramedics just treated patient's symptoms and transported them to hospital, when in fact they form a diagnosis and treat the patient according to the diagnosis. Once the patient is stabilized, then they transport the patient to hospital.

Another assumption that was incorrect was that during a cardiac arrest, only one ambulance is dispatched. It was only through expert interviews, that I learned that there could be two to three ambulances dispatched to a cardiac arrest and the fire service could also be on scene aiding.

The assumption mapping allowed to me to find out the information I did not know and helped me learn more about paramedicine, and the skills and scope of practice each paramedic has.

Examining airway management videos

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https://www.youtube.com/watch?v=ycQs27YVE60&t=242s

Figure 25.Examining a step-by-step video on how to insert an advanced airway device into a patient. (Paramedic Science, 2017). Note this video demonstrates using an I-Gel which is similar to an LMA but it does not need to be inflated. This is a shortened version of the steps.

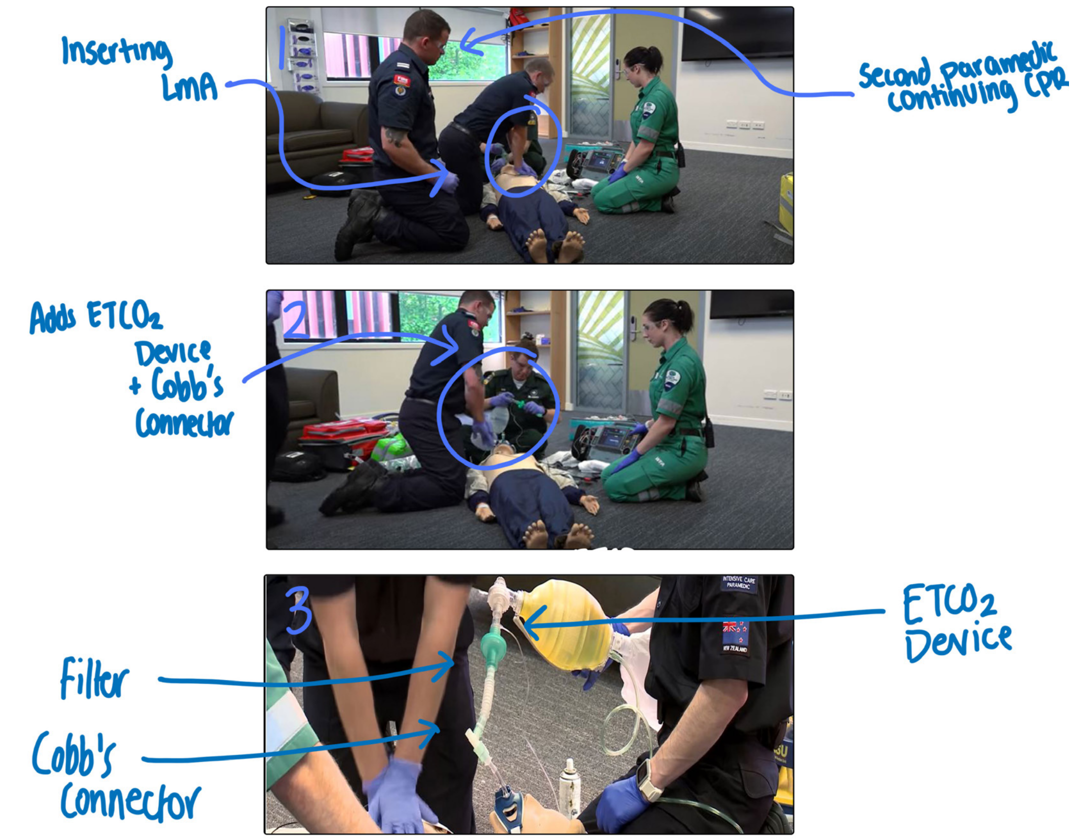

Figure 26. Task Analysis of airway management procedure in High Performance CPR video. Note: These were some of the screen grabs from that video. (AUT Paramedicine, 2019).
Reprinted with permission of Wellington Free Ambulance, St John, Fire and Emergency NZ and AUT.

The instructional video allowed me to learn how an airway management device is inserted into a patient (training manikin) (figure 25) while the AUT high performance CPR (2019) video showed the airway management procedure in the context of a simulated patient resuscitation scenario (figure 26). The instructional video was slow paced as it was broken down into steps to make it easier to understand how to perform the airway management procedure. Whereas the high-performance CPR video was a fast-paced scenario with a patient (training manikin) needing advanced life support. This cardiac arrest scenario highlighted what a 'real' emergency may look like with various paramedics and healthcare providers on scene to help the patient. It also helped me understand what external factors might impact paramedics when responding to a cardiac arrest call some of which included external noise (from AED), gathering patient information, and keeping track of time. By understanding these factors, it allowed me to think more deeply about how design can have a positive impact in a stressful, busy environment.

Insights

Figure 27. Environment of emergency was a well-lit room. (AUT Paramedicine, 2019).

Note: Reprinted with permission of Wellington Free Ambulance, St John, Fire and Emergency NZ and AUT.

Figure 28. Paramedic is preparing a towel to lay equipment on. (AUT Paramedicine, 2019)..

Note: Reprinted with permission of Wellington Free Ambulance, St John, Fire and Emergency NZ and AUT.

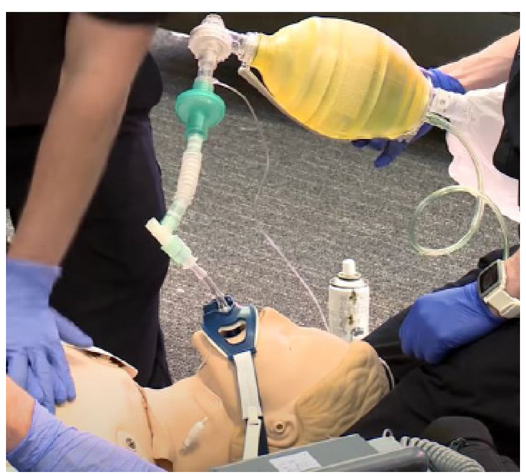

Figure 29. Configuration of Airway Management equipment. (AUT Paramedicine, 2019).

Note: Reprinted with permission of Wellington Free Ambulance, St John, Fire and Emergency NZ and AUT.

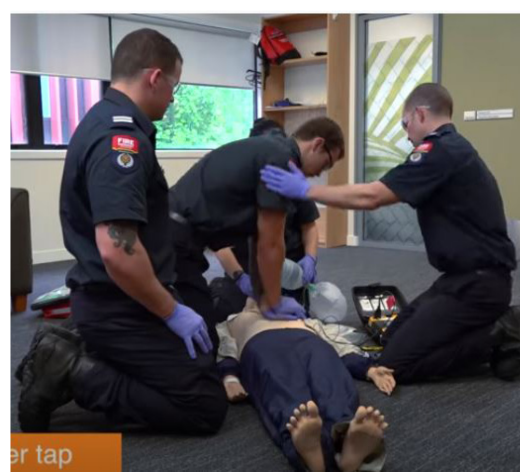

Figure 30. Communicating to paramedic that shock is advised using a shoulder tap. (AUT Paramedicine, 2019).

Note: Reprinted with permission of Wellington Free Ambulance, St John, Fire and Emergency NZ and AUT.

Environmental factors

Although the emergency scenario took place in a well-lit room, it did highlight external factors that may impact paramedics during an emergency. One factor is noise from the AED. The metronome was on to help the paramedic performing CPR to keep track of the speed of chest compressions as they need to pump the chest at 110 beats per minute (BPM). Each CPR cycle lasted for 2 minutes (AUT Paramedicine, 2019)

Equipment Preparation and Placement

Equipment was prepared by one paramedic and laid out on a towel. This was a 'clean' surface for paramedics to prepare the equipment on. When the initial paramedic who was preparing the equipment, swapped tasks and took over chest compressions, another person had taken the role of preparing the airway management equipment and eventually inserted the LMA device into the patient. There were a lot of steps taken before the airway device was inserted into the patient. After it was inserted, there were a lot of airway 'accessories' to add on to the device to ensure ventilation.

Equipment configuration

I found that even as an instructional video, the AUT High Performance CPR video had a different configuration of equipment when the Laryngeal Mask Airway was inserted. The configuration was Cobb's connector, filter, and $ETCO_2$ as opposed to the 'correct' configuration of filter, $ETCO_2$, and Cobb's connector.

Team Work/Communication

During the patient resuscitation, after a full cycle of CPR, an offsider paramedic near the AED, would check (using the AED) if the patient needed to be shocked with electricity to 'start' the heart. If a shock was advised, the offsider paramedic would communicate to the paramedic performing chest compressions, that the patient will be shocked. This was done by the offsider paramedic tapping the shoulder of the paramedic performing CPR. This could be because it is quite a noisy environment and communication through touch may also be a better way to communicate that they need to stop compressions. If the paramedic performing chest compressions does not move out of the way, they may receive an electric shock from the AED.

Human Factors/Ergonomics of an emergency scene

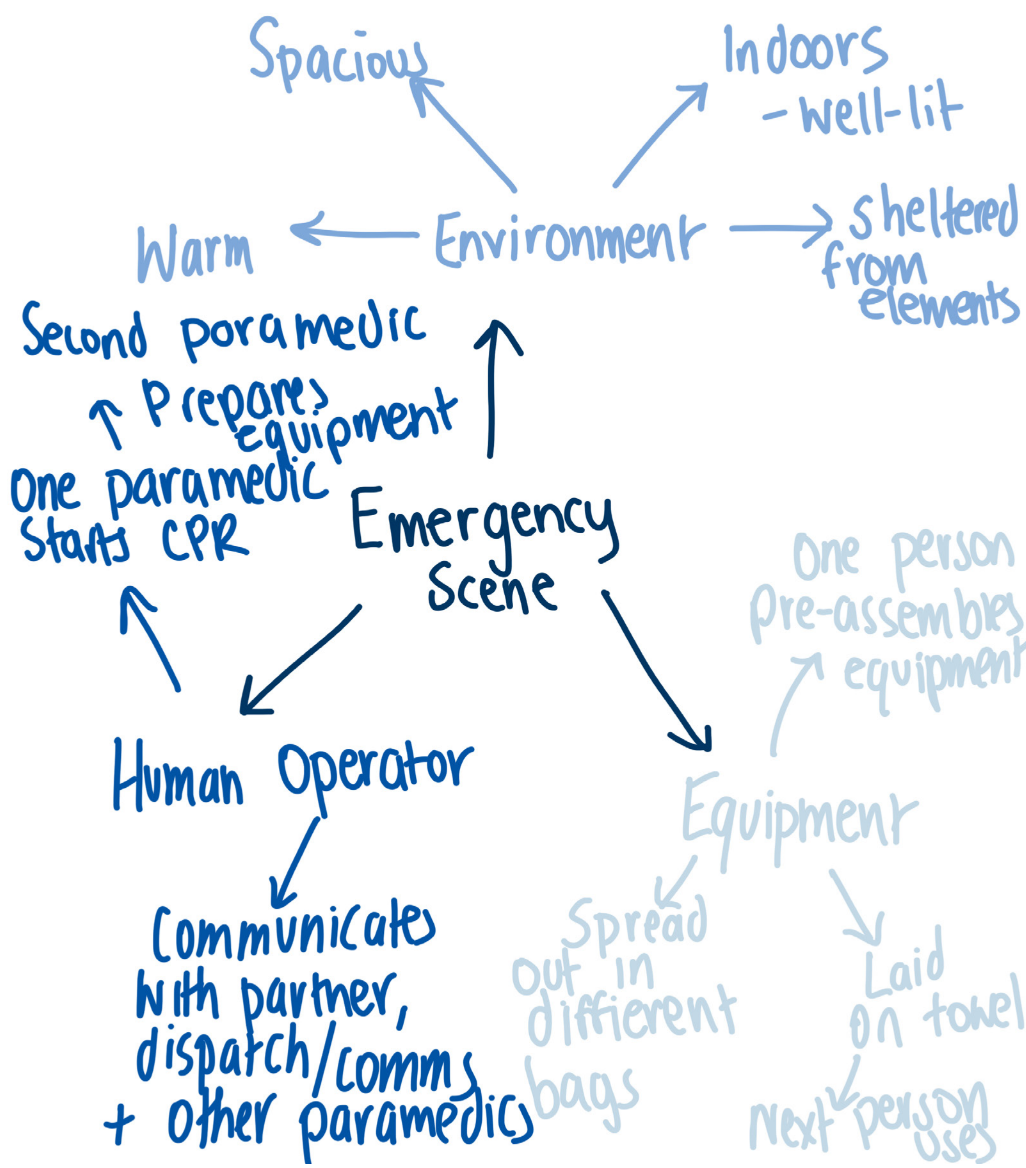

Figure 31. Map of factors that impact paramedics during patient resuscitation.

I mapped the factors that impacted Paramedics during the emergency. Using Bitan's (2020) three pillars of design for emergencies framework, I was able to map the different f actors present t hroughout t he emergency scenario. T his framework allowed me to gain a better understanding of the human factors and ergonomics I needed to consider for design.

From this I discovered that there were a lot of external factors that impact a paramedic. For example, there was noise from the AED, equipment spread out in different bags, and communication with other paramedics on scene.

Expert Interviews

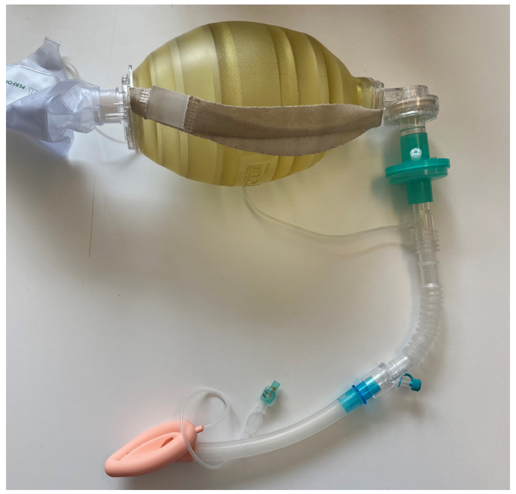

Figure 32. Airway Management equipment connected.

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https://www.tvnz.co.nz/shows/paramedics.

Figure 33. Example of equipment sequence from TV show Paramedics. (Paramedics, 2020).

The initial expert interviews led to a number of insights related to the issues with airway management equipment in the pre-hospital setting. I found that these issues were similar to the insights generated from watching the online High Performance CPR video.

Issues with connecting airway management equipment

Once an airway device is inserted into a patient, there are additional devices that need to be added to facilitate oxygen ventilation.

Three participants thought that there were too many pieces (Filter, $ETCO_2$ device, and Cobb's Connector) to fit together. One recurring theme was the need to connect the equipment quickly and the fact that connecting all these pieces together— the filter, $ETCO_2$ device, Cobb's connector, BVM—wastes time.

Figure 34.Example of equipment sequence from AUT high performance CPR video (AUT Paramedicine, 2019).

Note: Reprinted with permission of Wellington Free Ambulance, St John, Fire and Emergency NZ and AUT.

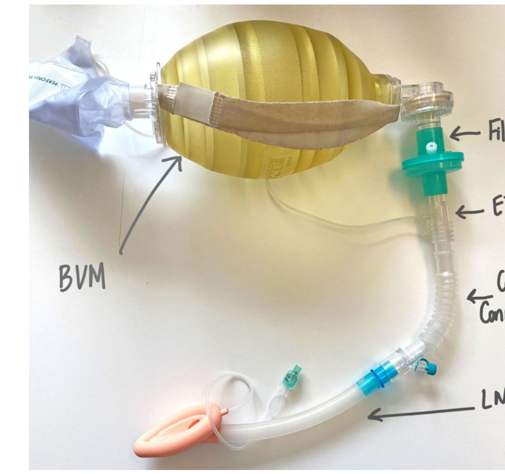


Figure 35. Correct sequence of equipment.

Especially if they are trying to connect it the incorrect way. This emphasised the need for a design that is faster and easier to use. A fascinating point was that the third-year paramedicine students, who have just learned how to insert airway devices and have done emergency simulations have noticed how time consuming it can be trying to connect all the equipment together in the correct configuration in a time critical situation. This highlighted how the frustration of trying to connect the airway management equipment in a time-sensitive situation could lead to increased stress levels.

Sequence/ Configuration of airway management equipment

Most participants felt that, during an emergency, it is quite difficult to connect all the airway management equipment in the correct order. Despite there being a guideline to the order of connecting all the airway management equipment, the

Figure 36.Example of an I-Gel.

paramedicine students connect each piece of airway management equipment in a different way. Whereas the experienced paramedic, knew and connected all the airway management equipment in the correct way because that is the correct procedure.

It is possible that over time, and with more real-life experience, the students may remember the correct configuration of airway management equipment. It is important to connect the pieces in the correct way so that the equipment is protected from vomit, aspiration, or bacteria (King & Cooke, 2012).

Muscle Memory

All the participants noted that they are trained so their actions become muscle memory. They essentially 'do' each procedure without 'thinking' too much about their actions. They also rely on their training and skills when administering Advanced Life Support.

Paramedics tend to rely on their memory of how to perform procedures so that they can focus on other tasks during an emergency. This highlighted the importance of introducing cognitive aids to help paramedics remember what they need to do or what they have forgotten to do. This is important as it is possible for paramedics to have cognitive slips like other healthcare professionals do when they perform a task 'without' thinking (Simmons & Graves, 2020).

Issues with equipment and issues as a result of patient type

One theme that arose during the interviews was issues of equipment not working or not catering for all body types resulting in paramedics adapting to the situation. The paramedicine students talked about the Laryngeal Mask Airway device failing in the field because of the inflatable cuff bursting. Another issue was with the patient's tongue flopping back and obstructing the airway which makes it difficult to insert the LMA into the patient.

The LMAs are manufactured in five different sizes according to age (size 1-Neonate, size 2-3 paediatric, size 4-5 adult). The size chosen is based on the weight of the patient.

Participants had issues or heard of issues with the existing LMA used in the field. One participant recalled having an experience where a patient was bariatric and had to adapt to insert the LMA by repositioning the patient. It is fascinating that paramedics must adapt to this situation instead of being provided equipment that is better designed to overcome these challenges.

Recommended Improvements

Most of the participants stated improvements that would make their experience using the airway management equipment on patients better. I-Gels are airway devices that were suggested as better alternatives to the LMA (figure 36). This issue is an organisational issue that is out of the scope of practice for this master's project. It is fascinating that pre-attaching the equipment was a preferred alternative to how it was used.

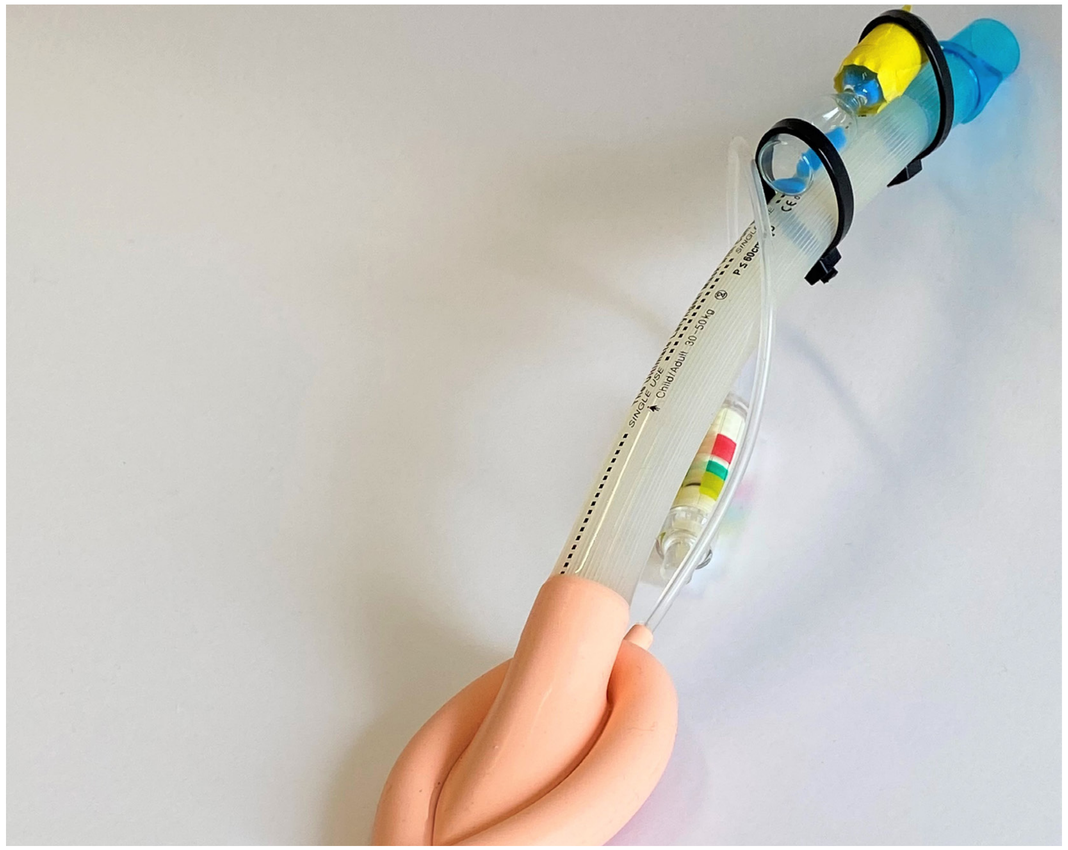


Figure 37.LMA critical artefact with an hour glass.

Figure 38.Exaggerated length of Cobb's Connector and Filter.

Figure 39. Larger connector pieces of Filter and Cobb's Connector.

When I presented the critical artefacts to the participants, they often tried to find a pragmatic purpose for the hour glass on the LMA. One participant also thought the exaggerated length of the Cobb's connector tubing and connector pieces would be beneficial when managing a patient's airway while another was frustrated and believed their stress levels would increase.

LMA with hourglass

The participants were curious as to the purpose of the hourglass. One thought it may time how long they have to insert the airway into the patient.

Longer Cobb's connector and filter

One participant thought that the exaggerated length of the Cobb's connector and the addition of an elbow connector would help with ventilation as they would not have to hold their arm up for very long. While another participants felt annoyed and stressed and deemed that because it does not fit, the equipment has failed meaning they cannot help their patient.

This was noteworthy as it underlines the mindset of a paramedic. In situations where the equipment does not work, they adapt to it and work around the issue. It also highlighted that equipment failing exacerbates feelings of stress and helplessness which drives them to adapt to help their patient.

Reflection

From the interviews conducted with the Paramedicine Students and Paramedic, it was apparent that the challenges faced had to do with the different parts that connected once an LMA or E.T tube has been inserted.

It was interesting that the Paramedicine students struggled with getting the right configuration of the equipment. It was also interesting that all three students stated that they are trained to the point where their skills become muscle memory. This was interesting as when I interviewed the experienced Paramedic this seemed to be the case. As it was challenging to describe the procedure without the equipment in their hands because it was muscle memory. Paramedics are trained to perform procedures without thinking about it too much as they must focus on other tasks.

Logistical issues arose when trying to organize times to conduct interviews (Groeneveld et al., 2018) with both paramedicine students and the experienced paramedic.

Recruiting participants for interviews was challenging as it was near the end of semester for Paramedicine students. They had exams to complete which may be the reason for low recruitment. It was similarly challenging to recruit experienced paramedics because of the nature of their shifts.

This was something that was out of my control, and it was something I had to accept and move on from. I was disappointed at the low recruitment rate but was grateful that I had some participants as their experience helped me gain an understanding of paramedicine and airway management.

Airway Devices

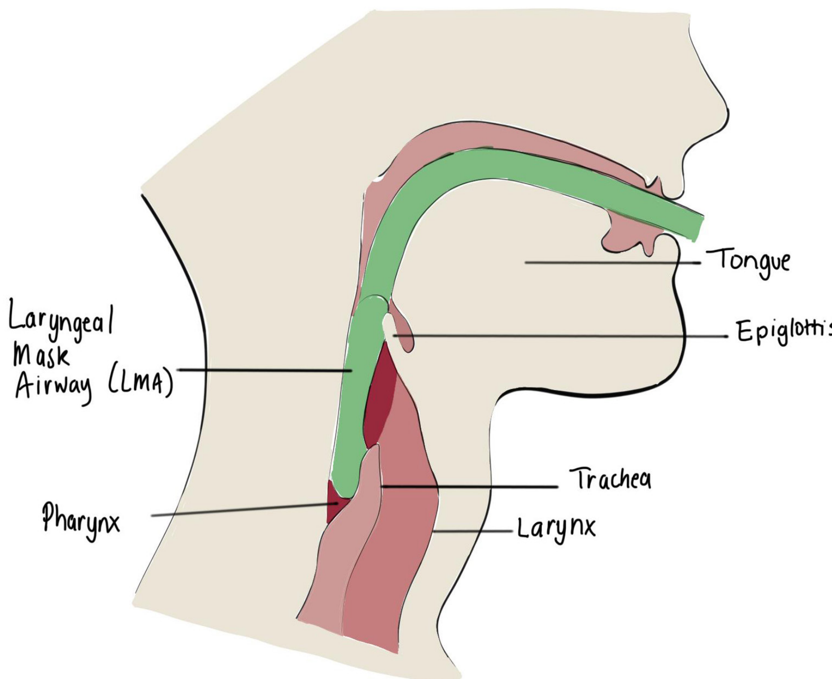


Figure 40. Diagram of epiglottis

Note: LMA inserted into Patient's airway.

Basic Airway Adjuncts

Basic airway devices are primarily used when a patient is semi-conscious, or has a decreased level of consciousness and may deteriorate and become unable to maintain a clear passage for airflow (Al-Shaikh & Stacey, 2013). There are two basic airways devices used—Oropharyngeal Airway (OPA) and Nasopharyngeal Airway (NPA).

Advanced Airway Devices

During patient resuscitation, more advanced airway devices may be required to maintain a patient's airway. Laryngeal Mask Airway devices and Endotracheal Tubes are primarily used in the pre-hospital environment by Paramedics and Intensive Care Paramedics.

Figure 41. LMA device.

Figure 42. OPA Device.

Figure 43. NPA device.

Oropharyngeal Airway (OPA)

This device is anatomically shaped and is inserted into the patient's mouth above the tongue (Al-Shaikh & Stacey, 2013) (see figure 42). This device ensures the patency (unobstructed) of the upper airway particularly in cases where the upper airway is obstructed due to the decreased level of consciousness in the patient (Al-Shaikh & Stacey, 2013). If a patient has a decreased consciousness it can lead to them losing pharyngeal tone which results in an airway obstruction caused by the tongue (Al-Shaikh & Stacey, 2013). This device is primarily used when patients are unconscious. (Kovacs & Law, 2008). This airway device is sometimes referred to as a 'Guedel Airway' and is made/manufactured in different sizes to accommodate patients of different ages—neonate to adult (Al-Shaikh & Stacey, 2013). They are made from plastic and have a bite-block that is colour coded to indicate the size of the device (Kovacs & Law, 2008).

Nasopharyngeal Airway (NPA)

Nasopharyngeal airway devices maintain a patient's airway by being inserted through the nose (Al-Shaikh & Stacey, 2013). It sits above the epiglottis (see figure 43) and below the base of the tongue (Al-Shaikh & Stacey, 2013). It is a useful alternative to the Oropharyngeal airway (OPA) device when the patient experiences locked jaw (also known as a trismus) (Al-Shaikh &Stacey, 2013). This is tolerated better in awake or semi-conscious patients with intact airway reflexes (Kovacs & Law, 2008). NPAs are made from soft materials such as silicone or latex (Kovacs & Law, 2008).

Laryngeal Mask Airway

The Laryngeal Mask Airway (LMA) is a device frequently used to maintain a patient's airway (Al-Shaikh & Stacey, 2013). It inserted into the trachea (figure 41) of the patient (Al-Shaikh &Stacey, 2013). This device allows Paramedics to insert the airway without needing to visualise the larynx and it is faster and easier to place when compared with Endotracheal tubes (Al-Shaikh & Stacey, 2013).

Ethnographic Study- Simulation One

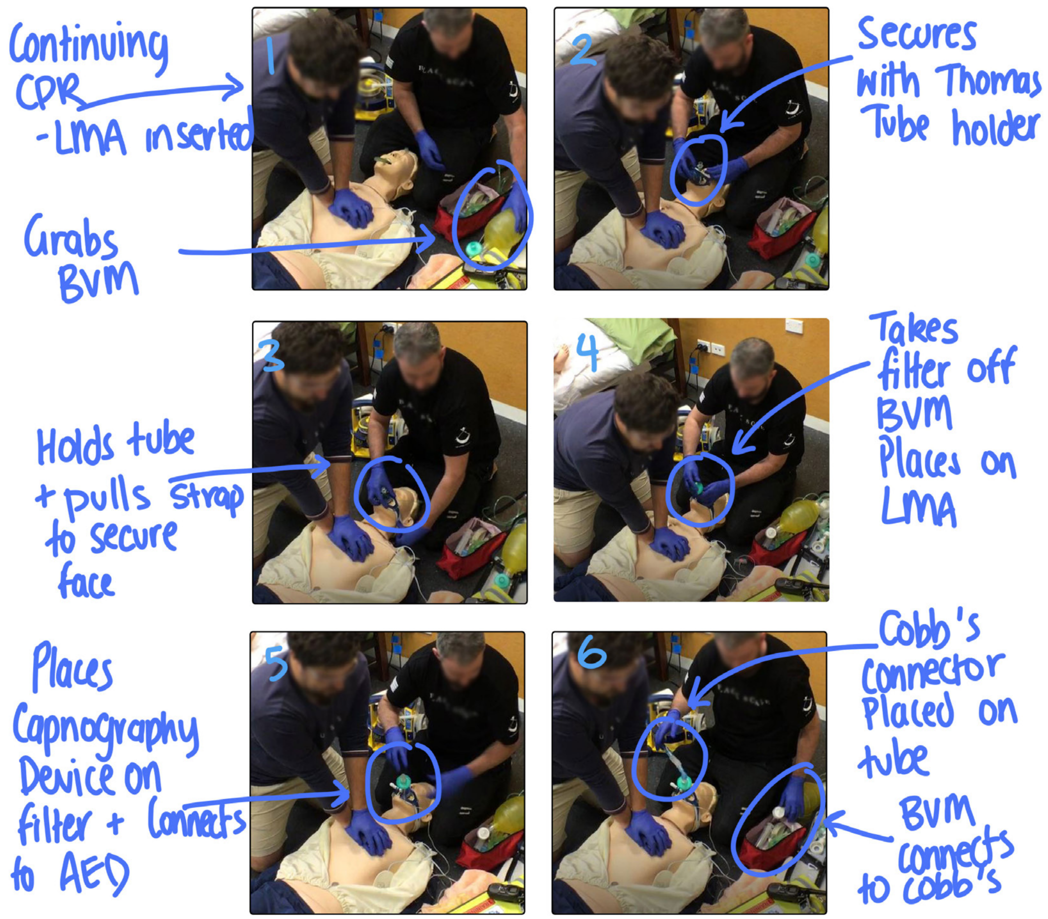


Figure 44. Task Analysis on the first cardiac arrest simulation conducted as part of this research. Annotations highlight behaviour patterns when accessing, using, and assembling the airway management equipment.

Ethnographic Study- Simulation Two

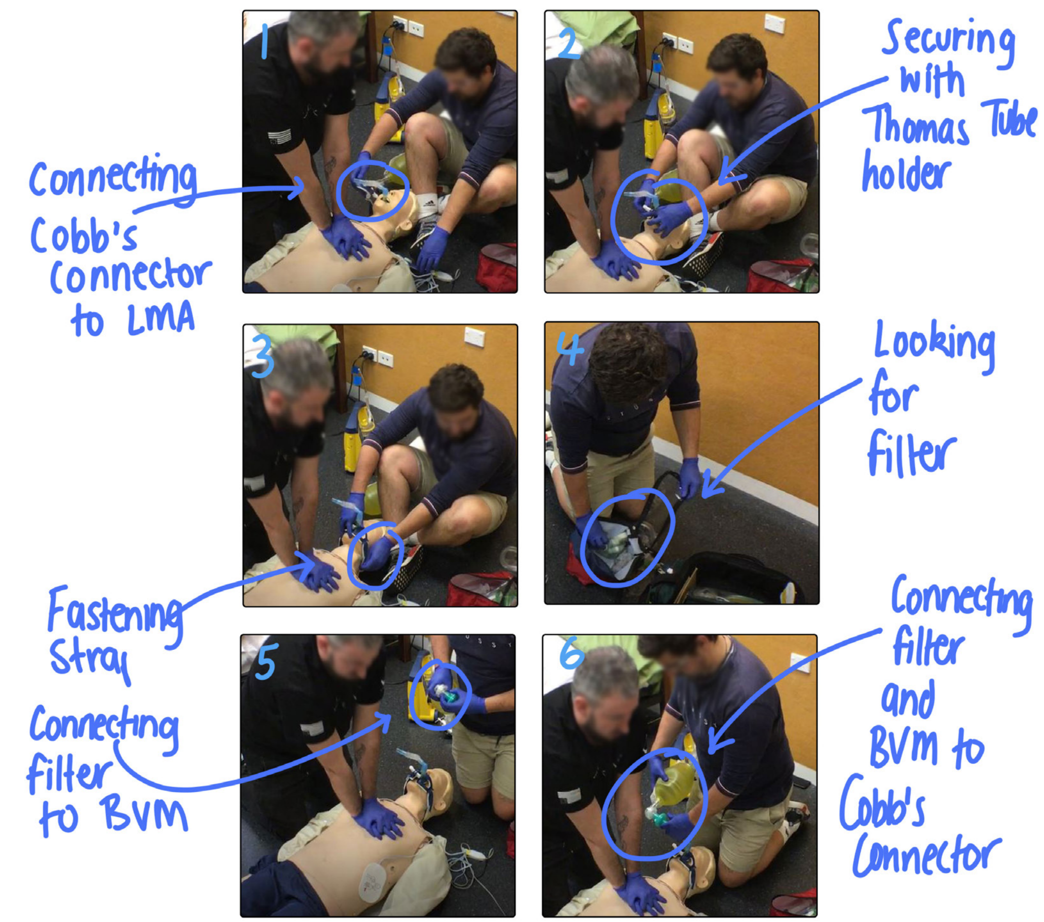


Figure 45.Task Analysis on the second cardiac arrest simulation conducted as part of this research. Annotations highlight behaviour patterns when accessing, using, and assembling the airway management equipment.

To identify an area for design, I needed to understand how paramedics approach emergencies, and use the airway management equipment. The cardiac arrest simulations allowed me to learn their airway management procedures in the context of a patient resuscitation.

In this simulation (figure 44.), the participant assembled the equipment in the correct sequence. They also spent time making sure the equipment pouch they grabbed from the bag had the equipment they needed.

The simulation demonstrated the cognitively and physically demanding part of being a paramedic. For example, in the simulation, there were noise distractions (beeping from the AED), an influx of information to keep track of (time, heart rhythm), and preparing equipment. It also highlighted the importance of teamwork in an emergency and communication as the two paramedics would often swap tasks after a cycle of CPR. This is because CPR is a physically exhausting task as one Paramedic is constantly pumping a patient's chest at a rate of 110 beats per minute (AUT Paramedicine, 2019). Due to the physically demanding nature of CPR, paramedics constantly rotate roles during different cycles of CPR. The Clinical procedure Guide (CPG) St John paramedics are given, stated that the CPR cycle lasts 2 minutes and the paramedic performing CPR should change every 2 minutes (St John, 2019). The CPG also stated that there should be a rhythm (pulse) check every 2 minutes (St John, 2019).

Think-aloud sessions

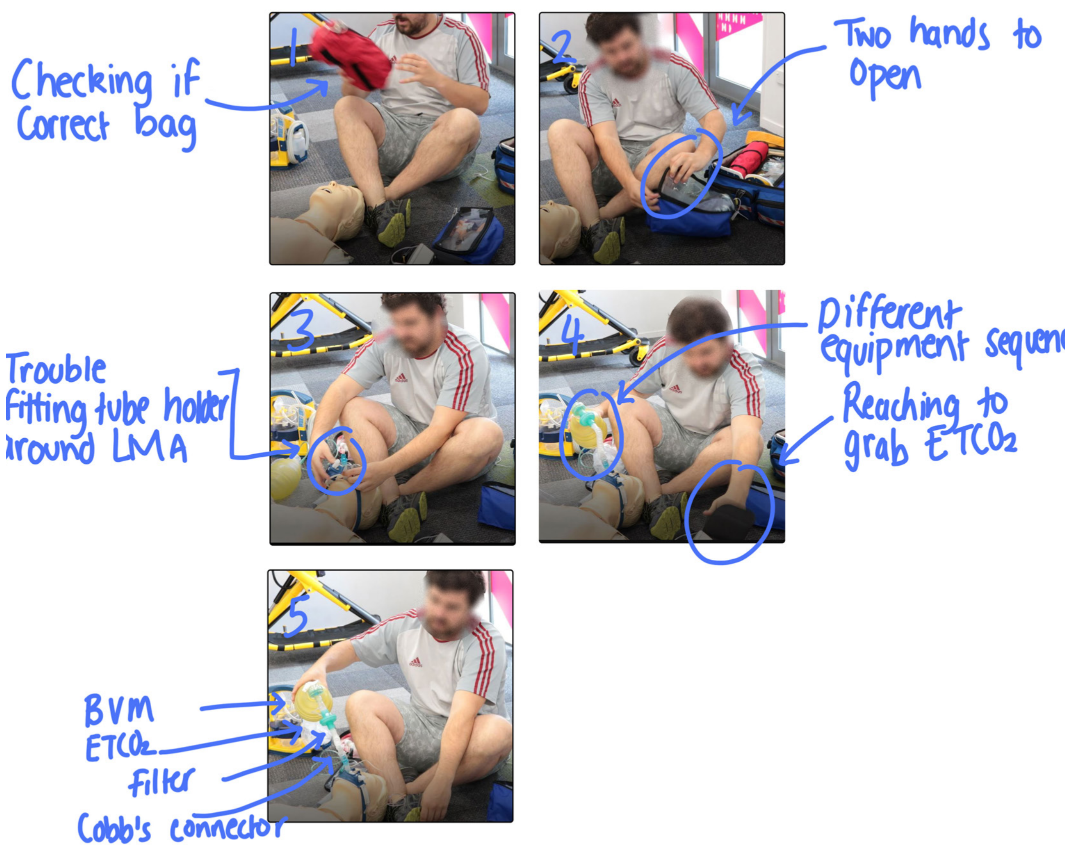


Figure 46. Think Aloud session of participant accessing, inserting and assembling airway management equipment. Annotated to highlight user behaviour.

The think aloud sessions consisted of participants performing airway management procedures on a training manikin while verbalising their actions. During these sessions, I learned more about the airway management procedures. For example, the amount of air needed to inflate the LMA and the amount of airflow titrated from the oxygen tank.

Figure 47. Think Aloud session of participant accessing, inserting and assembling airway management equipment. Annotated to highlight user behaviour.

I learned from the Think-aloud session, that the Cobb's connector is used for patient extrication as this gives the paramedic more room to manoeuvre around the patient if needed. This was interesting as this piece of equipment is no longer used in the hospital as it creates too much dead-space. But paramedics use it when they need to move the patient and ventilate at the same time.

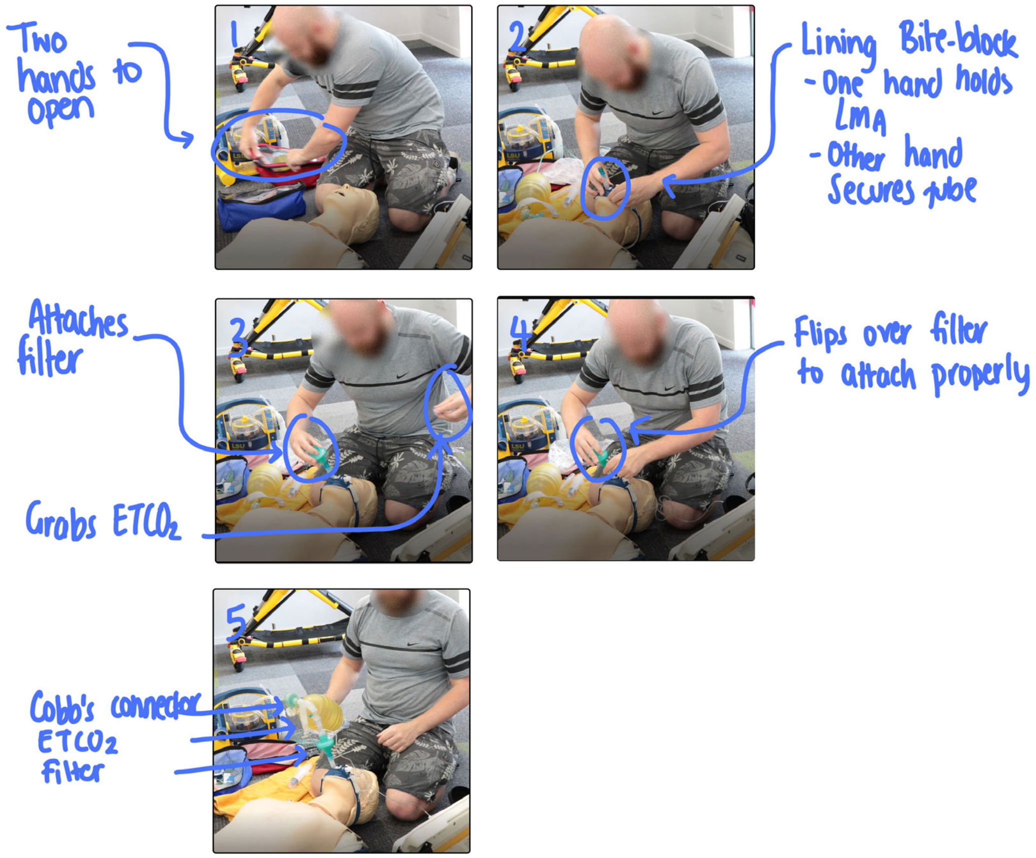


Figure 48. Think Aloud session of participant accessing, inserting and assembling airway management equipment. Annotated to highlight user behaviour.

Equipment Storage

Through observing the ethnographic study simulations, I discovered that the person initially in charge of the airway, takes three smaller bags from the Paramedic bag which contain the airway management equipment. They also check the contents of the bag by looking at the PVC window each smaller bag has. They spend some time trying to identify the equipment they have just taken out of the larger Paramedic bag. This presented an opportunity to create a design solution that reduces the time needed to retrieve equipment.

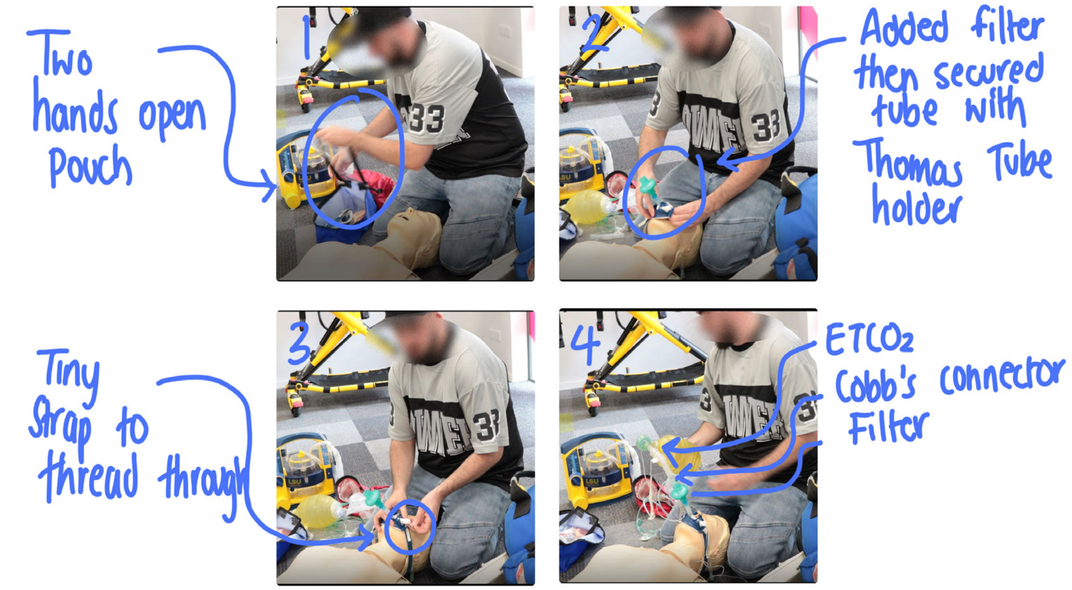


Figure 49. Think Aloud session of participant accessing, inserting and assembling airway management equipment. Annotated to highlight user behaviour.

During the think-aloud session , trying to find the equipment was also a theme that was occurred with the participants. They would have to check whether the bags had the correct airway management equipment they were looking for. During one of the simulations, the participant spent some time trying to identify the correct sized LMA. The participant also needed to search for the filter which wasted time.

Issues with equipment configuration

In both the simulations and think-aloud session, some participants would place the airway management accessories (filter, $ETCO_2$, and Cobb's connector) in an incorrect sequence.
I found that even though there is a 'guideline' for assembling the equipment, participants generally arranged it to suit them. They also thought any configuration is fine if all the equipment is attached especially in an emergency where this procedure is time critical. This was similar to the AUT Paramedicine (2019) video, which was a simulated cardiac arrest scenario. As mentioned before, this incorrect sequence of equipment could be due to the time pressure involved, forcing paramedics to quickly attach the accessories to ventilate the patient.

During one of the simulations, the participant connected the equipment in an incorrect sequence. It seemed as though they connected it based on what was in front of them a the time. They also ventilated the patient and then detached all the equipment to place the $ETCO_2$ device.

Issues with connecting equipment

There was an issue of connecting the filter onto the LMA in the correct way during one of the think-aloud sessions. The participant had to flip the filter around a couple times before connecting it to the LMA. This emphasized the need for design to prevent misuse with equipment to decrease time wasted troubleshooting the equipment.

Issues with tube-holder

Through my observations of the think-aloud session, I noticed one participant placed the Thomas Tube Holder upside down on the patient. This was an incorrect use of the product according to the product guideline. It further emphasised that people tend to use products to suit them in any given situation. This participant believed they were using the Thomas Tube Holder the 'correct' way.

Another interesting observation was that the slide stick on the Thomas Tube Holder snapped for one participant during the think-aloud session. This could be due to it being used for training so it could have wear and tear over time (single-use product). However, it called to attention that equipment can fail during patient resuscitation. To overcome this, design needed to consider how it may fail and needed to build in fail-safes.

Reflection

Similar reoccurring themes arose when watching the AUT high performance video (2019), the simulations and think-aloud sessions. These themes helped identify an opportunity for design. I received more information about Airway Management procedures during the Think-Aloud session compared to the interview. This could be because the equipment was in front of them which would make it easier to talk about.

The simulations tended to show the external factors that impact paramedics during a cardiac arrest while the think-aloud session was slower paced and allowed the paramedics to talk more about the purpose of certain actions or behaviours. I found that I could ask more questions to clarify equipment selection in the think-aloud session as this was not a simulated emergency where a 'patient' needed to be resuscitated so they had time to answer the questions. If I were to ask a question during the simulation, this would distract them from their tasks (CPR and airway management) which would not help me understand the factors that impact paramedics during an emergency. The benefit of conducting both the simulation and think-aloud session was that I could observe how paramedics behave during the simulation and also understand their choices and decisions in the think-aloud session.

The pre-hospital setting and cardiac arrests can be time critical. But there are multiple steps, and equipment needed to facilitate airway management. This underlined the need to consider time-pressure present and how design can help support paramedics during emergencies. The airway management equipment needed to be better adapted to the pre-hospital setting for paramedics working under time sensitive conditions.

I learned so much about the airway management process and patient resuscitation. I felt as though gaining this knowledge helped me gain a better understanding of paramedic behaviour and why they perform certain actions. This allowed me to think more deeply of where design could be beneficial within the airway management process.

Role-play

Figure 50. Trying to figure out which end of the filter connects to the LMA.

Figure 51. Attaching tube holder to training manikin.

Figure 52.Inflating the LMA after attaching the filter and Cobb's Connector.

It was an interesting experience inserting a Laryngeal Mask Airway (LMA) into a training manikin. It was quite challenging as the LMA needed to be inserted until resistance was felt. That was an indicator of the LMA being in place.

Once I inserted the LMA I tried to connect the Filter, Cobb's Connector and then BVM. As shown, in figure 51, I completely forgot to inflate the LMA cuff first and was carried away with assembling the equipment. When I did remember to inflate the cuff, I carried on and placed the tube holder on the patient's face. It was only after the role-play that I realised the tube holder was placed upside down (gap facing me) (as shown in figure 52).

I identified problems with securing the tube holder to the patient as it can be challenging threading the slide stick through the hole. I also discovered that the tube can be kinked if the Set Screw mechanism were screwed in too much which could lead to inadequate ventilation as the LMA or ETT would be compromised.

I also found myself checking which side of the filter would attach to the LMA because it was difficult to attach it when I first picked it up.

Although this role-play was not a cardiac arrest simulation, I did forget certain steps within the airway management process. This could be due to the fact that I am not a trained paramedic or paramedicine student and this was my first time using the equipment in the context of a patient. However, it did highlight that it was easy to forget the 'steps' of airway management if the paramedic has not had enough practice or training. It is a skill that requires constant training and experience.

This research method allowed me to gain a better understanding of what it is like to access, prepare, and use airway management equipment.

User Journey Map

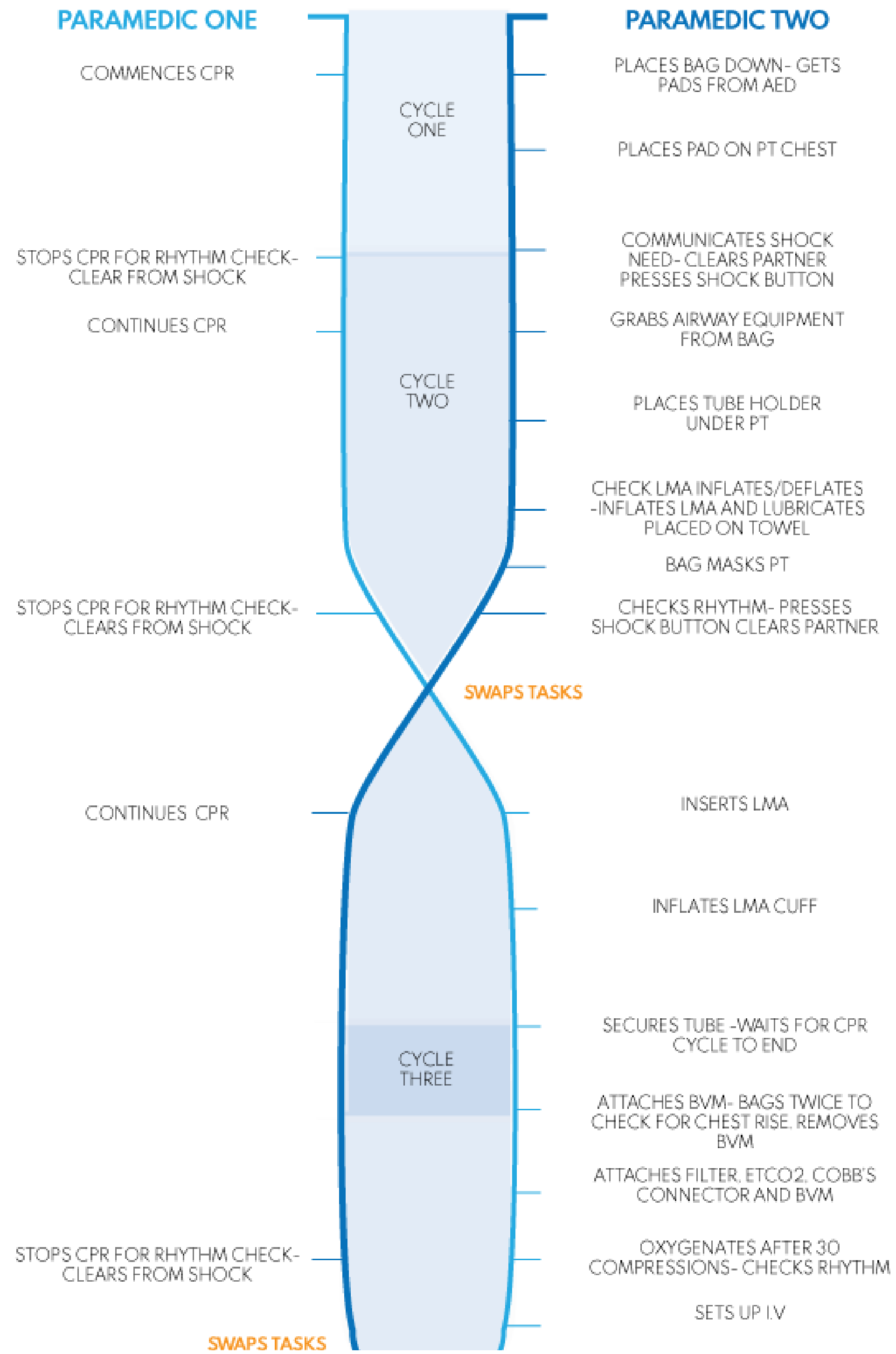


Figure 53. User Journey map of two paramedics attending a cardiac arrest emergency. This map is focused on the airway management part of resuscitation and demonstrates the amount of steps taken before and after an airway device is inserted into a patient.

I gathered information regarding how paramedics respond to cardiac arrest emergencies before I could create a user journey map.

The user journey map helped breakdown the process of cardiac resuscitation. It also highlighted that Cardiac Pulmonary Resuscitation (CPR) is a complex process that requires teamwork and good communication. Paramedics must take in a lot of information when helping a patient. There are a lot of steps to complete within each cycle of CPR. Figure 53 demonstrates how each paramedic swaps tasks and spends time preparing the airway management equipment. Each CPR cycle lasts for 2 minutes (St John, 2019) which means the paramedic in charge of the airway, needs to find the appropriately sized equipment, and prepare it before the third cycle of CPR.

Empathy map

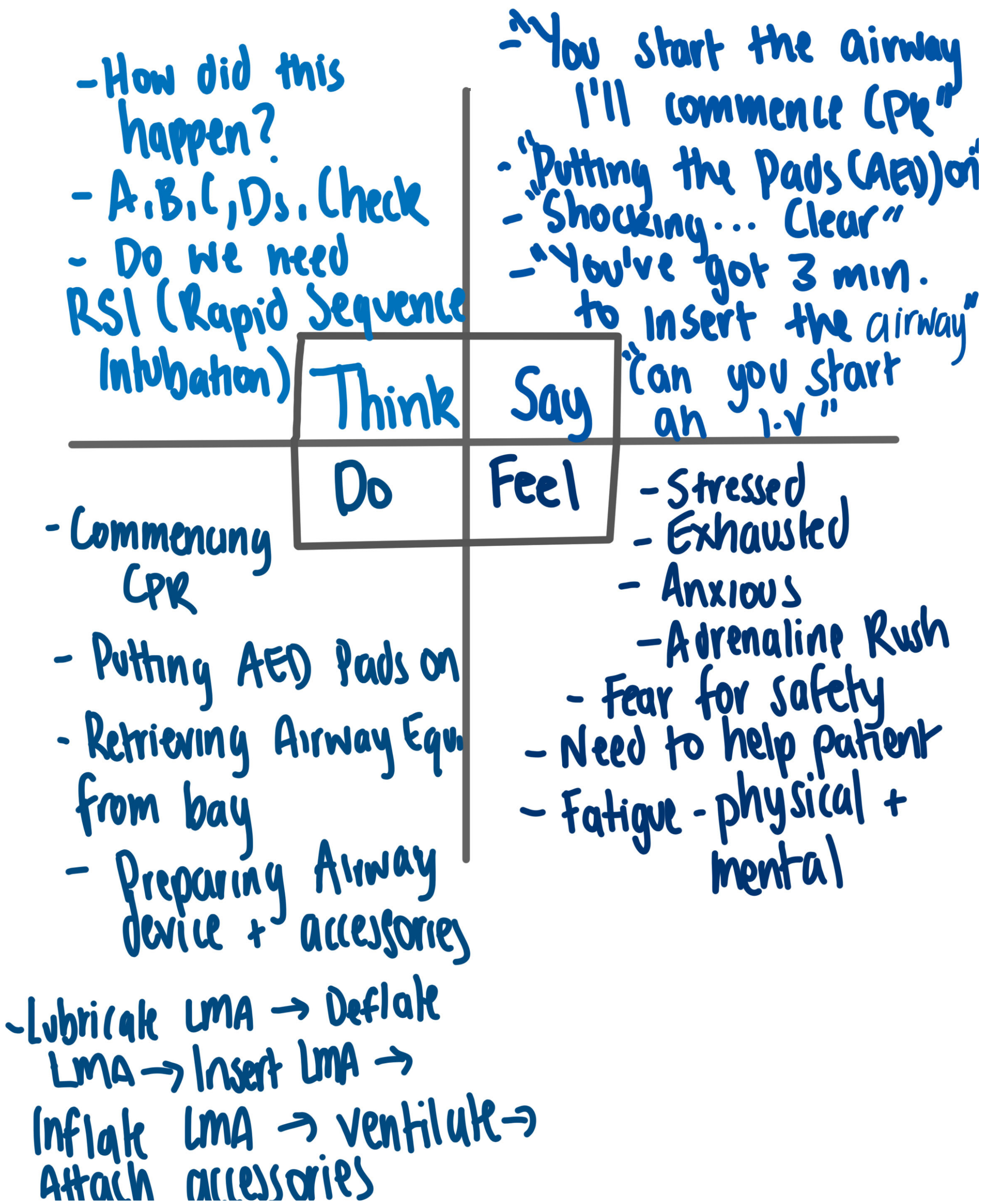


Figure 54.Empathy Map of what a paramedic may Think, Say, Do, and Feel at a cardiac arrest emergency.

To understand paramedics needs, I first need to build empathy. I mapped what it would be like to be a paramedic attending an emergency.

From the interviews, ethnographic study simulations and think aloud sessions, I tried to put myself in a Paramedics shoes. I noted down what I would say, think, do, and feel. This made me want to design something that could help alleviate feelings of stress and anxiety. Just thinking about providing Advanced Life Support brought about feelings of stress and anxiety. It's worth noting that I have not been trained for these situations, but paramedics have. Anderson et al. (2018) noted that in their interviews, Paramedics had to pretend to perform CPR in fear of the actions of the bystanders. Thinking about the emotions in this environment really highlighted that Paramedics must process a lot of information as well as being aware of their surroundings and their personal safety.

Reflection

It was challenging to recruit participants at the beginning of this research. It was also challenging arranging times to meet. What I learned from this experience was to make it easy as possible for participants to choose to participate. For example, I would arrange the time around the participant's schedule. Recruitment of participants takes time. The Covid lock-downs also impacted the Role-play session I initially arranged to do with an AUT lecturer to help me perform an airway management procedure on a training manikin. As a result, the AUT lecturer was busy after the lock-down and I had to complete this session on my own relying on online video tutorials.

A lot of insights were generated from the application from these research methods. I often had to watch the simulation videos a couple of times to see in detail what each participant was doing as the scenario was fast paced. Through each viewing, I would identify different patterns of behaviour regarding accessing the equipment, attaching the airway management equipment, and securing the LMA with a Thomas Tube Holder.

From the simulations and think-aloud session, it was apparent that participants would spend time rummaging through the bags to find the airway management equipment. Sometimes checking if the bag they have grabbed contained the airway equipment they needed. This could waste valuable time needed during a time critical cardiac arrest.

I identified three areas where design could positively benefit paramedics during patient resuscitation. These areas were connecting the airway management equipment together, the tube holder, and the airway management storage solution.

Please note: Each of the areas of design identified, were designed simultaneously but will be presented as separate design processes.

CHAPTER FOUR: DESIGN PROJECT ONE

CONNECTORS

Market Analysis: Filter, End Tidal CO_2 ($ETCO_2$)

Images have been removed by the author of this thesis for copyright reasons.

55. Fairmont Medical. (2021). Deltastatic Filters, HME Filters, Pleated Filters [Image https://www.fairmontmedical.com.au/product/anaesthetic-filters/.
56. Medical Expo. (2021). Air Filter [Image]. https://www.medicalexpo.com/medical-manufacturer/antibacterial-filter-30366.html.
57. Medical World. (2021). Filter/Catheter Mount [Image]. https://www.medical-world.co.uk/p/anaesthetics/breathing-system-accessories/filter/catheter-mount-x-1-luerlock-combined-clear-therm-3-hmef/40717.

Market analysis of filters overseas and in New Zealand.

Figure 55. Deltastatic Filters, HME Filters , Pleated Filters (Fairmont Medical, 2021).
Figure 56. Air Filter (Medicalexpo, 2021).
Figure 57. Filter/Catheter mount, (Medical world, 2021).

From the interviews, the simulations, and the think-aloud session, it was clear that there were issues with how the airway management equipment connects and fits. Participants would either forget the correct sequence of equipment or have trouble connecting them correctly under the added time pressure of a cardiac arrest.

I researched the current filter products and $ETCO_2$ devices that paramedics may use to try and understand what already exists on the market that may differ to the current products used by St John ambulance service.

Images have been removed by the author of this thesis for copyright reasons.

58. https://www.ems1.com/capnography/articles/3-things-to-know-about-capnography-and-advanced-airways-GykYDxO1GWMWGEAA/.

59. https://www.masimo.com/products/ventilator/capnography/emma-capnograph/?_t_id=1B2M2Y8AsgTpgAmY7PhCfg%3d%3d&_t_q=EMMA&_t_tags=language%3aen%2csiteid%3a7fa4a473-3872-42fb-b584-85c0e557d676&_t_ip=139.180.97.51&_t_hit.id=Masimo2_Models_Pages_StandardPage/_f7429ce1-8c9f-44e2-8307-43b8318ab0c6_en&_t_hit.pos=1.

60. https://www.boundtree.com/etco2-sampling-lines/c/189.

61. https://www.nejm.org/doi/full/10.1056/NEJMvcm1105237.

Market Analysis of $ETCO_2$ devices overseas and in New Zealand.

Figure 58.Waveform Capnography (EMS1, 2015).
Figure 59. EMMA Capnograph (Masimo, 2021).
Figure 60. ETCO2 sampling lines (Boundtree, 2021).
Figure 61. Monitoring Ventilation with Capnography (The New England Journal of Medicine, 2012).

The majority of the filters were a circular shape. Some were rectangular. Most filters had a straight connector at the top. Some filters had an elbow connector. The elbow connector may make it easier to attach to breathing circuits so it is not in an awkward position. Most filters had a port for a CO_2 sampling line which is like the $ETCO_2$ device.

The $ETCO_2$ device can come in different forms. There were two devices that have the reading directly onto the device (see figure 59, 61) where as the other devices are connected to an AED. The nasal prongs in figure 60 are for conscious patients but I added it to this market analysis as it functions the same as the $ETCO_2$ device.

The Filter, and $ETCO_2$ devices used by paramedics are similar to these ones. However, it seems as though the filters (figure55-57) may be used in the hospital setting. Viewing these filters underlined that they do not have to be circular or one size. They can vary depending on the manufacturer or intended purpose (hospital use).

Product Autopsy of Airway Accessories

HEPA Filter

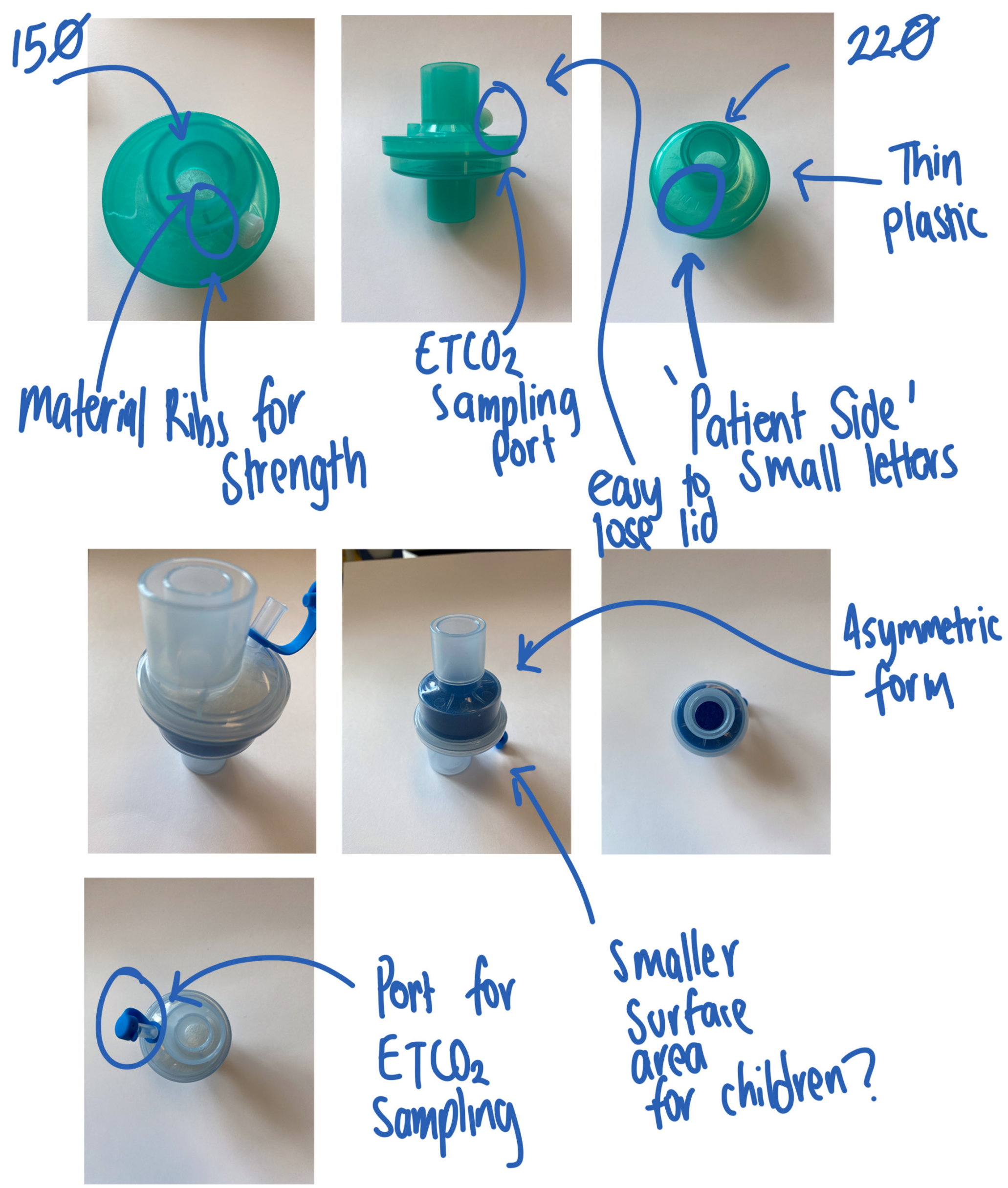


Figure 62. Annotated product autopsy of the HEPA Filter from AUT Paramedicine department, noting the material, the purpose of each part and the manufacturing process. St John paramedics use these filters.

A bacterial filter is added to the LMA or E.T tube to minimise the risk of contaminating the equipment (Al-Shaikh & Stacey, 2013). The HEPA filter is positioned as close to the patient as possible to protect the equipment attached to it (Al-Shaikh & Stacey, 2013).

The filter is made from plastic with an electrostatic fabric sheet in the middle of it. From the interview with the Anaesthetist I discovered it only lasts for 8 hours once the packet is opened. This makes sense as it will only be on the patient until they are transported to the hospital. Most of the equipment is designed to be used for short periods.

End Tidal CO2 device ($ETCO_2$)

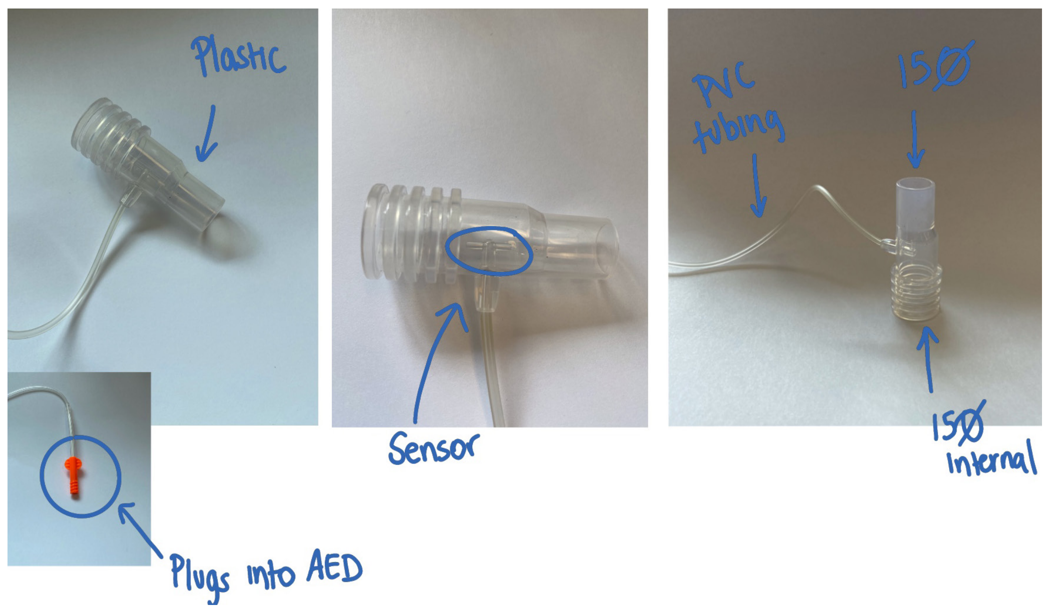


Figure 63. Annotated product autopsy of an End-tidal CO2 device ($ETCO_2$) investigating the purpose of each part.

End tidal CO_2 ($ETCO_2$) device allows clinicians to monitor the amount of CO2 inspired and exhaled during the respiratory cycle (Al-Shaikh & Stacey, 2013). This is device is connected to an AED which displays a Capnography which allows Paramedics to determine the CO_2 reading (Al-Shaikh & Stacey, 2013). This is important as it determines how much oxygen a patient is receiving and can help Paramedics form a diagnosis that impacts patient care. There is a hydrophobic head inside the $ETCO_2$ device and a filter in the clear cord to protect the AED from secretions from the patient.

The equipment above has universal connectors (ø22mm male and ø15mm female) that known as ISO connectors (International Organization for Standard) (Cook, 2012). ISO created a universal standard that ensures all anaesthesia equipment is compatible (Cook, 2012). However, these standards are voluntary and are not enforced by ISO (Cook, 2012).

Although this enables manufacturers to ship universally, and for breathing circuits and systems in hospitals to have an international standard, it does leave room for misuse. Simmons and Graves (2008) have stated that redesigning connectors (Luer connectors) to prevent misuse creates a safety net for healthcare workers. This applied to the ISO connectors as each piece of airway management equipment can be connected in a different sequence compared with the set guideline which makes it easier for paramedics in a stressful situation to connect it differently or connect it in a way that works for them. This highlighted how design in stressful situations needs to be resilient and not be easily misused.

Catheter Mount/ Cobb's Connector

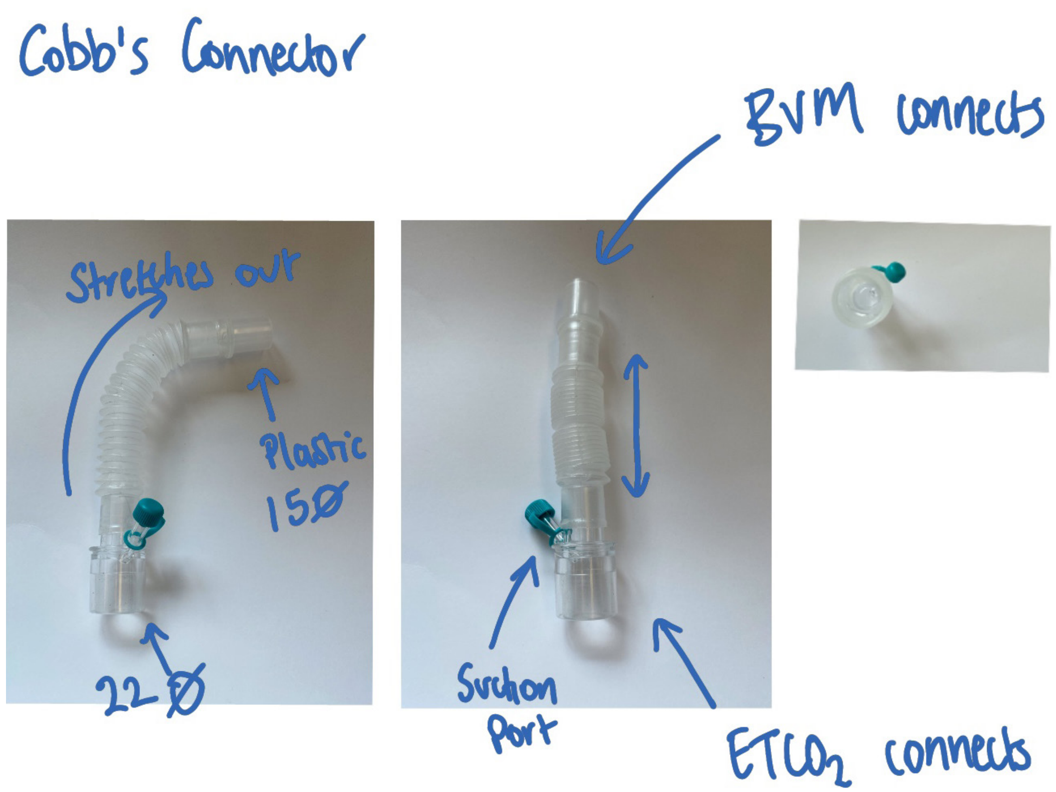


Figure 64. Annotated images of Cobb's Connector, analysing the size, the material and the purpose of each component.

A Catheter Mount or Cobb's Connector is a flexible, corrugated plastic tube that is attached to E.T tube, LMA or even a face-mask (Al-Shaikh & Stacey, 2013). It is disposable and has a concertina design that allows the length to be adjusted (Al-Shaikh & Stacey, 2013). Paediatric patients have different anatomy to adults which means they do not require a Cobb's Connector during airway management procedures because it creates dead-space (Fenlon, 2012; Al-Shaikh & Stacey, 2013). Dead space is when there is no gas exchange occurring (Mongolis, 2004). In the UK, surgery for children makes up 10% of the total surgery performed which results in the market for airway devices primarily focusing on adult sizes (Fenlon, 2012).

The Catheter Mount has a standard 15mm straight connector and a 22mm elbow connector (Al-Shaikh & Stacey, 2013). From the interview with the anaesthetist I found that the Cobb's connector is not used in the hospital because it creates dead space which differs from paramedicine as it is used in the pre-hospital setting for extrication.

I analysed the equipment that AUT's paramedicine department provides for their students. Most of the equipment was designed for single use— with exception of the Bag Valve Mask and Laryngoscope handles used by Intensive Care Paramedics.

From the expert interview with the anaesthetist, they confirmed the order of the airway management accessories. The filter is always first, then the end-tidal CO_2 device, a Cobb's Connector (only for adult patients) and then the Bag Valve Mask (BVM). The filter provides protection from contamination of the equipment.

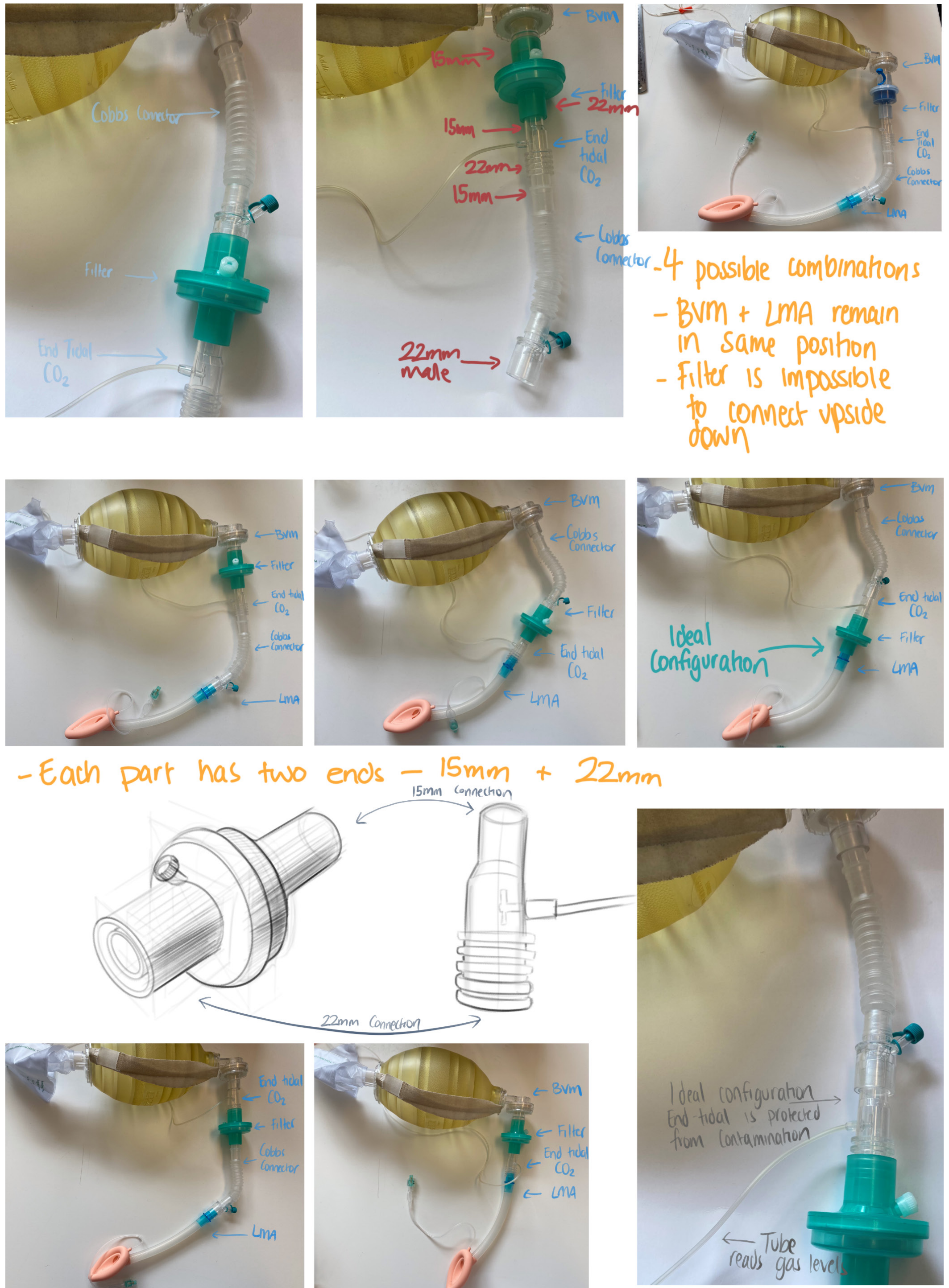


Figure 65. Exploring the different combinations the equipment can be connected.

I experimented with the configuration of the equipment to see how easy it was to assemble it differently. I discovered that there are four possible combinations of the same pieces of equipment— the filter, $ETCO_2$ device and Catheter Mount/Cobb's connector. This makes it easy for Paramedics to attach the equipment in any configuration that works for them.

I also discovered that it is impossible to attach the filter to the LMA upside down. This influences the equipment that is attached after the filter has been connected. However, it is still possible to attach the following airway management equipment in a different order.

I interviewed an Anaesthetist to find out more information of the different pieces of equipment. I interviewed an Anaesthetist because the Airway Management equipment originated from this department. Therefore, I thought they would have a good understanding of the equipment. It was fascinating that Catheter mounts are not used in the hospital setting but are used in the pre-hospital setting. This highlighted the differences of the environment and practice and the fact that in a pre-hospital setting extra equipment is needed. Especially during extrication. The equipment was designed for a hospital setting but is no longer used in the hospital. I discovered, from a participant, that the Cobb's connector is sometimes utilized in pre-hospital care because they need that extra space to manoeuvre around the patient or swap tasks with other Paramedics.

It was clear that the airway management accessories could be connected in a different sequence and the design allowed this to happen. After researching the connectors of the Airway Management equipment, I created a design criteria. The design criteria was created as a guideline for me to check my design against.

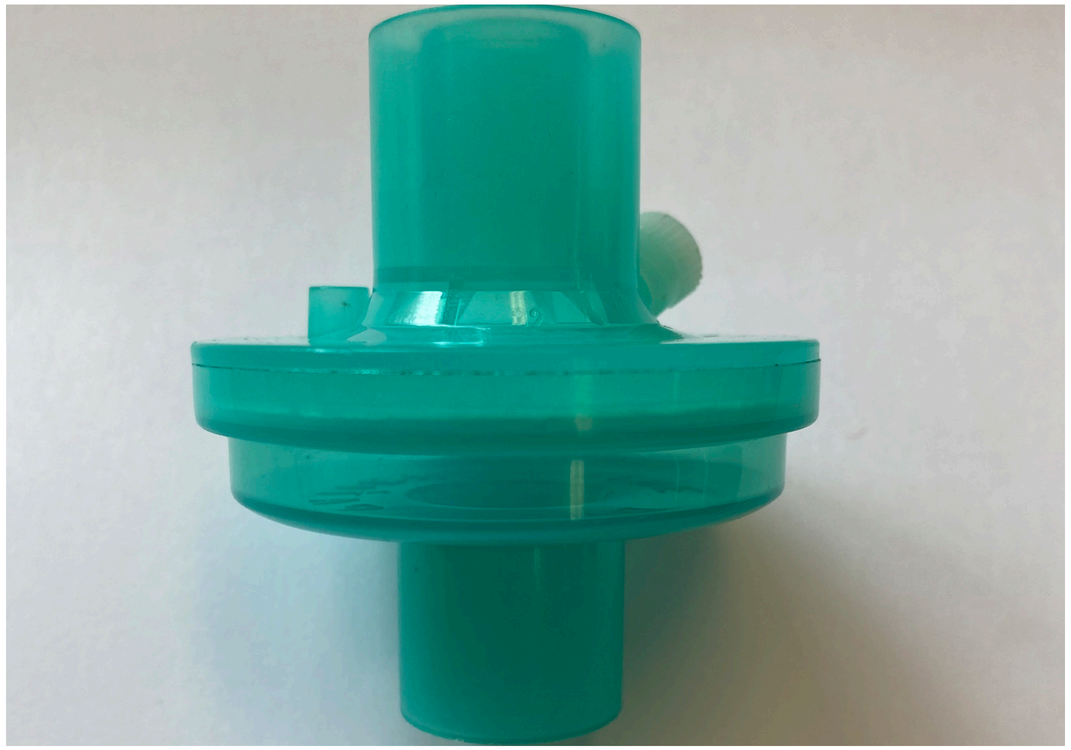


Figure 66. HEPA filter used by Paramedics.

Figure 68. ETCO2 device used by paramedics.

Figure 67. Cobb's Connector used by paramedics on adult patients.

Design Criteria

For a design to be beneficial I created a design criteria. The design of the connectors must be:

- Easy to use during high stress situations (i.e. an emergency cardiac arrest)
- Cannot be misused or connected in the incorrect way
- Easy to understand how each piece connects to one another

Ideation

Concept One

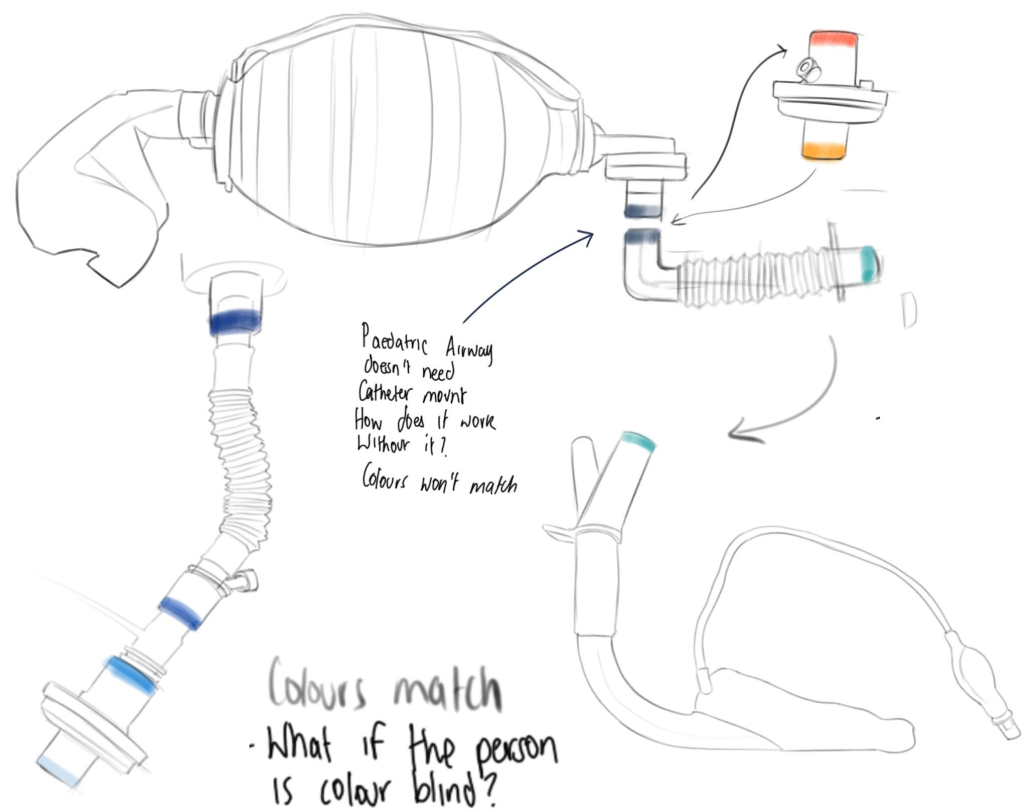


Figure 69. Ideation sketches of a colour coded system, inspired by a cognitive aid, to help paramedics connect the equipment in the correct order.

From the expert interviews, simulations, and think-aloud session, it was clear that an issue with the airway management equipment was how it all connects and fits together. Participants would either forget the correct configuration of the equipment resulting in the equipment being attached to the Laryngeal Mask Airway (LMA) in a different order or wasting time by not connecting the filter to the LMA the first time as it can only fit on one way. I discovered that size of the connector pieces adhere to a universal standard. I sketched concepts that made it easier to connect each piece of airway management equipment in the 'correct' way while working with the universal standard of connectors (ISO connectors).

The first ideation was to use a colour coded connector piece to communicate the correct order of connecting the equipment together.

Concept Two

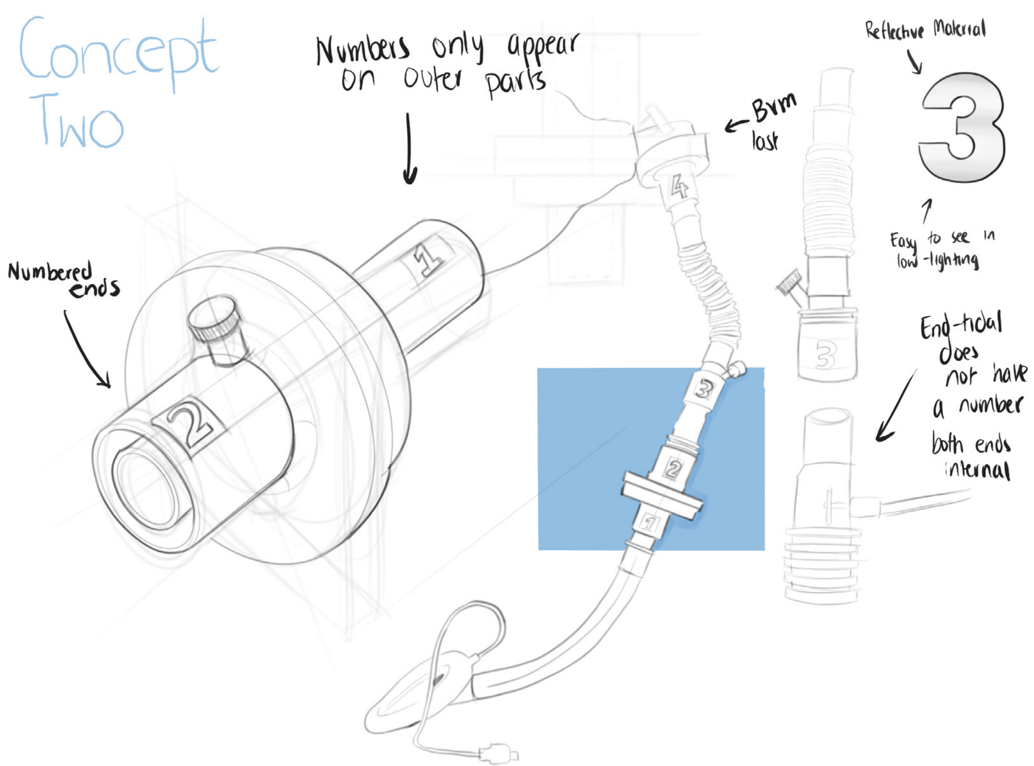


Figure 70. A numbered concept that acts as a cognitive aid to communicate the order in which the equipment needs to be assembled in.

I ideated concepts that would make it easier for Paramedics to assemble the equipment. This was inspired by the cognitive aids described above in the contextual review (figure 7-9). I thought that if I labelled the connector ends of the pieces of equipment it would help paramedics assemble it in the correct configuration during patient resuscitations. My thinking was that colour coding each piece would be a beneficial solution.

However, I came up with the second concept as I needed to think about people who would be colour blind or using the equipment in low-lit environments that may effect the hue of the colour.

Concept Three

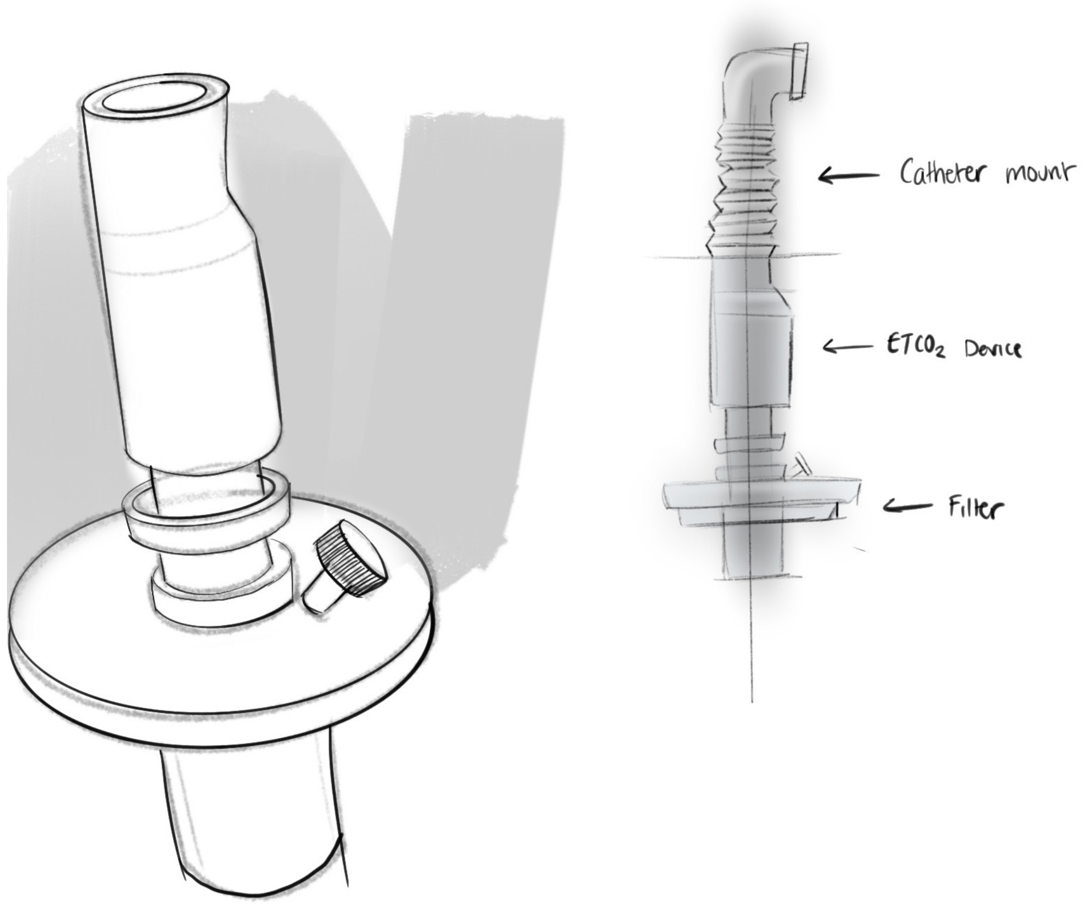


Figure 71. A sketch of a pre-assembled concept consisting of the HEPA filter, $ETCO_2$ device and the Cobb's connector being assembled as one piece.

I also created another concept where the equipment was pre-assembled which was suggested by one of the participants during the interview. During my contextual review I found evidence that syringes that were pre drawn, effected patient outcomes as they were faster for paramedics to use (Swinton et al., 2018). Using this idea, I designed a pre-assembled concept to reduce the cognitive load and possibly reduce stress by being faster to use.

Prototypes

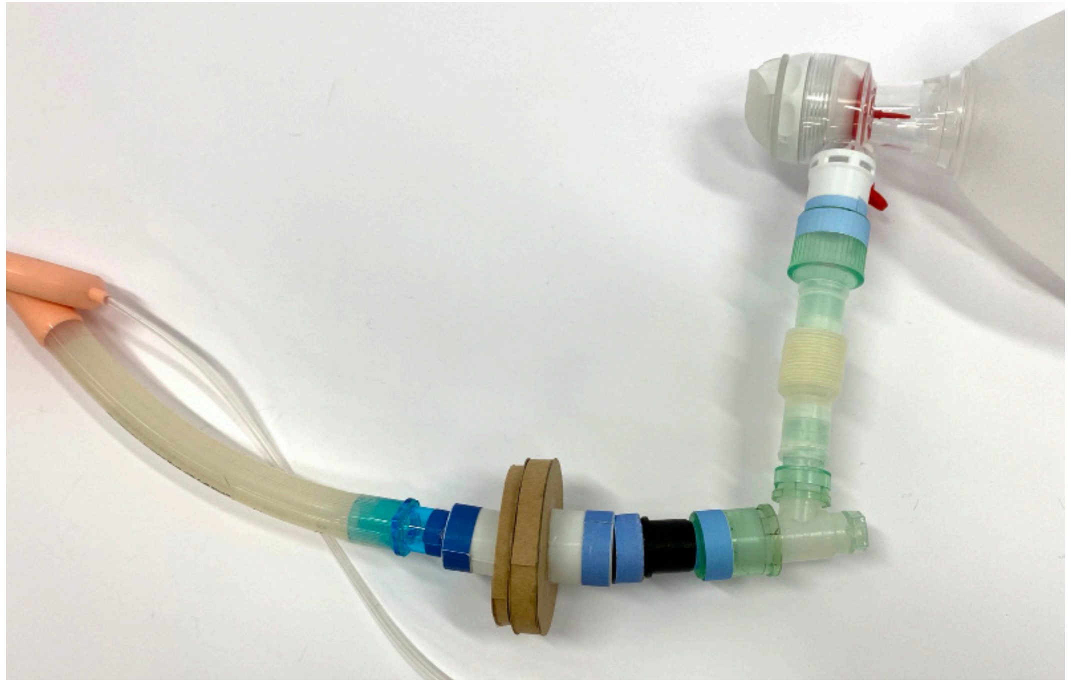


Figure 74. Prototype of colour coded concept, demonstrating how the equipment would fit together.

Figure 72. Prototype of numbered concept testing white numbers on a 'reflective background'. Numbers printed on a grey background to replicate a reflective material.

Figure 73. Prototype of numbered concept testing out numbers with a 'reflective' material. This was a paper model printed in grey to replicate a reflective material.

Figure 75. Pre-assembled concept of a Filter, $ETCO_2$ device and Cobb's Connector.

I created prototypes of all three design concepts. I wanted to gain feedback on these concepts so that I could choose the concept that better suited the paramedic's needs during patient resuscitation.

I had to 3D print the $ETCO_2$ device for all concepts as I could not borrow one from AUT's paramedicine department. This stood as a stand-in for the real $ETCO_2$ device.

User Testing Session One

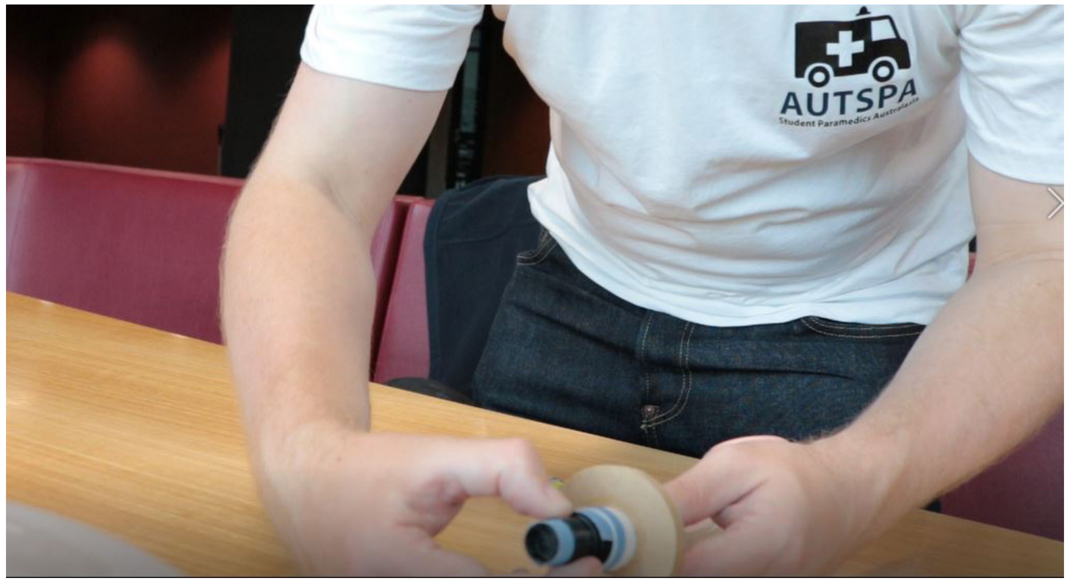


Figure 76. Participant trying to connect the colour coded connector concept.

Figure 77. Participant connecting the colour coded concept in the correct order.

Concept one: Colour coded connectors

Both participants liked the idea of having the connector pieces of each piece of airway management equipment colour coded. Participants liked the fact that they could easily assemble the airway management equipment according to colour. However, they both suggested that it should be changed to “rainbow” colours (red to red, yellow to yellow etc.) as shades of blue were difficult to match up.

Figure 78. Participant connecting the numbered concept filter to $ETCO_2$ device.

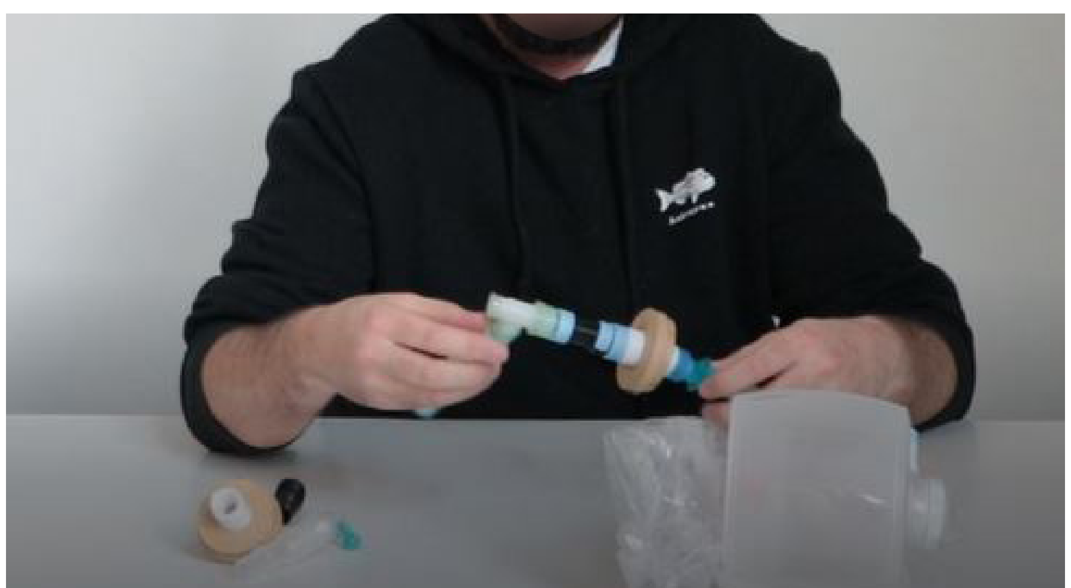


Figure 79. Participant connecting the numbered concept in the incorrect order.

Concept Two: Numbered Connectors

I asked participants to assemble each piece of airway management equipment according to the number that was labelled on the connector piece. Participants found this much easier to connect.

Interestingly the colour coded connectors on each piece of equipment were found to be more useful than connecting it by numbers. The numbers placed on the connectors were only located on the outer connection pieces and not any internal pieces (e.g. both sides of the $ETCO_2$ fit into the filter and Cobb's connector) which resulted in one participant connecting each piece of the airway management equipment in an incorrect configuration because the $ETCO_2$ device did not have any numbers on it. This meant that the $ETCO_2$ device really needs to have a sign on it so that all the equipment can be connected in the correct sequence.

Figure 80. Participant providing feedback on the pre-assembled concept.

Figure 81. Pre-assembled concept of HEPA filter, ETCO2 device and Cobb's Connector.

Concept Three: Pre-assembled airway accessories

I presented the concept of pre-assembled airway accessories which consisted of a filter, $ETCO_2$ device and a Cobb's connector.

This concept was viewed as saving time during an emergency as the main airway management accessories (filter, $ETCO_2$ device, and Cobb's connector) were taken out of the airway kit as one piece. Another interesting insight was that participants' thought this would reduce their cognitive load as there were less pieces of airway management equipment to remember to attach.

Concept Matrix

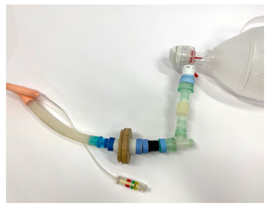
			
Easy to use	=	+	+
Easy to understand	+	+	+
Not be able to misuse	+	-	+
	2	2	3

Figure 82. Concept matrix comparing each connector concept to help decide which design is the best to move forward with.

Reflection

I used a concept matrix to decide which of these concepts would be better to move forward with(see figure 82). The pre-assembled concept had a higher score meaning it fitted the criteria I set out for this area of design. The scores for both concepts one and two were equal. I realised that concepts one and two were not solving the poorly designed system, it just reinforced it. I found through further research that if a sign (colour coded connectors or numbered connectors) needs to be put on a product to signal correct use it is highlighting bad design (Rutherford, 2020). Therefore, I moved forward with the pre-assembled idea.

This first user testing session really helped refine the design concepts and helped me choose which concept would be beneficial to develop further. It was helpful receiving feedback as participants have experience using the equipment in a high stress scenario (even if it was a simulation) which helped them think more about what would work best in that pre-hospital setting.

The concept matrix was helpful to decide which concept was overall the best to move forward with as both participants liked all concepts. They were also leaning towards the pre-assembled concept.

I discovered that the colour coded concept and numbered concept were reinforcing poorly designed systems which was not ideal as it meant it would influence paramedics to adapt to poor design. The pre-assembled concept was another approach to create a beneficial design solution that was helpful.

Participants feedback also influenced my decision to move forward with the pre-assembled idea. They were the experts in this field so they would know what would benefit them the most during patient resuscitations.

Concept Development

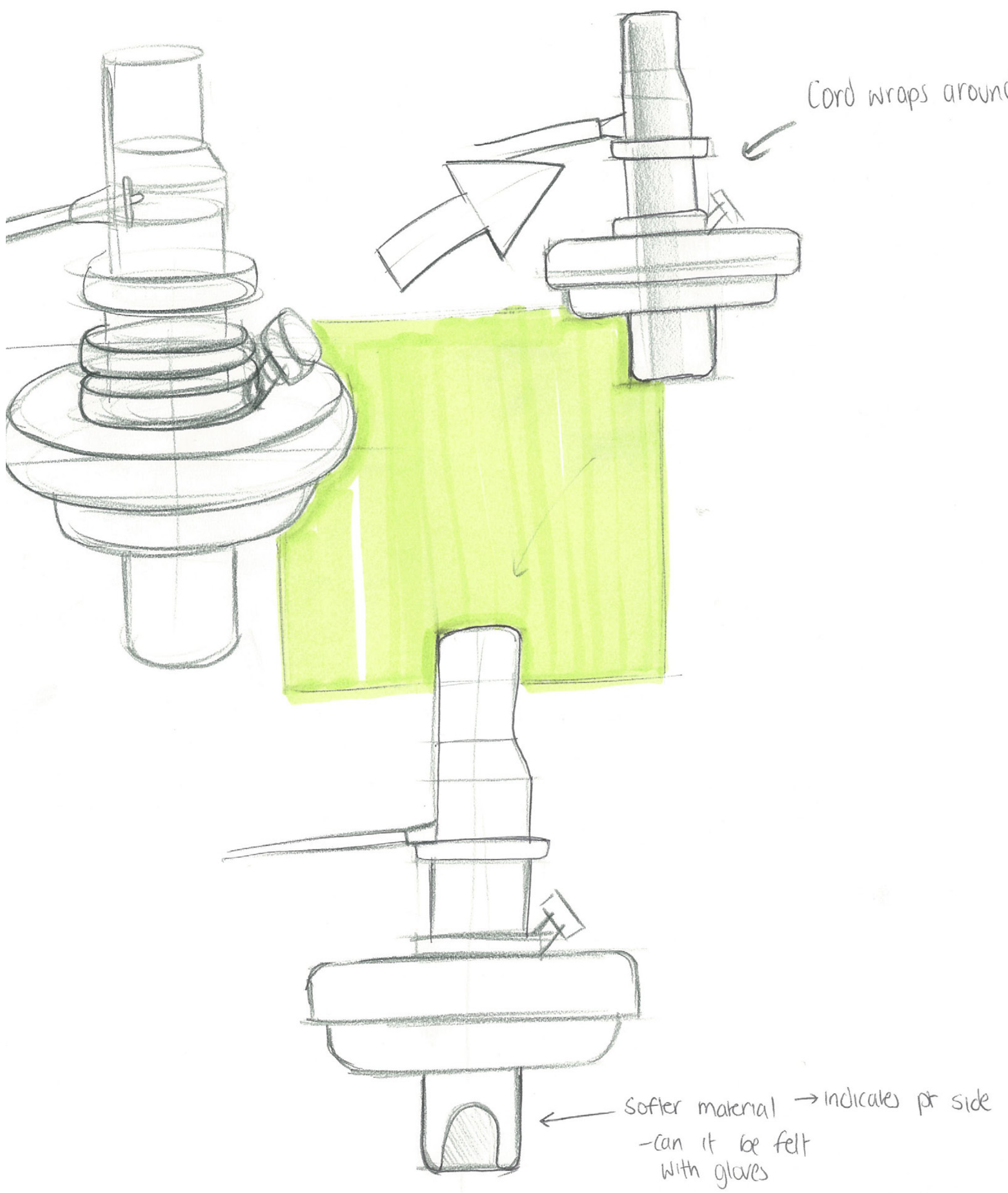


Figure 83. Concept development sketches of a filter combined with an $ETCO_2$ device. Exploring form and a way to communicate patient side.

Moving forward with the pre-assembled airway equipment idea, I needed to explore how I could develop and further refine this concept so that it is not just three pieces of equipment that was prepared and connected before use.

When paramedics need to insert an airway device into a paediatric or neonate patient, they do not attach a Cobb's connector as this creates dead-space (i.e. no gas exchange). Keeping this in mind, the design of the pre-assembled airway accessories, needed to cater for all aged patients. This meant it needed to be easy to remove the Cobb's Connector in relation to the age of the patient. If all three pieces (filter, $ETCO_2$, and Cobb's connector) were always connected then it would create an extra step during the airway management process to remove the Cobb's Connector for paediatric and neonate patients. Therefore, I combined the filter and $ETCO_2$ device.

Concept Development: 3D printed prototypes

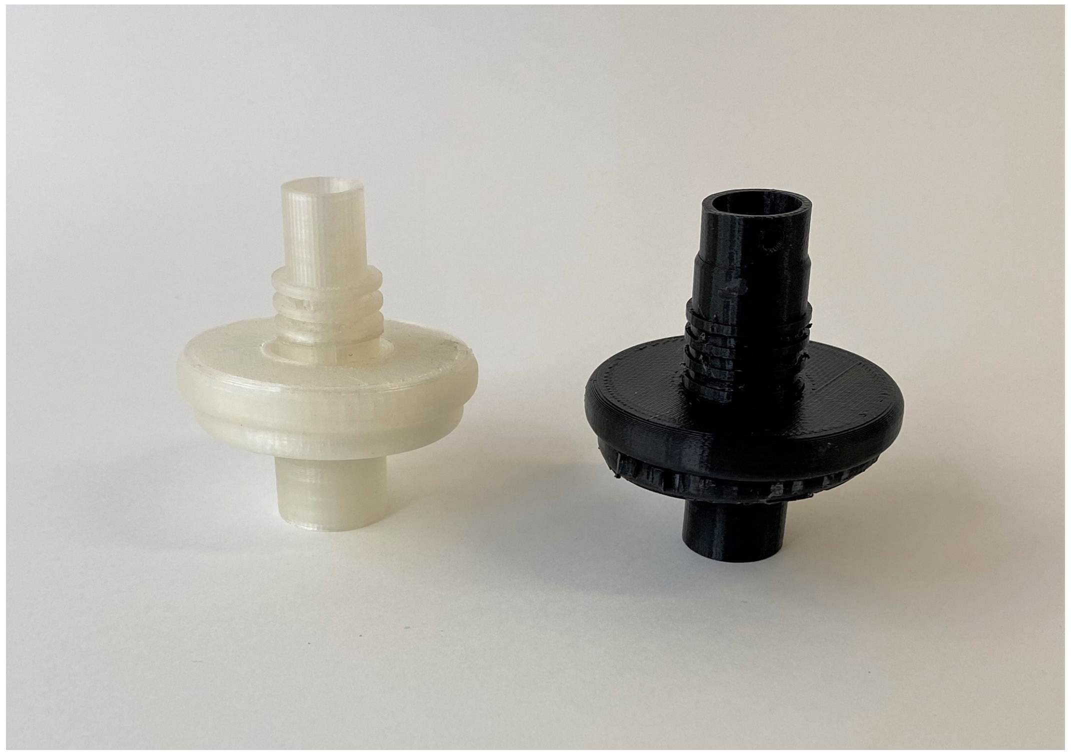


Figure 84. 3D printed filter/$ETCO_2$ device to test proportion of $ETCO_2$ device on the filter.

I 3D printed this concept for the next user testing session. This was quick to mock-up and present to participants. The design combined the filter and the $ETCO_2$ device. I kept the design of the $ETCO_2$ connector similar to the existing device so that it communicated that was the $ETCO_2$ device that attaches to the Cobb's connector and BVM.

User Testing Session Two

Figure 85. Participant providing feedback on Filter/ETCO$_2$ device.

Participant feedback

From the second user testing session, the participant thought the Filter/ETCO2 concept would make it easier as it is one less device to attach to the airway device. It was also easier as they do not have to remove the ETCO2 device from the AED bag and attach to the filter. Which was an extra step when preparing the airway management equipment during the patient resuscitation.

Reflection

This user testing session was insightful as I learned that this design was less cognitively demanding. It seems like devices that are less cognitively demanding are viewed as beneficial as it makes paramedic's jobs easier. This emphasized the need to design for cognitive support in cognitively demanding situations.

From this session, I did not receive any feedback to improve the design. However, I decided to further develop the form of the filter/ETCO2 device. I wanted to communicate it's purpose and try and prevent misuse (connecting it the wrong way).

Development Two

Figure 86. 3D printed prototype of Filter/ETCO$_2$ device exploring how a PVC tube would be attached similar to the current ETCO$_2$ device .

Figure 87. 3D printed Filter/ETCO$_2$ device prototype that looks more like the current filter design with the ports on top.

I received positive feedback for this design and decided to develop the form a bit more. I wanted to explore what it would look like with a PVC tube—like the current ETCO2 device. I also wanted to change the measurements for the top connector so that it creates a seal when the BVM or Cobb's Connector was connected. This was so oxygen would not leak.

The ETCO$_2$ device has a sensor that connects directly to the AED. My thinking behind this concept was to have the same sensor attached to the top half of the filter. Theoretically it would act just like the current ETCO2 device without needing to add the ETCO2 device onto the filter as this was built in. I explored a different form and a different top piece connector that was like the current filter design.

I redesigned the top connector of the filter to make it look more like an existing filter. I also added a ø22mm male connector piece so that when the Cobb's connector or BVM was attached, it was more secure meaning no air would escape. The seal was not tested with a BVM pumping air into it as the prints were printed in solid form without it being hollowed. This was because it was difficult to print a hollowed version for prototyping due to support materials being difficult to remove. I printed the model that resembles the filter better with the different ports on the top half.

I took this design to the next user testing phase.

User Testing Session Three

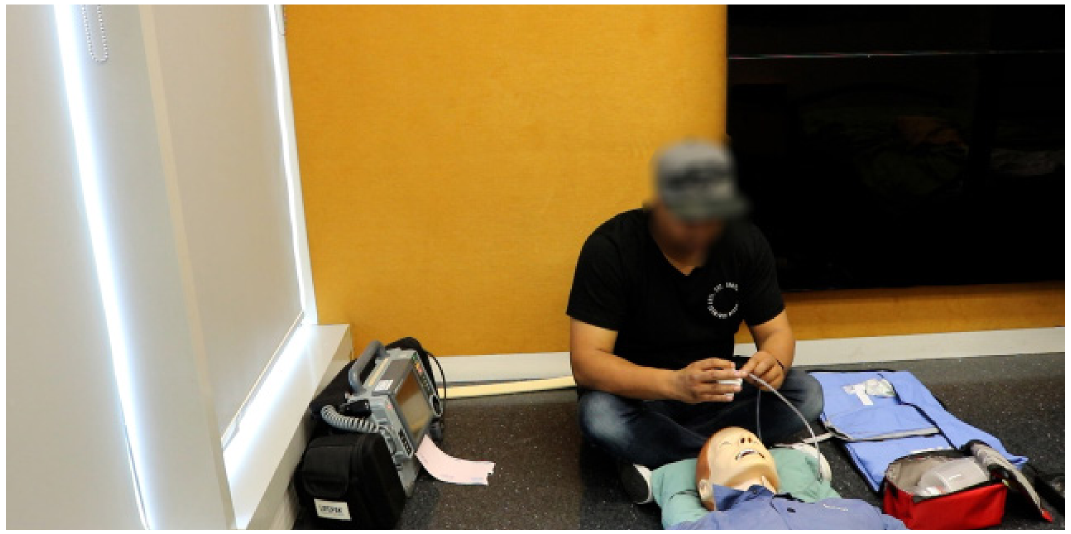


Figure 88. User testing session for filter/ETCO2 device.

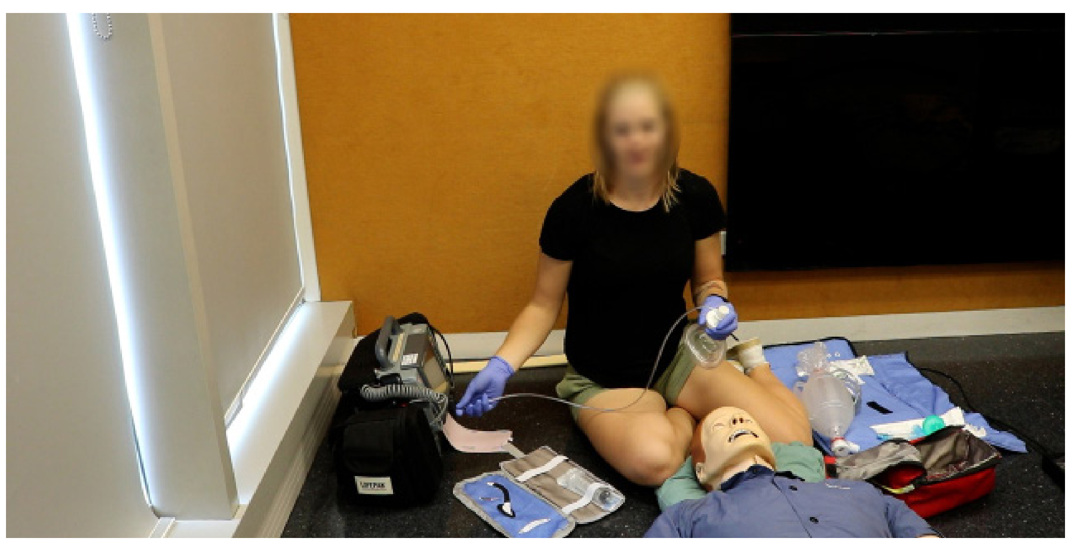


Figure 89. User testing session for filter/ETCO2 device participant asking if it plugs into AED.

Figure 90. User testing session for filter/ETCO2 device. Participant thinking of feedback to provide.

Figure 91. User testing session for filter/ETCO2 device.

Participant feedback

I asked participants to provide feedback on my filter/$ETCO_2$ design. I needed their feedback to develop and refine the design.

The filter $ETCO_2$ concept received positive feedback as they viewed it as being less of a cognitive burden. The filter/$ETCO_2$ idea was liked because of the reduction of cognitive load . Participants noted that the $ETCO_2$ device was often forgotten because it was in the AED bag and not with the airway management equipment.

One participant mentioned the device needed to be calibrated using the AED before using it. This is something I did not think about and needed to think about how this device works within a patient resuscitation.

Another participant thought that people may still try and connect this device to the LMA the wrong way. The top end could not fit on to an LMA because it was the same diameter so this would result in time wasted flipping it to fit the correct way.

These points made me think more about how this filter/$ETCO_2$ device fits within the process of airway management in patient resuscitation and how it could be designed so that it would not be connected in the wrong way.

Reflection

This user testing session was insightful as I learned that the design needed to consider how the device would be calibrated. I needed to think more about how it is used within the airway management process. Paramedics currently use a pre-attached filter on to the Bag Valve Mask when oxygenating the patient. My design either replaces that filter and would be calibrated when the paramedics need to read the Capnography (on the AED) or it would be stored in the LMA storage and would be calibrated when the LMA is inserted.

This session gave me a lot to think about. This design may require a slight change to the current patient resuscitation process.

Development Three

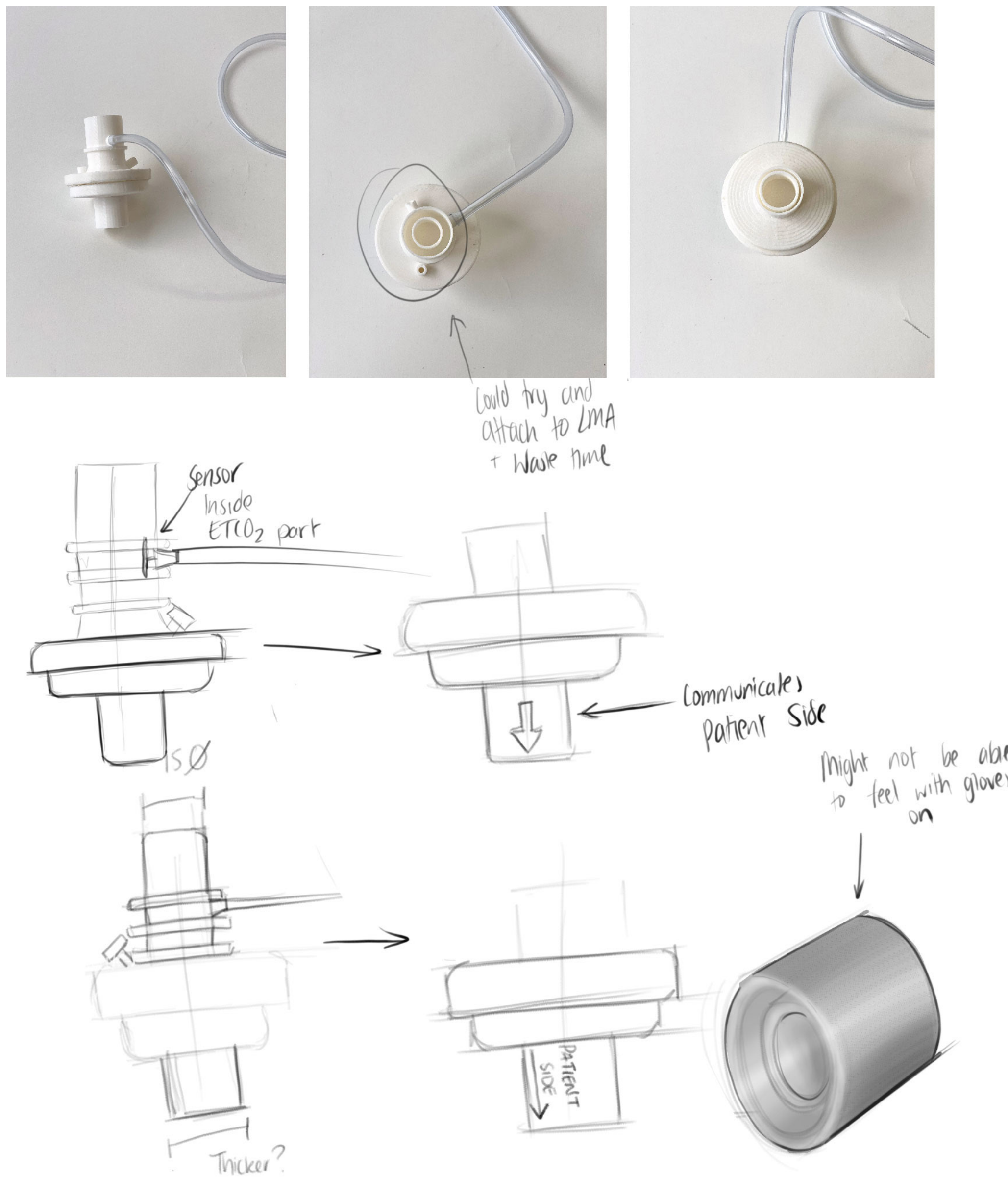


Figure 92. Filter development sketches exploring a softer sided connector to communicate patient side.

One piece of feedback a participant provided was that paramedics might still try to connect this design the incorrect way on the LMA. It would not fit but time would be wasted trying to connect it properly. I explored, through sketches the best way to prevent that from occurring.

On the existing filter there is a label to communicate 'patient side'. However, this was in small letters underneath the filter. I think it may be worth trying to explore a material change to communicate 'patient side' (figure 92.). This material change will be a soft, silicone-like material that coats the outer connector. I needed to test whether this may be able to be felt when using gloves.

The top connector of the filter needed to be clear so that paramedics could identify any blockages. This would be similar to the current $ETCO_2$ device.

Development Three continued

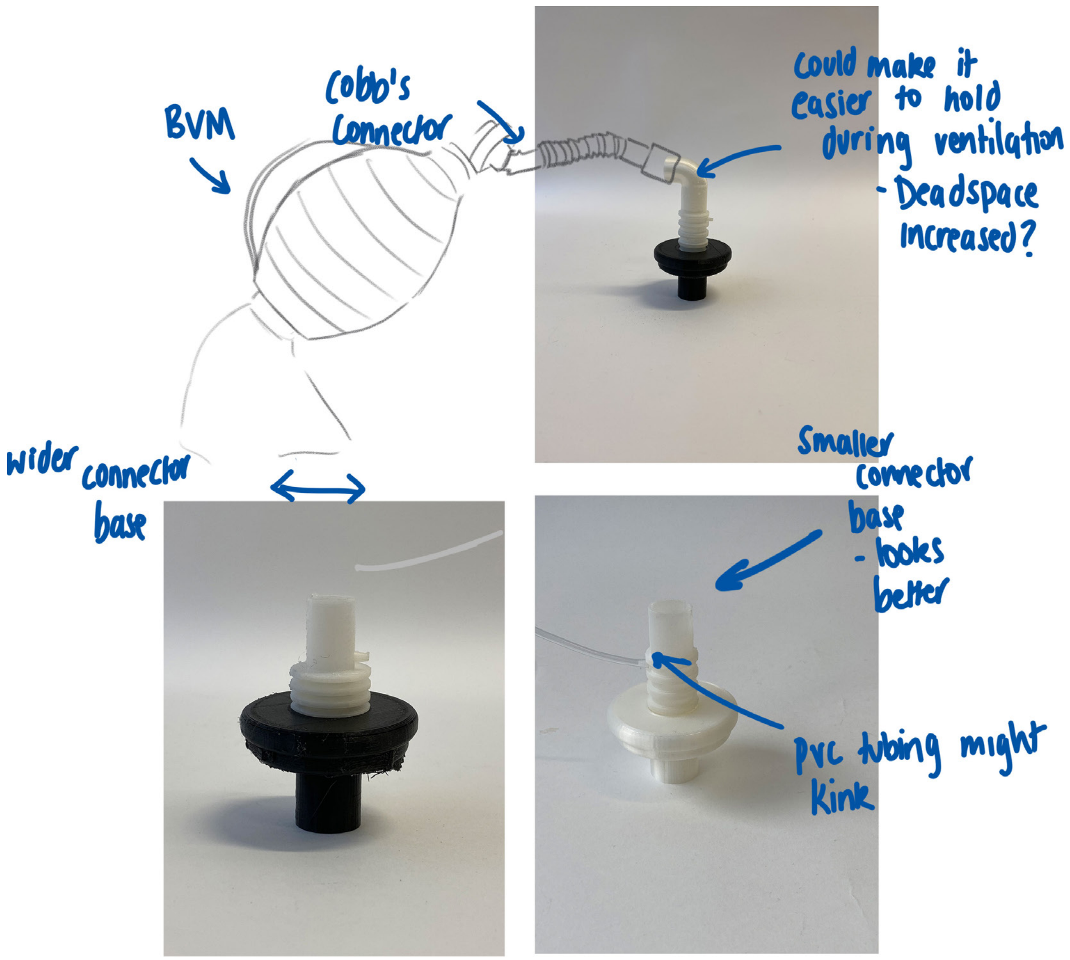


Figure 93. Prototyped Filter/$ETCO_2$ device exploring different sized connector pieces. Sketch overlay to communicate how it would interact with a BVM. The connector with the smaller base seemed like a good choice to move forward with.

From my observations, during the cardiac arrest simulation, I noticed that participants sometimes would ventilate the patient using one hand while also performing CPR. I wanted to explore a filter design that made it easier to do this. I tried to make the top connector, on the filter, an elbow connector to make this possible. However, it may increase dead-space. It also did not look aesthetically pleasing.

I prototyped a larger connector base to explore what it may look like. These explorations with the elbow connector and wider base were created for aesthetics purposes. I decided to stick with a thinner connector piece that resembles the ETCO2 device paramedics are familiar with. My hope is that the top piece was designed with similar visual cues from the current $ETCO_2$ device which should communicate that it connects to either the Cobb's connector or BVM and not the LMA.

User Testing Session Four

Figure 96. Participant providing feedback on Filter/$ETCO_2$ in the context of a patient resuscitation.

Figure 94. Participant connecting Cobb's Connector to Filter/$ETCO_2$ device.

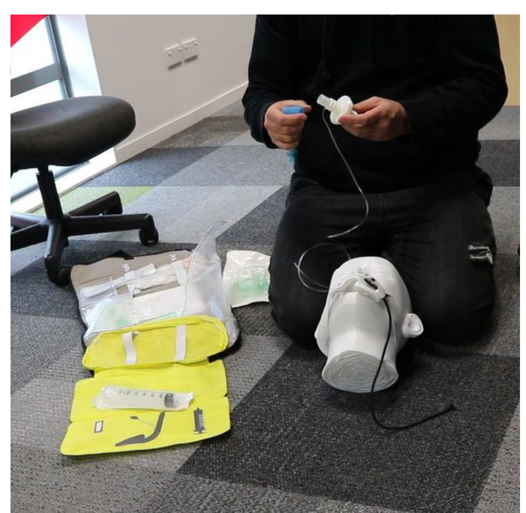


Figure 95. Participant comparing Cobb's connector to Filter/$ETCO_2$ device.

Participant feedback

This was the last user testing session I conduct for this research project. This session further emphasised the need to explore how the design would fit in the airway management process.

Participants liked that the filter/ETCO2 device saves time during an emergency and reduced cognitive load as they do not have to remember all the airway accessories that need to be attached to the LMA. One participant pointed out that they would not have to disassemble the airway equipment to attach the $ETCO_2$ device as this solution is already on the filter. They also stated that they do not need to look through the AED bag for the ETCO2 device.

In the previous user testing session, a participant pointed out that the $ETCO_2$ device needs to be calibrated. I asked participants in this round of user testing if this would be a problem. One participant stated that it would not be a huge issue as it does not take long to calibrate. The participant suggested that it could be worked around but would need to be incorporated into the process of resuscitation. There also would not be a problem of pre-attaching this device to the Bag Valve Mask (BVM) as the filter is already attached to the BVM.

I asked if this design would prevent paramedics from trying to connect the wrong end to the LMA, one participant stated that there will always be someone who would try and connect it incorrectly.

I asked if this could be prevented if the bottom connector piece was the same colour as the tube holder, and two participants thought it may work.

Reflection

I initially had planned sessions with more participants but they had to cancel due to other commitments. This was difficult as I wanted to get more feedback responses on the design so that I could have a better idea of what needs to be improved. I found through previous user testing sessions, people with different experiences tend to give feedback based on their perspectives. It would usually be something I did not think about. I was hopeful to gain a variety of perspectives on this design. However the feedback I did gain was insightful.

This last user testing session gave me a lot to think about in terms of how the Filter/ETCO$_2$ device fits within the process of resuscitation. One participant stated it would not be hard to implement, it just needs to be worked into the process of airway management.

This emphasised the need to research the whole airway management process. I think if I had more time, it would be beneficial t o track how the equipment is used in the pre-hospital setting to the hospital setting. This may reveal insights into the best way to implement the filter/ETCO$_2$ device within the pre-hospital setting.

I asked participants if colour coding the Filter/ETCO$_2$ device to the tube holder would prevent trying to connect it the incorrect way because I wanted to eliminate the element of misuse that was present with the solutions used by paramedics. This design needed to be easy to use without being easily misused. From the feedback I think I've achieved that, except there probably will be someone who tries to connect it incorrectly.

I want to keep refining this design with more user testing sessions but unfortunately there was not any time left. I gathered the feedback and developed the design further before the presentation of the final design.

Final Development

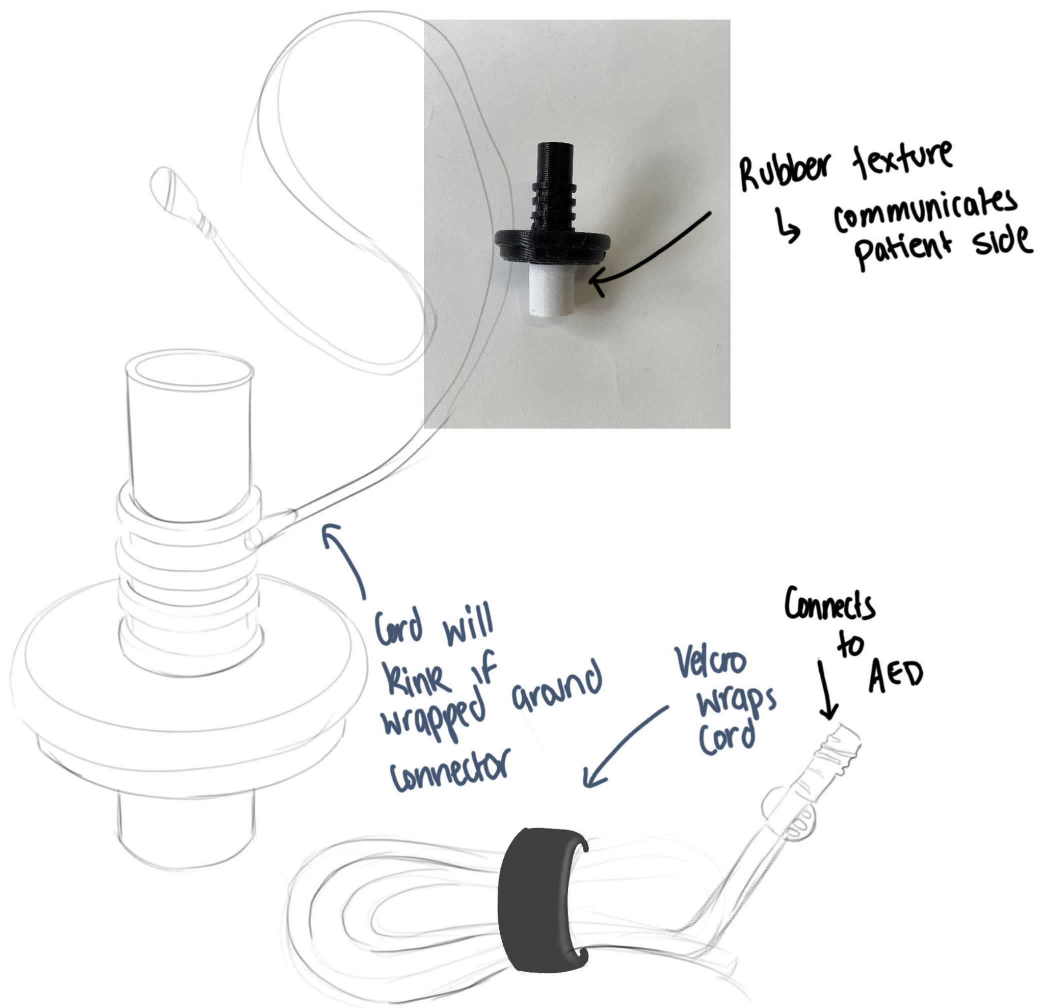


Figure 97.Final development sketches based on feedback from participants.

One of the main points from the feedback session was working out where in the airway management process, this design would be calibrated. Taking on that feedback, I think it would be best if the filter was kept in the bag with the Bag Valve Mask and was used during the pre-oxygenation just like the current solution. For this to work, the PVC tubing needs to be wrapped up. I decided it would be best if Velcro was used to wrap the cord. It was a cheap and easy to open method to access the cord and plug it into the AED.

Final Design

Final design: Filter/ETCO$_2$ Device

This design aimed to reduce the time wasted assembling the airway management equipment as well as reduce cognitive load. Reducing cognitive load by reducing the number of airway management equipment pieces needed to assemble was crucial as one of the main issues were paramedics potentially forgetting the correct sequence. Combining the filter and the end-tidal CO2 device resulted in paramedics only having to remember to attach a Cobb's connector (for adult) and Bag Valve mask. From the findings, it was clear that this design would improve how paramedics use airway management equipment during patient resuscitation.

This design was a single use product as the filter was used to prevent the equipment attached to it from being contaminated by bodily fluids, vomit, blood or transmissible diseases. There were infection control guidelines for the disposal of this product.

CHAPTER FIVE: DESIGN PROJECT TWO

TUBE HOLDER

Market Analysis Tube Holder

Through the expert interviews, ethnographic study simulations, think-aloud sessions and my role-play it was evident that the Thomas Tube Holder had usability issues that could impact how paramedics secure the Laryngeal Mask Airway (LMA) or Endotracheal Tube (ETT).

I researched different tube holders that were present on the market. I found that most designs were similar to the Thomas Tube holder (figure 98) which was used by New Zealand Paramedics.

I found two devices that did not wrap around the patient's neck and were secured differently to the Thomas Tube holder (figure 102, 104). From the simulations in the ethnographic study, it was evident that in a patient resuscitation, paramedics want to secure the tube as fast as they can so that they can ventilate the patient on time.
Figure 103, demonstrates the original securing method before the Thomas Tube holder. This method used tape or tube tie to secure the tube to the patient's mouth.

One other product has tried to replicate the Thomas Tube holder by having a mechanism that screws in to secure the tube (figure 105).

Most of the designs are curved to fit the patient's face and have foam for patient comfort. Figures 102 and 104, seem like they are tube holders for long term use in the hospital as there was soft material to allow the device to sit on the patient's face. Figure 104, seems like it has tape to hold the tube holder in place where as figure 103 is wrapped around the whole head and sits above the lip.

It was interesting to explore what already exists. It was apparent that the Thomas Tube holder has had an influence on other designs in this area.

Images have been removed by the author of this thesis for copyright reasons.

98. https://laerdalcdn.blob.core.windows.net/downloads/f995/Brochure_4988_AirwayFamily-995.pdf

99.https://www.teleflexarcatalog.com/anesthesia-respiratory/airway/category/hudson-rci-sup-reg-sup-endotracheal-tube-holder.

100. https://discountcardiology.com/Ambu-ET-Tube-Holder.html.

101. https://www.precisionmedical.com/hospital/airway-products/endotracheal-tube-holder/c-25/c-105/p-3201.

102. https://www.marpacmedical.com/product/products-330/.

103. https://www.youtube.com/watch?v=ycQs27YVE60&t=242s

104. https://rtmagazine.com/products-treatment/monitoring-treatment/therapy-devices/products-2017-airway-management/.

105.https://www.medsmart.co/products/endotracheal-tube-holder-o-t-consumables/flexi-care/et-tube-holder-adult-(038-96-001)/pid-14970331.aspx.

Figure 98. Thomas Tube Holder (Laerdal, 2021).
Figure 99. Hudson rci® endotracheal tube holder (Teleflex, 2021).
Figure 100.AmbuET tube holder with velcro strap (Discount Cardiology, 2021).
Figure 101. Endotracheal tube holder (Precision Medical, 2021).
Figure 102. Adjustable Paediatric Tube Holder (Marpac Medical, 2021).
Figure 103.Clincal skills-Airway Management (Paramedic Science, 2017).
Figure 104. Neotech Neobar (RT Magazine, 2017).
Figure 105. ET Tube holder Adult (Medsmart, 2021).

Market Analysis of tube holder products available on international markets.

Tube Holder Product Autopsy

Figure 106. Product autopsy of Thomas Tube holder examining the material and possible manufacturing decisions.

Once an Laryngeal Mask Airway device (LMA) or Endotracheal Tube(ETT) is inserted into a patient, it is then secured with a tube holder. This is important because if the tube is not secured properly it may dislodge or not provide a clear passage way for oxygen to flow resulting in the patient not receiving oxygen.

As part of the interview and role-play I discovered that the tube holder was a difficult product to use. Participant's described the securing mechanism as fiddly.

I pulled apart the Thomas Tube Holder and found that it was designed to be disposable. Easily separating the foam and fabric strap from the plastic part makes it recyclable. However, after I thought about this more, I realised it was probably designed for easy assembly rather than disposal. It was a single use product and there were infection control protocols that prohibit it from being re-used as it could encounter bodily fluids, blood, and vomit.

From the interview with the anaesthetist, they confirmed that the Thomas Tube Holder was only used in the pre-hospital setting and is not used in the hospital. In the hospital, they tie the tube with tube tie or use tape as their patient's would be long-term users. The Thomas Tube holder would physically injure patients in the long term because of the pressure that is added to the face.

The Thomas Tube holder strap was also colour coded as either pink (paediatrics), blue (adult), or green (military) (Laerdal, 2010).

I identified problems with securing the tube holder to the patient as it can be challenging threading the slide stick through the hole. I also discovered that the tube can be kinked if the Set Screw mechanism were screwed in too much which could lead to inadequate ventilation as the LMA or ETT was compromised.

Design Criteria

In order to create a beneficial design solution, I created a design criteria. The final design needed to meet these specifications. The design must be:

- Easy to use in an emergency situation
- Unable to kink tube when securing
- Easy to place in the patient's mouth
- Easy to access within the storage solution

Tube Holder Ideation

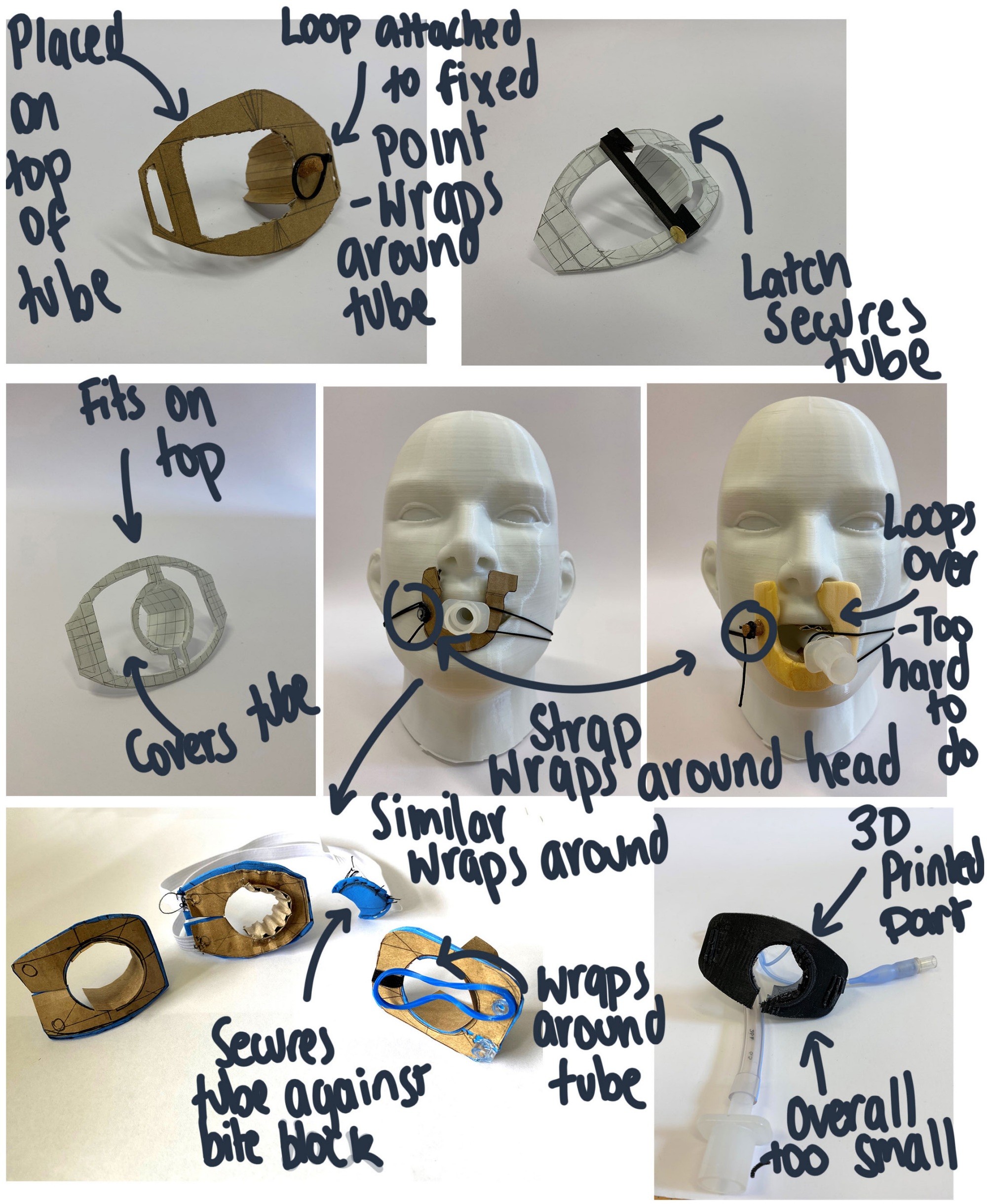


Figure 107. Exploration of prototyped tube holders using different materials to test size and form.

I explored different forms of the tube holder by initially prototyping with foam board, clay, and cardboard.

I tried to ideate a different securing mechanism as I discovered that it can be quite easy to kink the Laryngeal Mask Airway tube or Endotracheal Tube by screwing it in too much. During my role-play I found it difficult to secure the tube holder to the patient's head and difficult to fit the bite-block in.

I tested these on the 3D printed head I had made. I needed to work on a model that best represented a person. As I did not have ethics to test on real people, the 3D printed head worked as a good replacement. However, it did have limitations as it was rigid, not representative of the size or body type of the New Zealand population and did not have any teeth like a real human would.

Prototyping allowed me to explore potential forms. I took inspiration from Oropharyngeal airway devices that were used as a bite-block when the tube was secured. During my role-play, I found the tube holder difficult to insert into the patient's mouth. I found it challenging to insert the bite-block and position it around the LMA. I also found it challenging to secure the strap to the patient's head as the slide stick was quite fiddly and had to be threaded through a hole.

My design aimed to eliminate the securing mechanism that currently allows the tube to be easily kinked.

Development
Concept One

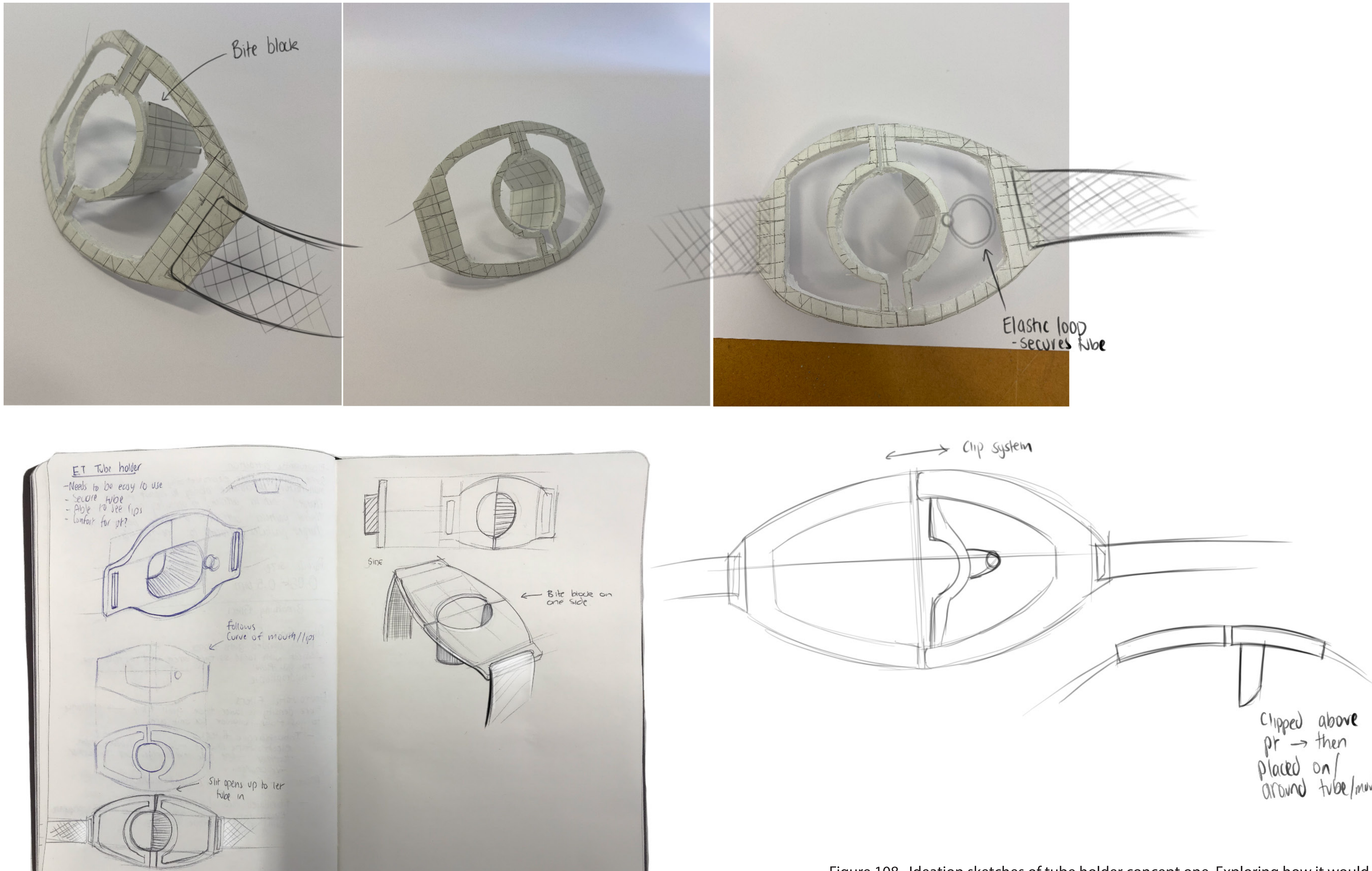


Figure 108. Ideation sketches of tube holder concept one. Exploring how it would secure the tube.

Concept Two

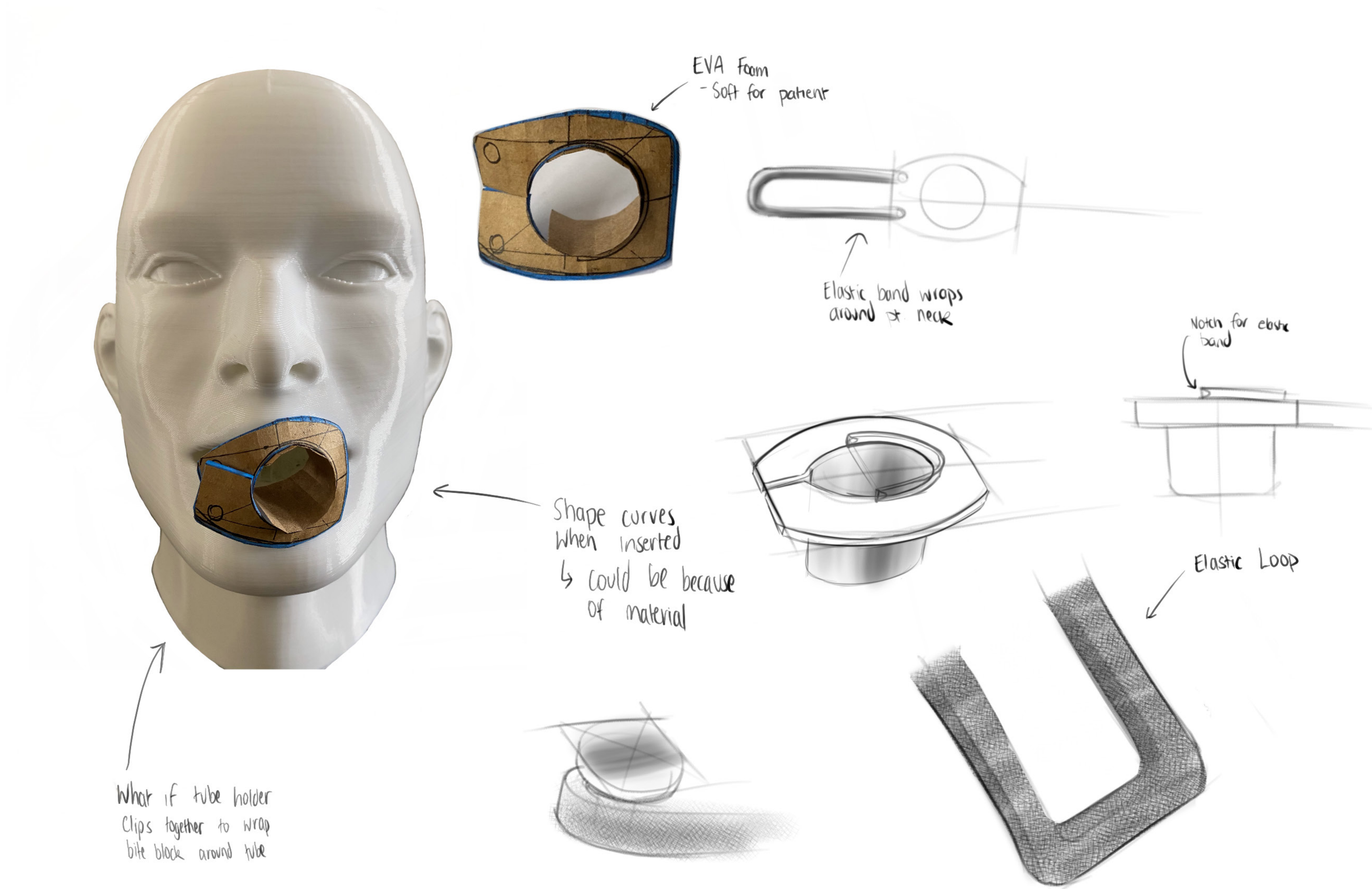


Figure 109. Tube holder sketches exploring a securing mechanism that loops over the tube.

Concept Three

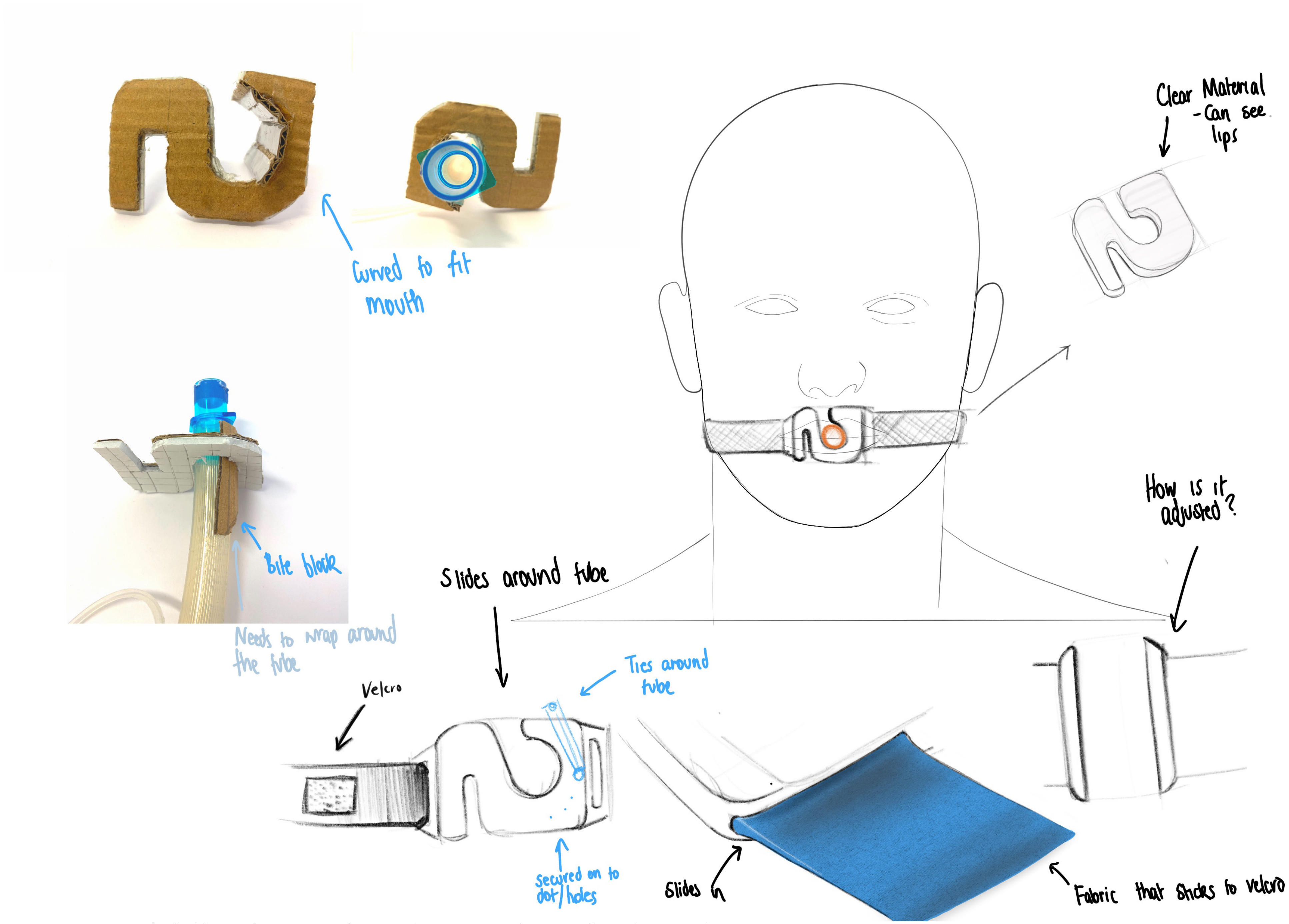


Figure 110. Tube holder exploring an 'S' shape and securing mechanism where the strap clips on to the side of the tube holder.

From my exploration of different shapes of the tube holder, I narrowed it down to three different shapes.

Each shape explored a different securing mechanism.
Figure 108 explored having the strap wrap around the patient's head while there was an elastic loop that hooked around the tube and was secured on an anchor point.

Figure 109 explored an elastic loop that wrapped around the patients head and the tube by threading it over the tube.

Figure 110 explored having the strap clip on to the side of the tube holder with a similar securing mechanism as figure 108.

I wanted to create a design that makes it easy to secure the tube without damaging it and creating an obstructed airway. I explored different ways to secure the tube and secure the holder to the patient (figure 107-110).

I learned that securing the tube was very important as it needs to be in the correct place for the patient to receive sufficient oxygen. In my design, this was done by wrapping the strap around the LMA and threaded through an anchor point on the side of the tube holder.

It is also important to have a bite-block as a patient may wake up and bite down on the tube resulting in the tube dislodging in their airway creating a different issue requiring surgery. The bite-block protects the LMA or ETT from this occurring. This is especially important if the patient is intubated as they are usually given medication to paralyse them (Swinton et al., 2018).

In my design, the bite-block gives the LMA extra support to lean against when it is secured.

Concept Matrix

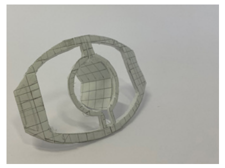
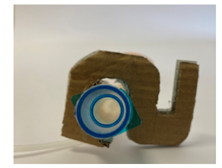
			
Easy to use in an emergency situation	-	+	-
Unable to kink tube when securing	+	+	+
Easy to place in the patient's mouth	=	=	=
Ensure a quick way to secure the tube (LMA or ETT)	=	+	=
	1	3	1

Figure 111. Concept matrix to decide which concept would be the best one to move forward with.

Each of the three concepts above were ranked against the design criteria I created at the start of this project. This was done to focus on a concept to further refine. From this concept matrix, it was clear that concept two was the concept to further refine as it scored the highest against the design criteria.

Development Two

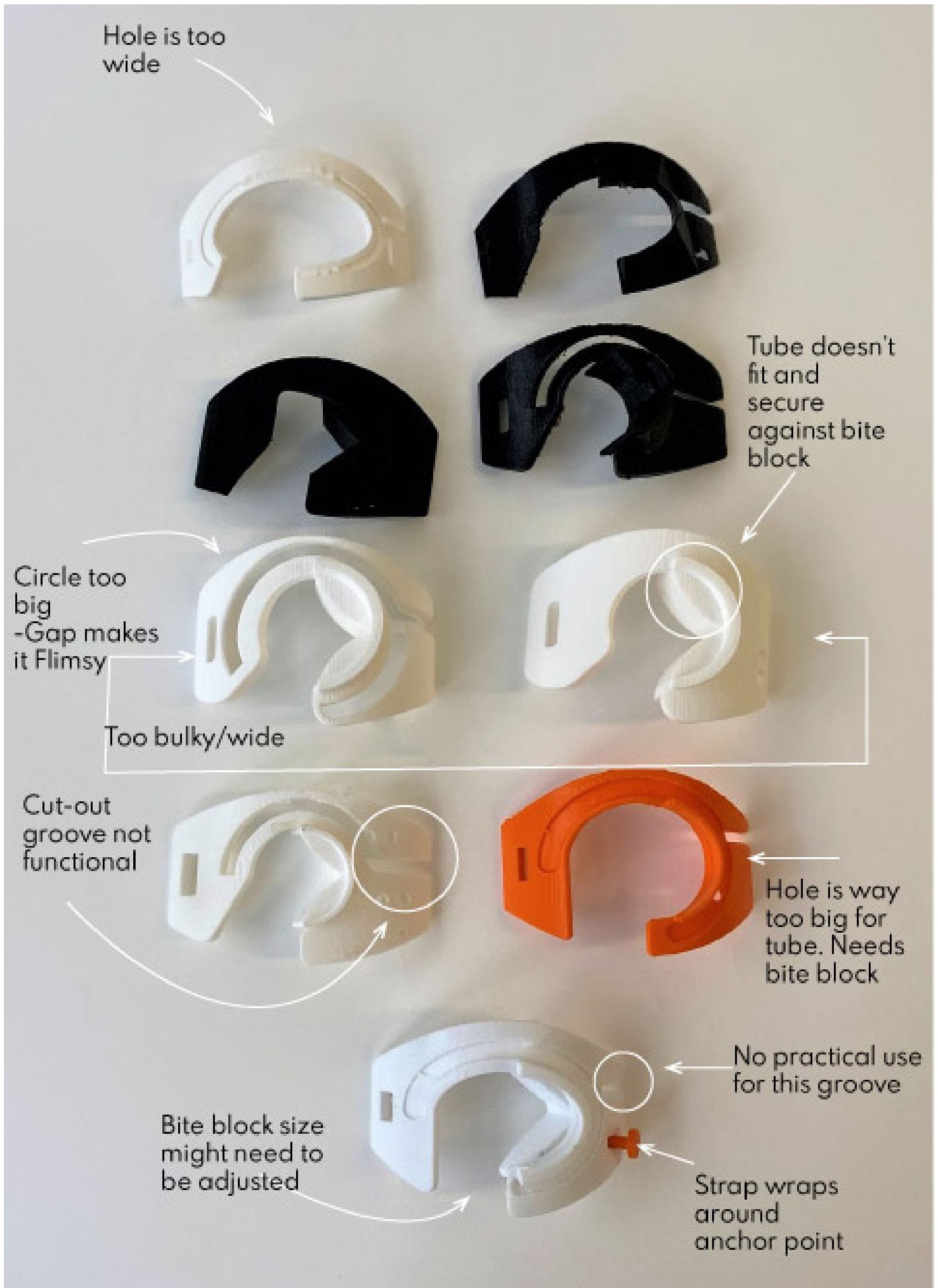


Figure 112. 3D printed tube holders that have been annotated to reflect what aspects of each design worked or did not work.

With this design project, I felt the need to make prototypes to test how the tube would be secured. I used Solidworks to 3D model each prototype so that I could 3D print them and test the size and proportion of the bite-block in relation to the 3D printed head. 3D printing was a quick prototyping tool to allowed this to happen.

By using Solidworks I could also start to think about how this might be manufactured. The challenging part of 3D printing these models was removing the support material as this would often be difficult to do and sometimes broke the model.

3D printing also allowed me to create the complex curved shape that would sit on top of the patients mouth. This was challenging to achieve with foam board or card board alone. The plastic 3D prints gave the design a rigidity that could not be replicated with the softer materials (Cardboard, foam board).

I decided to take the last tube holder in figure 112 to the first user testing session. This tube holder had a securing mechanism where the strap wrapped around the tube and then around an anchor point to create some tension to hold the tube against the bite-block.

Reflection

I 3D printed the tube holder to better understand the form of the tube holder and how it might sit on top of a patient's face. To do this, I needed to learn how to CAD the tube holder form in Solidworks. Through this process, I learned how to use the Surface tool to construct the form and the bite-block details. By doing this, it allowed me to consider how this design might be manufactured. I could easily print the tube holder as one part but from a manufacturing point of view, I needed to think about the best way it may be constructed.

This process helped me think about the best approach to 3D print a specific part, as I needed to be wary of the support materials created during the 3D printing process.

3D printing allowed me to prototype faster and create different iterations of the tube holder. I found that by prototyping with 3D prints, I could easily develop and change different aspects of the design. It also allowed me to experiment with sizes of the hole where the LMA would sit as well as the size of the bite-block. I could also refine some of the usability details. I tested these on the 3D printed head as it would be a health and safety issue to test this on myself as the bite-block may be deemed as a choking hazard.

I felt lost when designing the tube holder, as I was waiting for St John to approve my request to recruit paramedics. At the time, I really needed their input and their experience to inform the design. To overcome this feeling of being lost, I reviewed the simulation videos to see how the tube holder was used in the context of an emergency. From this, I noticed aspects of the usability of the tube holder that I did not consider before. For example, I found that it took 3 steps to secure the LMA to the patient. This made me realise that I could make my design more efficient. I decided to develop my design further to make it faster to secure to the patient, while also being easier to use.

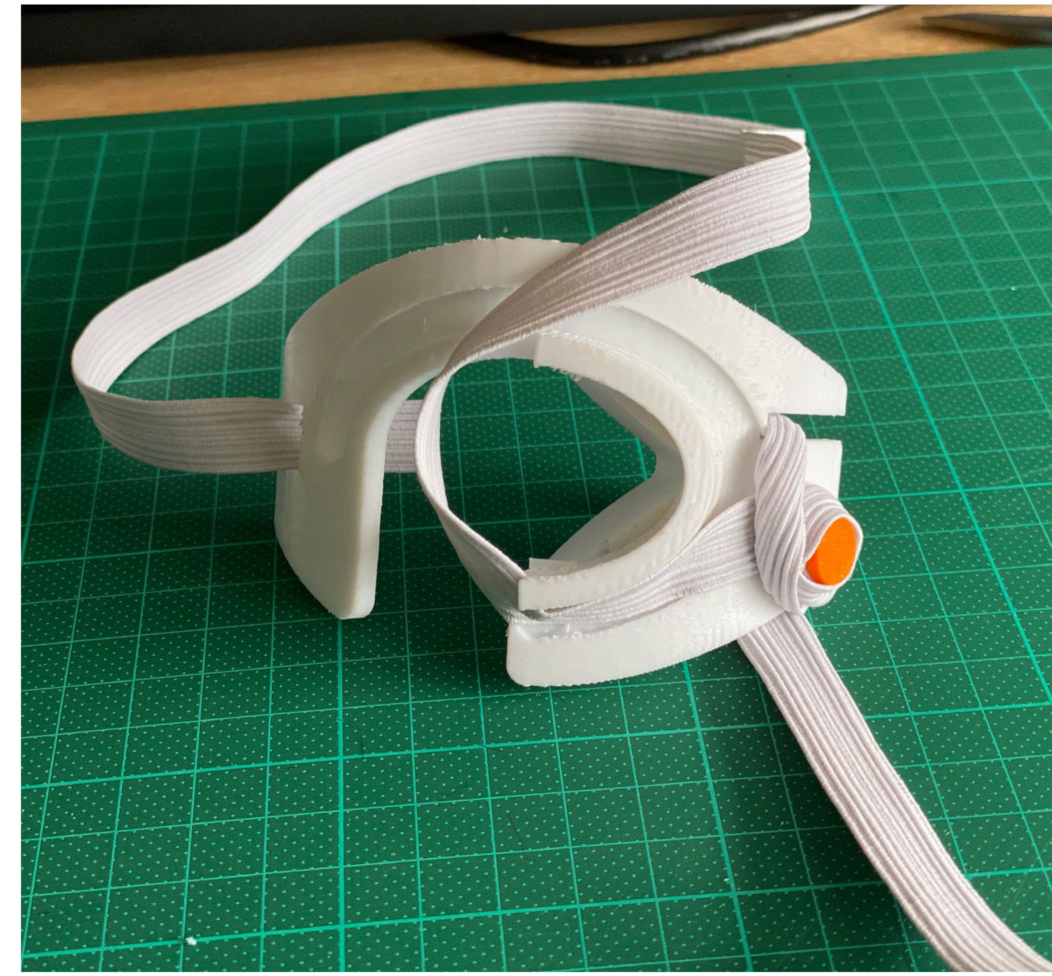


Figure 113. Tube holder design that I decided to take to the first User testing session. Strap wraps around patient's head, then LMA tube and then was secured around an anchor point.

User Testing Session One

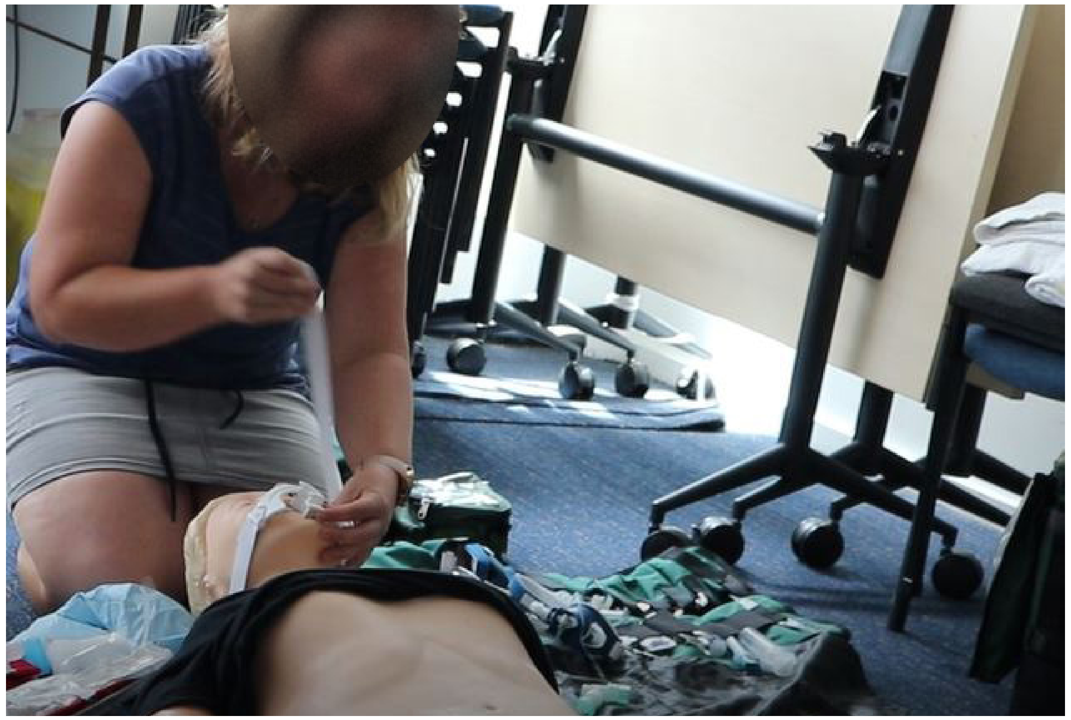


Figure 114. Participant securing tube on a training manikin using my tube holder design.

Participant feedback

The tube holder was viewed as better and faster than the current solution. This participant disliked the current solution and found this to be a better alternative. I discovered that the bite-block size and fastening strap needed to be developed further. The participant suggested creating a spot for a timing light to sit on to. A timing light is a cognitive aid that helps indicate to the paramedic when it is the appropriate time to ventilate (squeeze the BVM) the patient. Creating a space for it was important because the participant claimed that sometimes people place the timing light onto the BVM because it fits on the circular part. However, this causes issues as then it makes it difficult to see if there are any blockages.

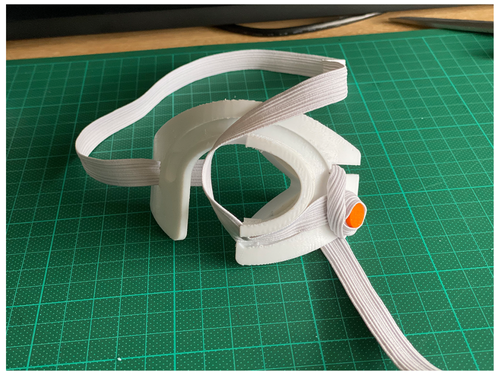
Reflection

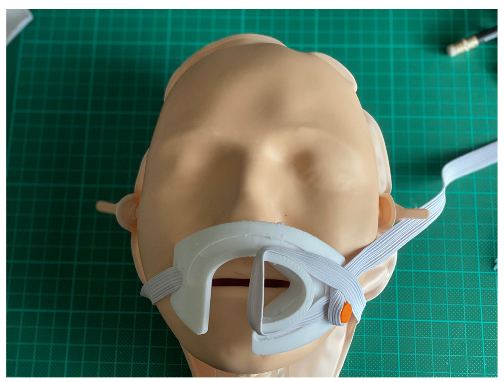
The first user testing session provided me with guidance to move forward with the design. I was not sure that securing the strap around an anchor point would work or having a part that clips into a hole to secure it. I needed to think more about the best way to secure the strap.

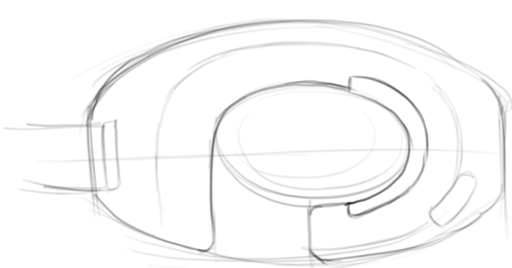
The feedback really affirmed that I was on the right path with this design. Through this session, I observed how the Tube Holder might be used in the context of a patient. I was using the 3D printed head to help me refine how it sits on a patient's face but seeing this design work on a training manikin helped to observe how it may be used in the real world. It also emphasised the need for a design that works properly the first time and does not have the ability to be misused or malfunction. For example, the bite-block did not fit the manikin's mouth which indicated that if this was a real-world emergency, paramedics would not have been able to use the Tube Holder to secure the tube resulting in adapting to the poor design or reverting to tape or tube ties.

The design of the bite-block needs to be better tailored to sit against the circumference of the LMA tube as well as fit in the patient's mouth.

Development Three







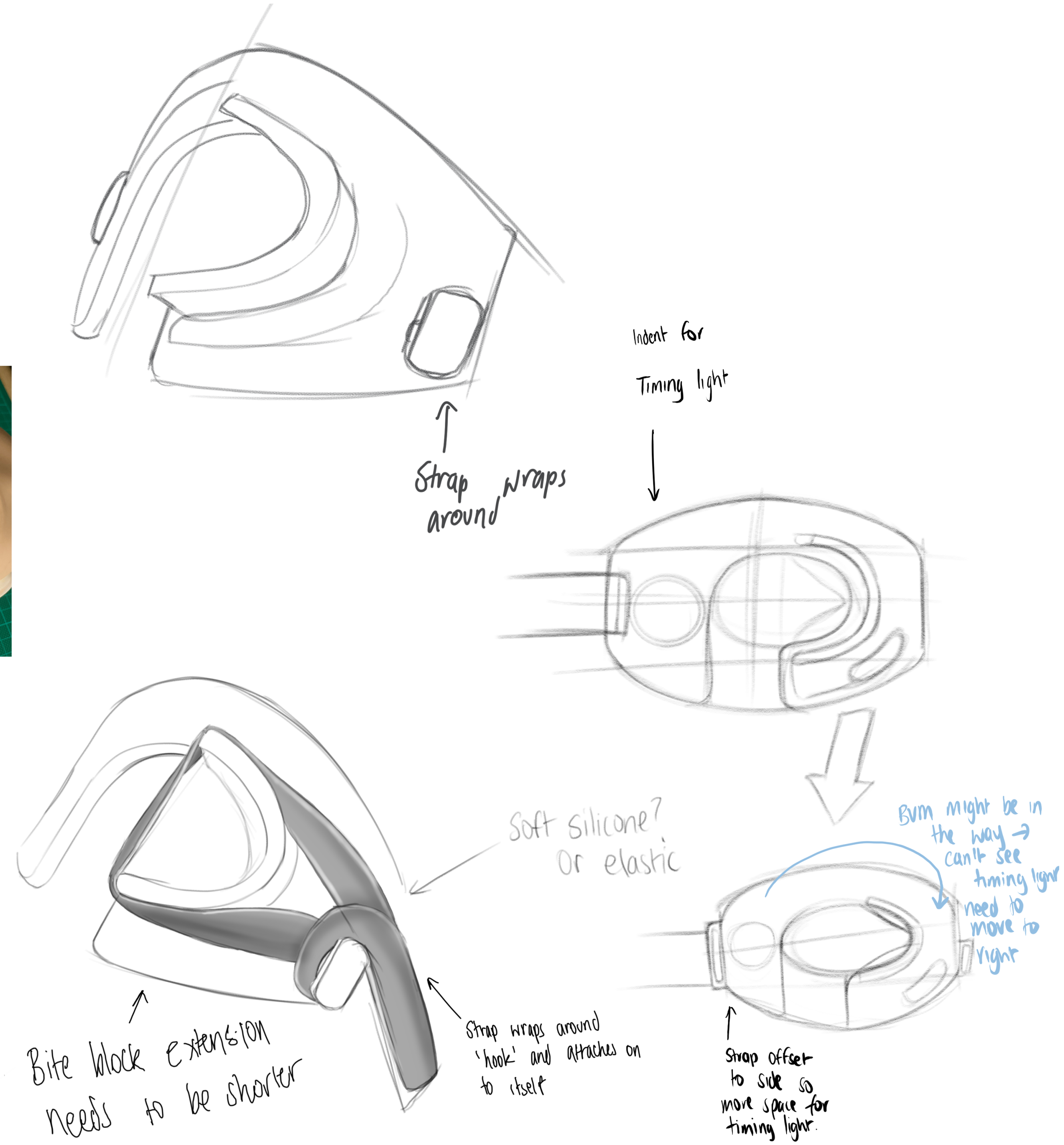
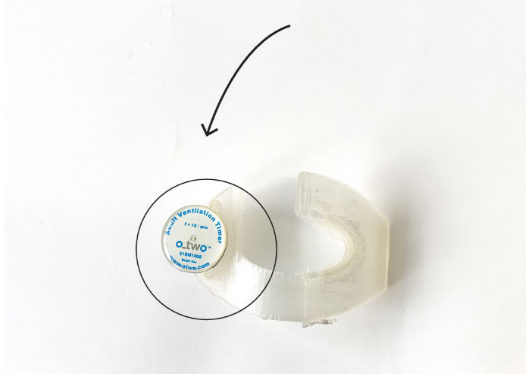


Figure 115. Development sketches of the securing method of the strap after it has wrapped around the LMA tube.

Development Three continued

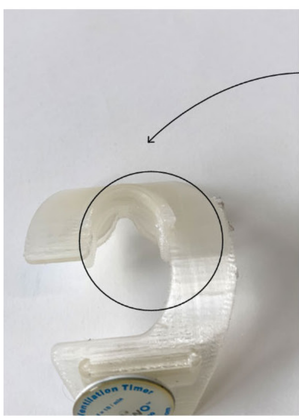
Timing Light
attached to the side

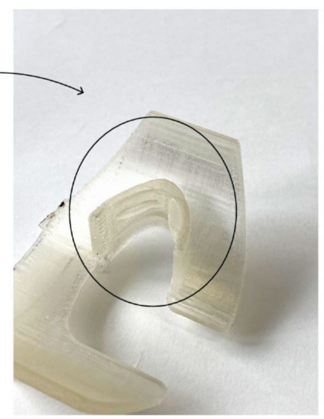


Bite block is
on the other
side

Does it make it easier to wrap strap around the right?

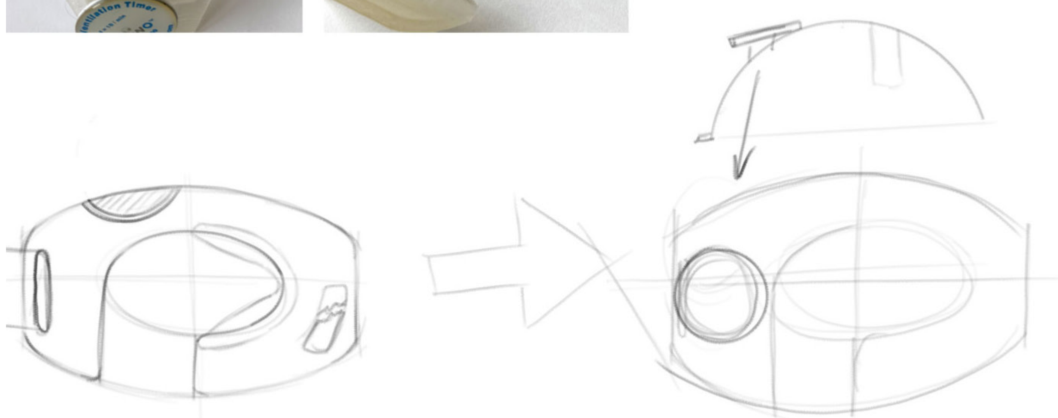
The tube will lean away from the bite block during ventilation





Bite block has 'ribs' to strengthen it

Size is still top wide. Needs to be reduced to 20mm to fit in patient's mouth



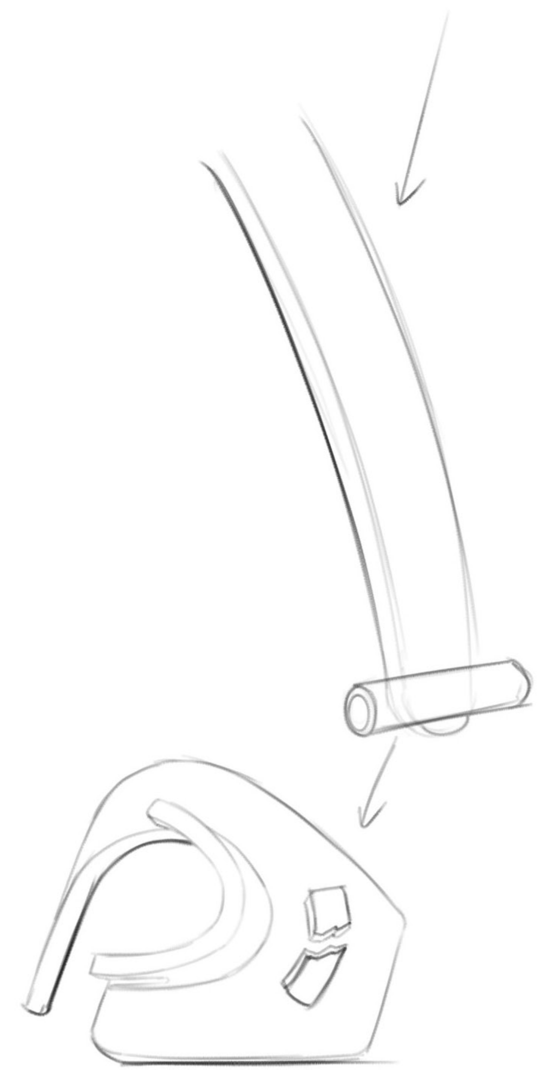


Figure 116. 3D printed prototype and sketches exploring how a timing light may be attached as well as placing the bite-block on the opposite side of the tube holder. Sketch also explores a sailing cleat as a securing method for the strap.

After the first user testing session for this design it was clear that I needed to re-think how the strap secured the tube.

Wrapping the strap around the tube and then the anchor point did not ensure that the tube will be secured.

I decided to think more about the strapping material as well as how it will be secured to the tube holder. I also wanted to create a place for the timing light to be placed on to (see figure 115).

During the last user feedback session, the participant suggested making a 'pit' so that a timing light could be placed on to the tube holder. I tried to incorporate this on to the tube holder but found this to be challenging as the timing light is quite big and does not fit on to the side of the tube holder (see figure 116).

I also tried to explore what it would look like to have the bite-block on the other side of the tube holder to make it easier to ventilate the patient without pulling against the strap that is securing it. (see figure 116).

I started thinking about how strong the bite-block would be and prototyped a model with 'ribs' to strengthen it. I couldn't test this on myself as it would be a choking hazard. So I applied a little pressure, using my hands to test the strength. The bite-block with the ribs were stronger than the ones without the ribs. This seems like a good idea to incorporate into the bite-block.

I still needed to secure the strap properly to the tube holder. I was inspired by a sailing cleat that has teeth that grabbed on the rope once its pulled through (see figure 116). Using this idea, I decided to prototype a sailing cleat inspired securing mechanism on to the side of the tube holder.

Development Three continued

Figure 117. 3D printed tube holder with the first iteration of a sailing cleat.

Figure 118. Front view of 3D printed prototype of tube holder with sailing cleat.

I liked the idea of the strap being secured by pulling it through a gap on the tube holder. It made it easier to secure. This design was used in the next user testing session.

Reflection

I found it difficult to incorporate all the feedback from the first user testing session into this concept. I tried to incorporate a 'pit' for the timing light but it was difficult to do this in Solidworks. I decided to hold off on this for a little while and try and refine the strap and securing method. This was more important as it was not fully refined in the previous iteration as it did not secure the tube well enough around an anchor point. There was not enough tension. I was inspired by a sailing cleat that grabs on to the strap and creates the tension it needed to secure the LMA device.

User feedback was extremely helpful in highlighting areas where the design needed improvement. The participant gave feedback based on their experience in a patient resuscitation which better tailored the tube holder to their needs. The tube holder needed to be quicker and easier to secure. This is one specification from the design criteria that needed to be further developed in the next iterations.

User Testing Session Two

Figure 119. Participant testing tube holder on training manikin.

Figure 120. Participant testing tube holder on training manikin.

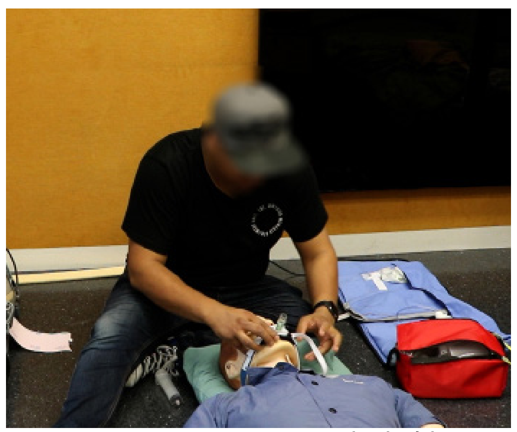


Figure 121. Participant using tube holder prototype to secure an LMA.

Figure 122. Participant using tube holder on 3D printed head.

Figure 123. Participant placing tube holder design on to 3D printed head.

Participant Feedback

I presented the tube holder concept with the sailing cleat inspired securing method to the next group of participants for feedback.

Two participants thought the tube holder would be fiddly as the securing mechanism needs work. Velcro was suggested as an alternative securing method.

Two participants wondered how it may perform in a moving ambulance as the vibrations and movement might not hold the LMA or ETT in place meaning it would dislodge and come out easily. I needed to think about how to secure it properly. I thought the sailing cleat idea was still valid, it was just the strap material that needed to change.

The feedback from this session gave me a lot to think about in terms of usability issues (securing the strap around the LMA) and how the design may behave during transportation with the vibrations from the ambulance.

Reflection

It was challenging receiving feedback that the design was viewed as fiddly as this was a term originally used to describe the Thomas Tube holder. This piece of feedback motivated me to improve the design and make it easier to secure the LMA tube.

I had to improvise with the tube holder concept as my previous 3D prints failed and the new ones were not ready by the time I conducted the session. This was due to the 3D labs at the university being quite busy which was understandable given the timing. I used an existing sailing cleat on one of my prototypes to communicate the basic idea. The next user testing session was the next day and the prints were still not ready, so I created my own prototype with parts I previously printed. From this experience, I learned that I should prepare a week in advance when it comes to 3D printing. It was a good idea to have 'back-up' prototypes.

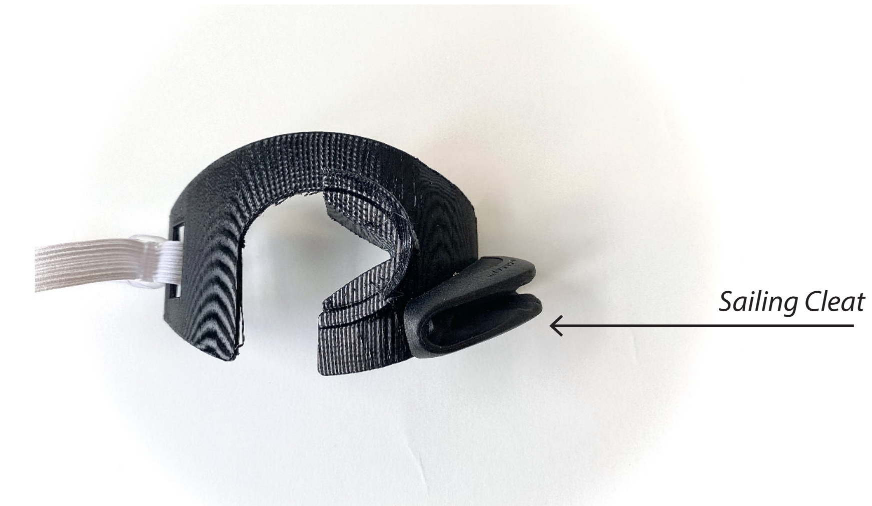
This user testing session really highlighted how experience can help inform the design. The postgraduate students relied on their experience to give feedback on improvements to the design. This helped me as their perspectives enriched the development of the tube holder design. They provided feedback on aspects that I may have not thought about as I did not have any experience as a paramedic responding to patient resuscitations.

Their feedback helped inform the next iteration of the tube holder.

Development Four

Through development sketches I explored the placement of the securing mechanism (inspired by a sailing cleat) and the placement of the timing light.

I needed to move the sailing cleat so it was easier to thread the strap through.



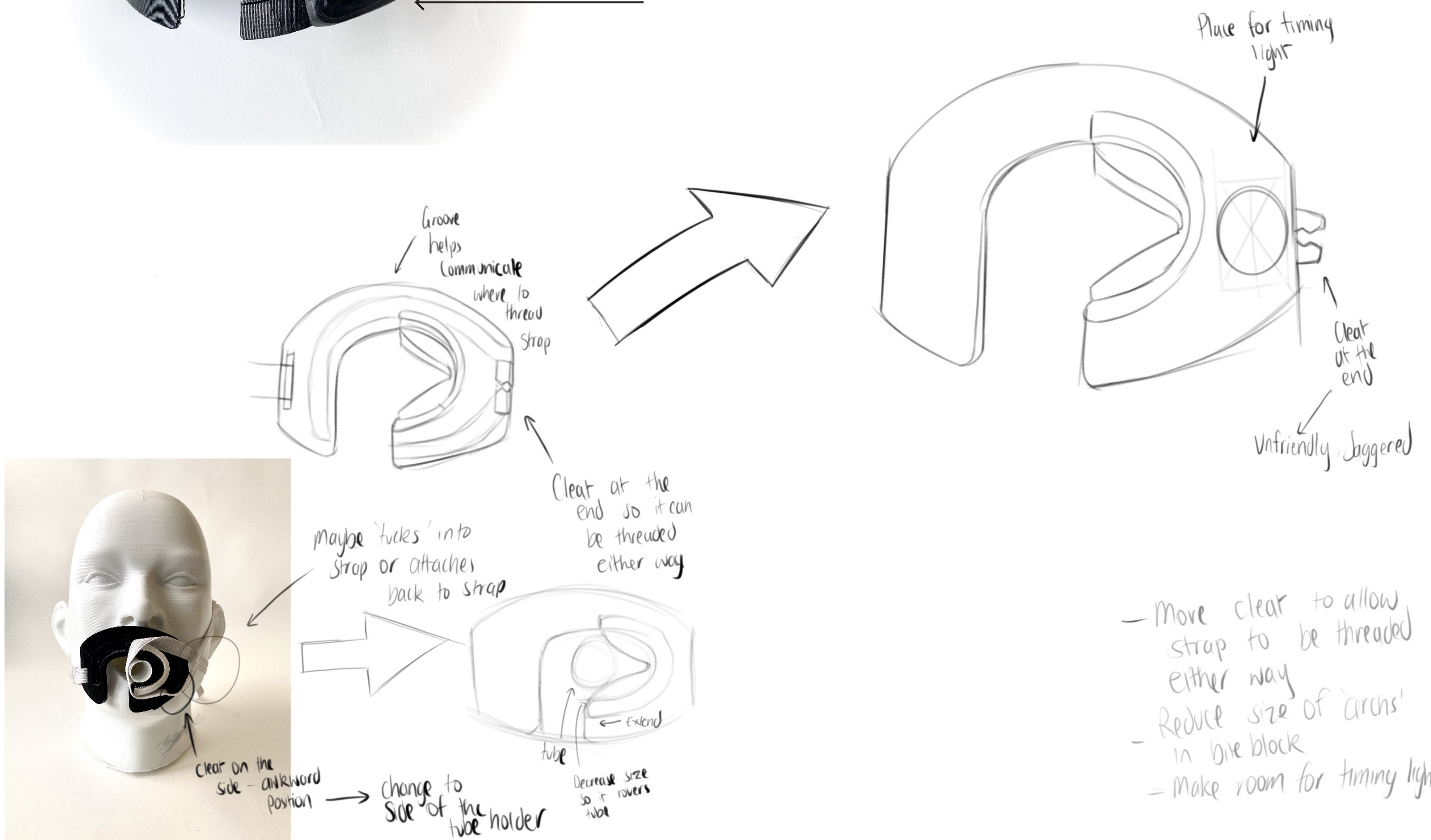


Figure 124. Sketches exploring the placement of the sailing cleat inspired securing method.

Development Four

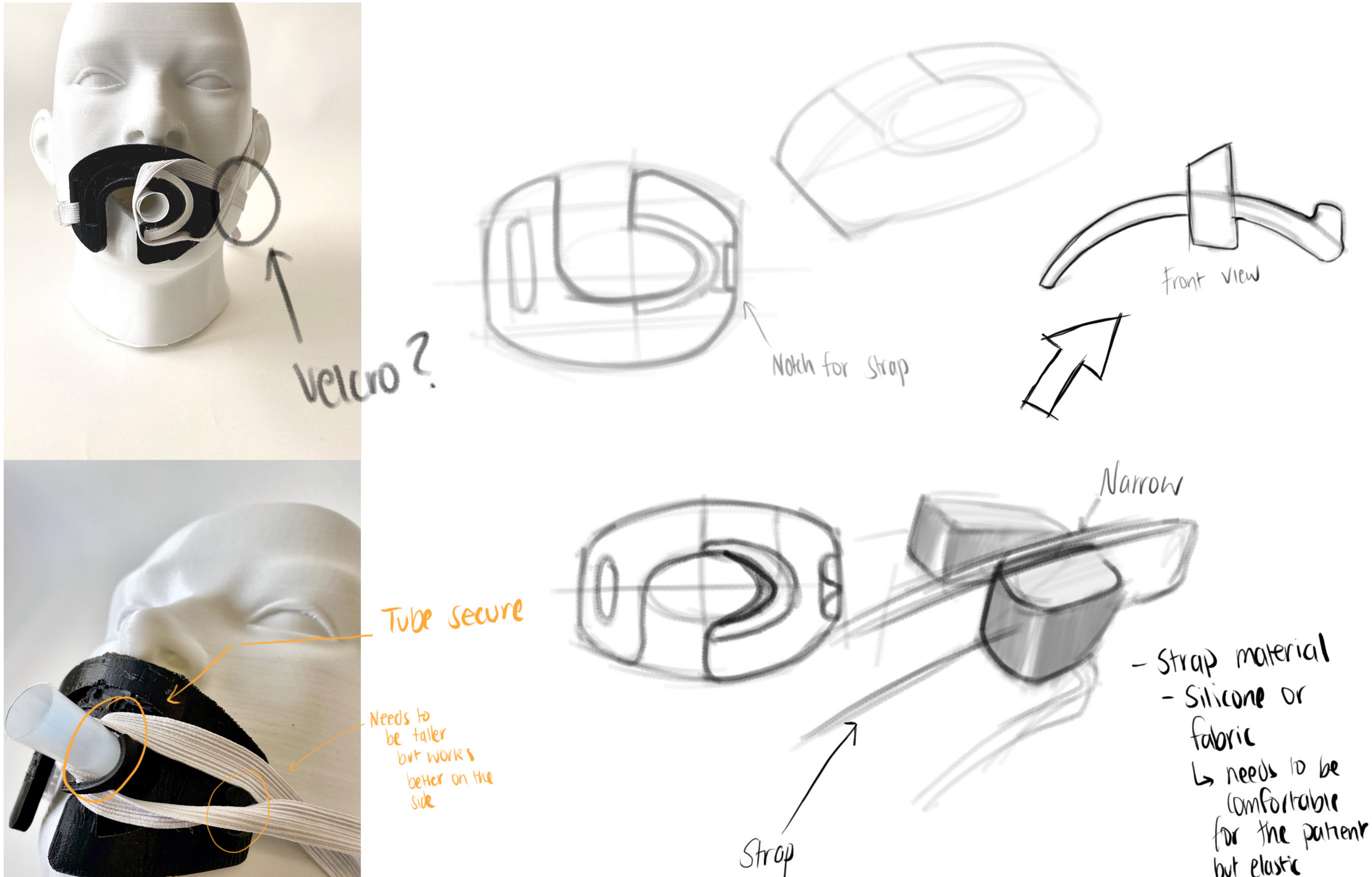


Figure 125. Sketches exploring the placement of the securing method as well as the strap material.

I generated more sketches around how the strap would thread through the cleat(figure 126). This was to work out the potential form of the tube holder.

I was also trying to work out the best material for the strap as it needed to be easy to wrap around the LMA tube but also comfortable for an unconscious patient. The tube holder should not be able to harm the patient. But the focus of this project was around paramedics using the tube holder during patient resuscitations.

I initially used flat elastic as the strap because it would stretch around the LMA tube. I was thinking of using silicone as the strapping material but needed to be aware of the potential of it breaking when threaded through the securing mechanism.

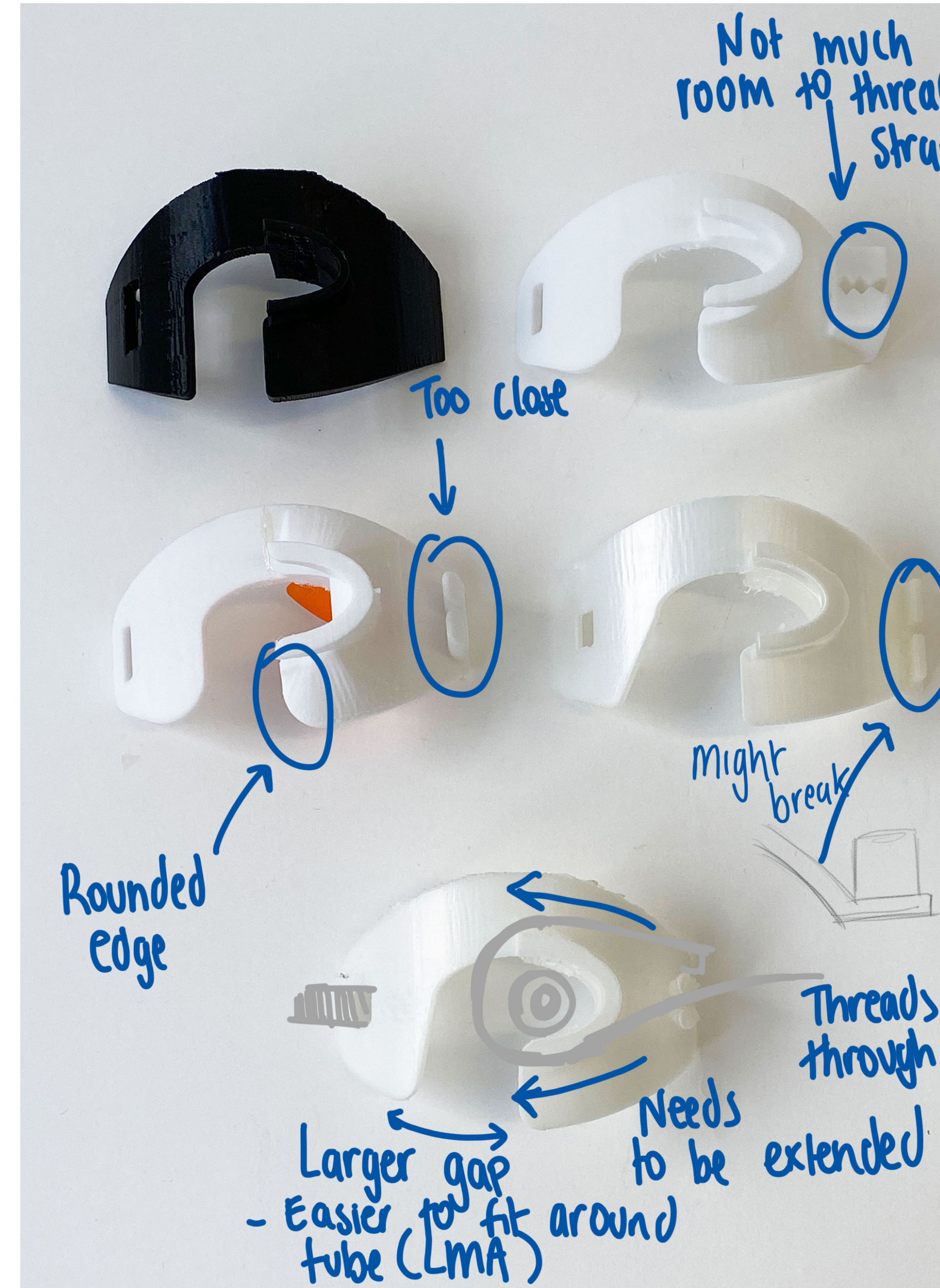


Figure 126. 3D printed prototypes of the tube holder with different sailing cleat designs.

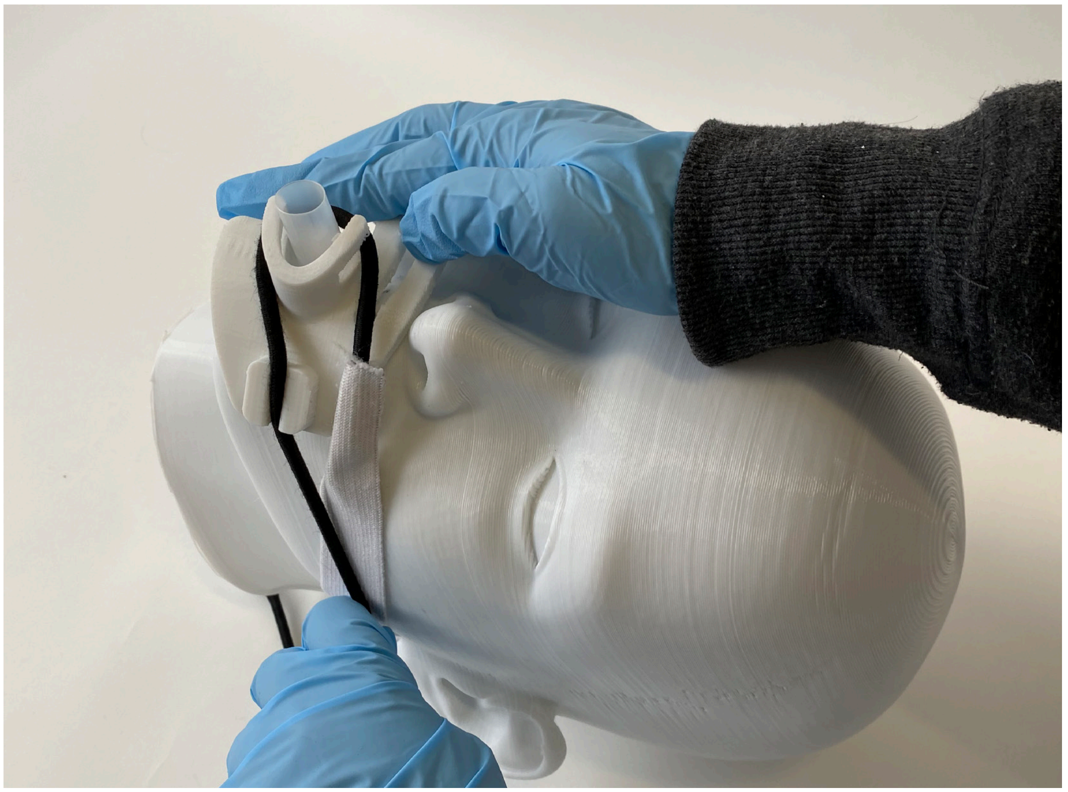


Figure 127.Testing tube holder , using gloves, with a different securing method design which makes it easier to thread the strap through.

More prototypes were 3D printed to explore the placement of the sailing cleat. This was important as it needed to be easy to thread through. It was difficult to determine the scale from CAD modelling software alone. Once the models were 3D printed, it was clear that the measurements needed to be adjusted as some of the models would not secure or hold the strap properly.

I changed the design of the sailing cleat so that it made it easier to thread the strap through. I tested this using gloves to role-play what it was like to be a paramedic securing the tube. Using the gloves allowed me to feel what it would be like to secure the tube and test whether I needed to have a pull tab or if the bungee cord has enough friction. It was easy to pull the bungee cord through the channel using gloves. It was not slippery. But as a nice design detail, it might be worth exploring a tab design. For the strapping material I thought it may be best to use a full bungee cord as this would make it easier to thread through the strap to secure the LMA tube. Some swimming goggles now use bungee cord as the strapping material. I thought this may be a good idea as it was stronger and more durable than a silicone strap.

I took this prototype to the final user testing session.

Final User testing session

Figure 128. Participant wrapping bungee cord around LMA tube.

Figure 129. Participant threading bungee cord through channel on tube holder to secure the LMA tube.

Figure 130. Participant wrapping strap under patient's head ready to secure LMA.

Participant Feedback

Strap

I received conflicting feedback on this concept as two participants (experienced paramedics) thought it was a better solution to the current Thomas Tube Holder whereas the other two participants (paramedicine students) still found the securing mechanism to be fiddly. One participant thought securing the LMA may be difficult as they would need to make sure the strap is tight enough around the tube.

One participant disliked threading the strap beneath the patient's neck especially if a patient is larger or has a large jacket on. This participant stated that the current Thomas Tube holder is easier to use than this design. But thought that this design was better because it eliminated the screw to secure the LMA. When asked if the tube holder would secure the Laryngeal Mask Airway (LMA), or Endotracheal tube (ETT) during transportation, one participant believed it would be difficult to dislodge as it was quite secure.

All participants identified an issue of using bungee cord as the whole strap that wraps around the patient's head. One participant thought it might cause pressure injuries for long term use (long transportation to a hospital). Another participant thought it would be best to have a flat elastic strap that transitions into a bungee cord that wraps around the LMA. One improvement to this, would be to shorten the length of the flat elastic strap so it fits around the patient's head better.
The participant also thought it would give more flexibility to use the tube holder on different sized people. Two participants liked the idea of using flat elastic that wraps around the patient's head because of the potential of it being more comfortable for the patient.

Figure 131. Participant threading bungee cord through securing mechanism on tube holder.

Figure 132. Participant wrapping bungee cord around 'tube'.

Figure 133. Participant threading bungee cord through tube holder part.

Hole for suctioning/ view of lips

As I noticed that the Thomas Tube holder has a hole on the surface for paramedics to use for suctioning (vomit, aspiration, blood), I asked participants if this would be ideal to have on this design. Both participants (experienced paramedics) did not use that hole for suctioning on the field but rather as a viewpoint to see if the bite-block was in place. In their experience they believed it was rare to use that hole to suction in the pre-hospital setting.
Whereas another participant thought it would be best to have a hole for suctioning. Another participant thought if there needed to be suctioning then the airway would not be functioning properly. So they were not too sure if this was needed in the tube holder design.

Intended use vs. Actual Use

An interesting observation was that one participant placed the tube holder upside down (gap toward themselves) and secured the tube that way. A possible explanation for this was that the participant may use the Thomas Tube holder in the same manor so would use this design the same as the Thomas Tube holder. It further emphasized that my intent for the design may not be used by the user in that same way. Therefore I need to make sure it cannot be easily misused. However, changing the orientation of the tube holder does not mean it would not work the same.

Reflection

I received conflicting feedback for this design solution. This was interesting as there was one participant that thought the Thomas Tube holder was better than this solution. This was a fair point as this design was not fully refined. I would have liked to refine the tube holder further by having more user testing sessions with participants. I found it interesting that the paramedicine students disliked this tube holder design as it was viewed as fiddly. Whereas the experienced paramedics liked this design because it was faster and easier to use. This inconsistency may be due to the experience of each participant. The experienced paramedics have been working in the field for some time whereas the paramedicine students have only been on placement on an ambulance for a short while and have recently learned how to use the airway management equipment.

These inconsistencies did make it more challenging to make design decisions to refine the design. In this case, I thought the feedback given by the paramedicine students were fair and needed to be thought more about for improve the design. While one participant provided feedback that indicated that the design needed to completely change, I decided to keep the tube holder design and refine the usability issues that were identified. This was because most of the participants thought the design could work, it just needed further refinement.

As a designer, I found it really challenging to let the user feedback inform the design as there was conflicting feedback. I think that if I had more participants, it would be easier to decide on what needed further refinement as I could gather a general consensus.

When I observed participants using the tube holder, one participant placed it on the 3D head upside down. From this, it was clear that design could be interpreted differently by others. The tube holder design secured the tube either way but it underlined the need for the design to anticipate how a paramedic would use it.

This was something I needed to consider for the design of the tube holder. If I had a wider range of participants (paramedicine students to experienced participants) I could conduct more user testing sessions to determine how one might perceive the design and use it.

Final Development

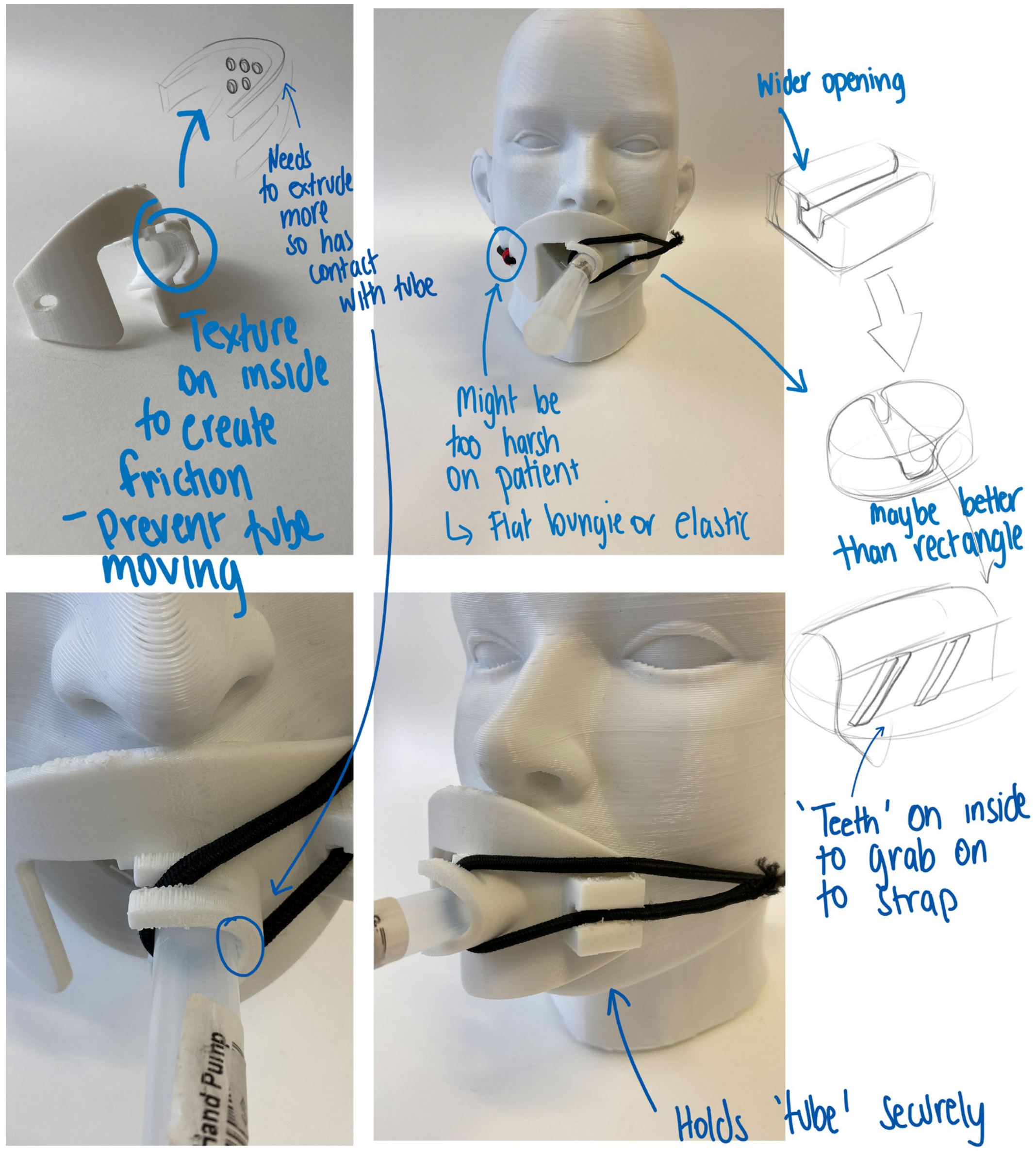


Figure 134. Sketches developing the tube holder further by exploring a textured pattern on the inside of the bite-block as well as changing the shape of the part where the bungee cord threads through.

To prevent the issue of the Laryngeal Mask Airway (LMA) device moving during transport (as identified in the second user testing session), texture was added to the inside of the bite-block. This would provide friction. The prototype demonstrated that the 'dots' needed to be extruded further so that it touches the LMA.

The securing method was a bit difficult to thread the strap through. It was modified so that the opening is wider to allow the bungee cord to slide through. This worked out better and made it easier to use.

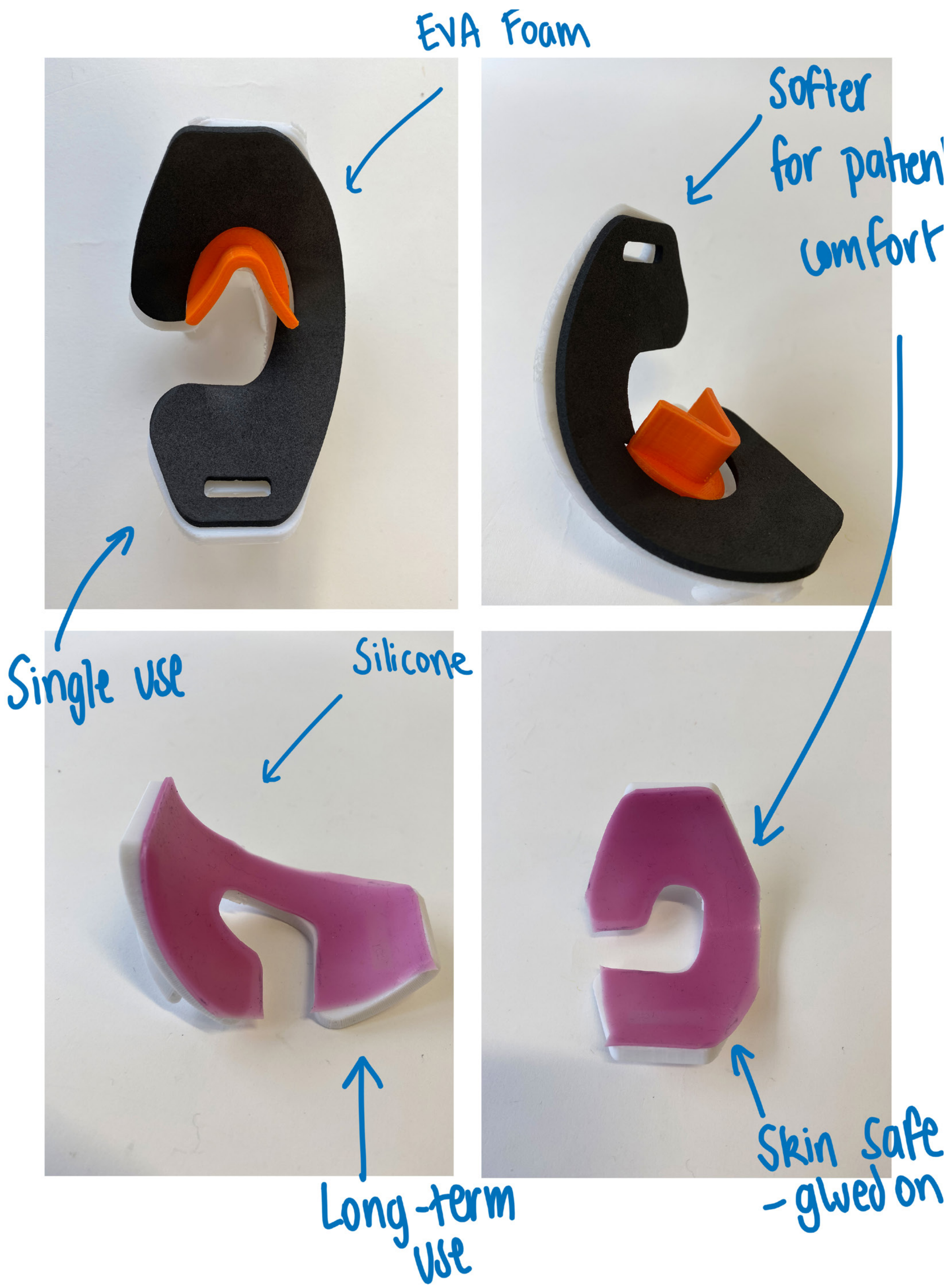


Figure 135. Annotated images of tube holder prototypes exploring EVA foam and Silicone for the underside of the tube holder (the part that sits on the patient's face).

Material considerations EVA foam vs. Silicone

From the ideation phase at the start of this project, patient comfort was always something I needed to consider. But when I was developing the strap to secure the tube, paramedic's needs took priority.

Initially I wanted to create a silicone layer which would sit on the patient's face for comfortability. However, through further research, I discovered that the use of silicone is for long-term use ("Silicone Rubber: What Is Medical Grade Silicone?", 2021). The tube holder is designed for short-term use because once the patient is transferred to the hospital, the tube holder is disposed, and tape or tube ties are used. The tube holder can encounter bodily fluids, vomit, blood, and disease. This meant that the tube holder could not be sterilised for reuse. By reusing the device, the transmission of infection could increase without appropriate sterilisation or reprocessing methods (Shuman & Chenoweth, 2012).

For this reason, I decided to use EVA foam as the base of the tube holder. This provides patients with comfort.

Final Development

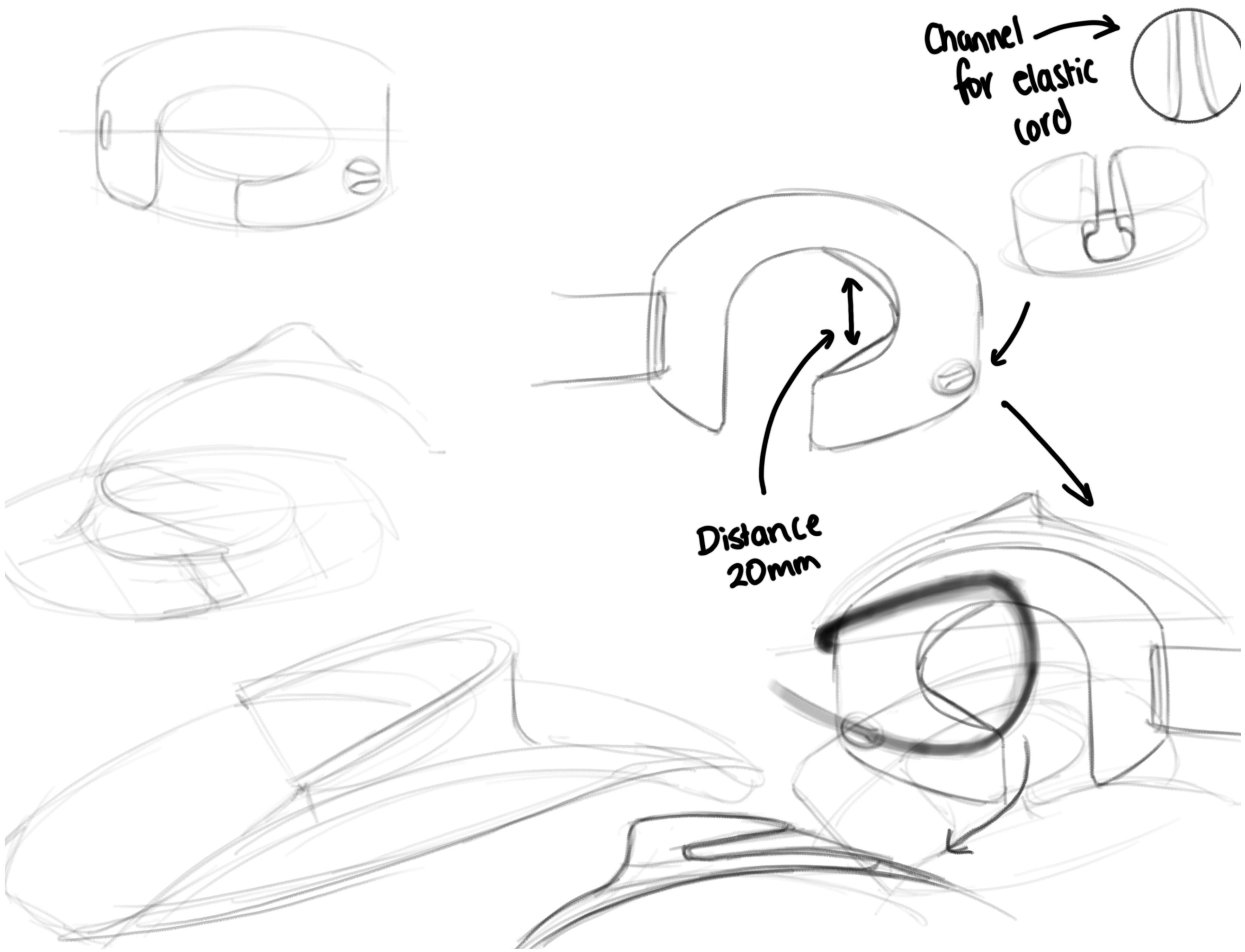


Figure 136. Final development sketches exploring the shape, and placement of the securing method as well as the orientation of the bite-block.

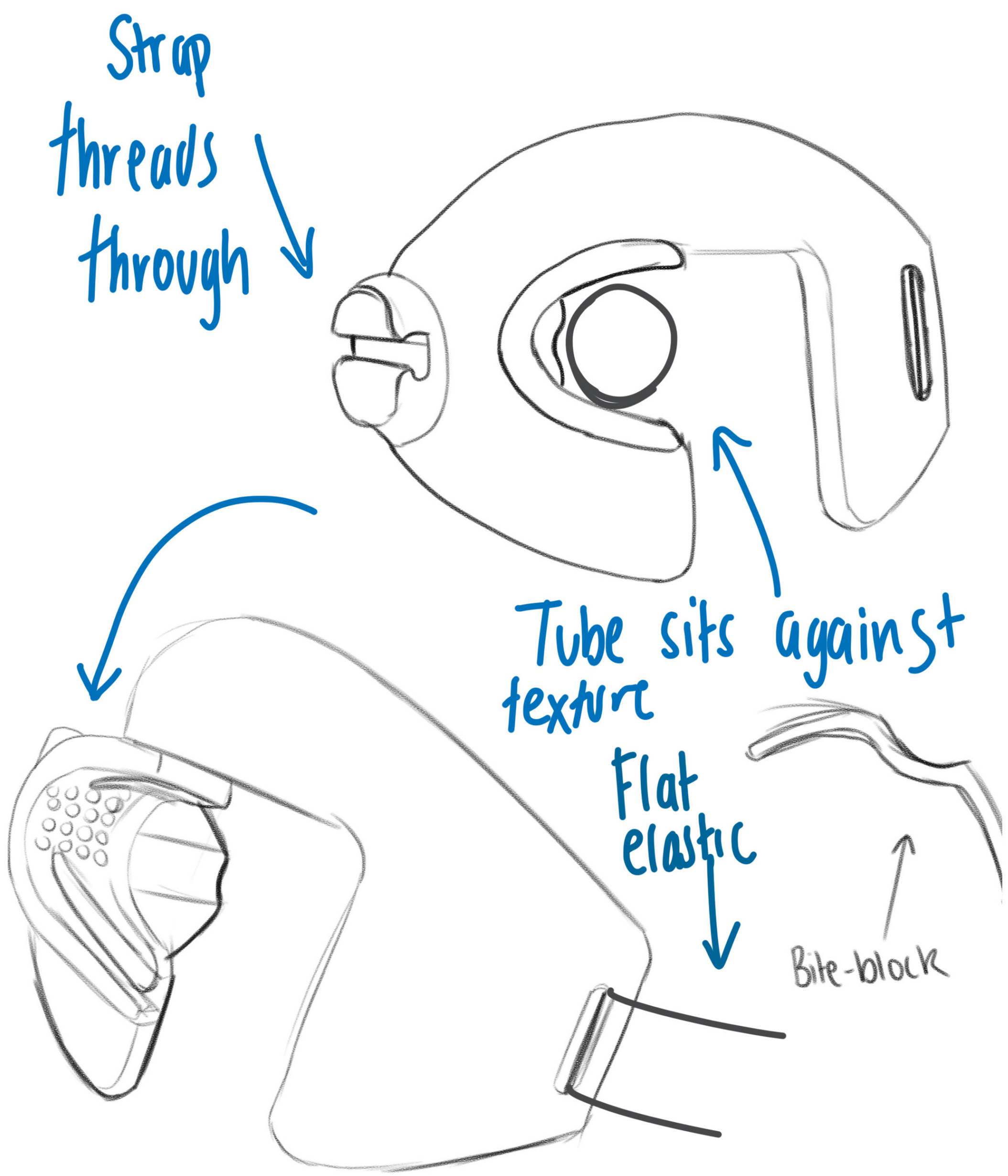


Figure 137. Sketches of the flipped tube holder with the texture inside the bite-block.

Pragmatically, I think it was best to change the side of the bite-block so it sits on the patient's right side. This is because I've noticed on the simulation videos, think-aloud videos and High- performance CPR online video (AUT, 2019), that the paramedic ventilates the patient on the right side, not left. I think it would be best to change this orientation so that the paramedic does not accidentally pull on the tube and consequently release the bungee cord securing it. I did explore this option previously (figure 116) but did not test this with participants. It should have been tested with them to gain their input. The usability should not change too much as the securing method was the same.

Final Design

Final design: Tube Holder

Final Outcome

The redesigned tube holder aimed to make it easier to secure either the Laryngeal Mask Airway (LMA) device or Endotracheal tube (ETT). I learned it was important for the LMA or ETT to be secured as dislodgement could result in an obstructed airway. Participants disliked the current solution (Thomas Tube holder) as it was found to be fiddly. The Thomas Tube holder also makes it easier to kink the tube when securing it which can result in the patient not receiving adequate oxygen.

This design allows for paramedics to easily secure the tube and tube holder to the patient in one motion. The benefits of this device were that the tube cannot be kinked, and it is faster to secure.
The tube holder design has prioritised use by paramedics as they are the intended users. Patient comfortability was considered but patients are usually unconscious during the patient resuscitation. However, if I had more time, I would thoroughly explore how it could be made more comfortable for the patient.

Material considerations

The tube holder would be made from plastic with an EVA foam layer that sits underneath.
It would be injection moulded to allow for mass production.

The strap was a flat elastic piece that transitions into a bungee cord. The flat elastic piece would be more comfortable for the patient compared with a round bungee cord.

CHAPTER SIX: DESIGN PROJECT THREE

AIRWAY KIT

Hospital vs. Pre-hospital

One of my observations during the ethnographic study simulations was that participants would rummage around the equipment pouches to find the correct sized Laryngeal Mask Airway device. I also noticed the storage was disorganised and spread out across the larger paramedic response bag.

Since airway management equipment originated in the hospital setting, I visited the hospital, as part of my interview with an anaesthetist, to view their storage solution for airway management equipment.

Hospital Setting

The airway management equipment was stored in a trolley, at North Shore Hospital. The storage provided staff with labelled drawers and symbols to support the contents of the drawer.
This organisational system makes it easier to access the correct equipment in the event of an emergency.

The hospital setting allows for the airway management equipment to be stored in an easy to access trolley as the patients come to them in the operating theatre. However, with the pre-hospital setting this can be different as paramedics go to where the patients are which constrains how the airway management equipment is stored. Therefore they carry all their equipment in a backpack to make it easier to bring care to the patient.

Figure 138. Annotated images of the storage of Airway Management equipment at North Shore Hospital.

Product Autopsy : Pre-hospital Airway Equipment Storage

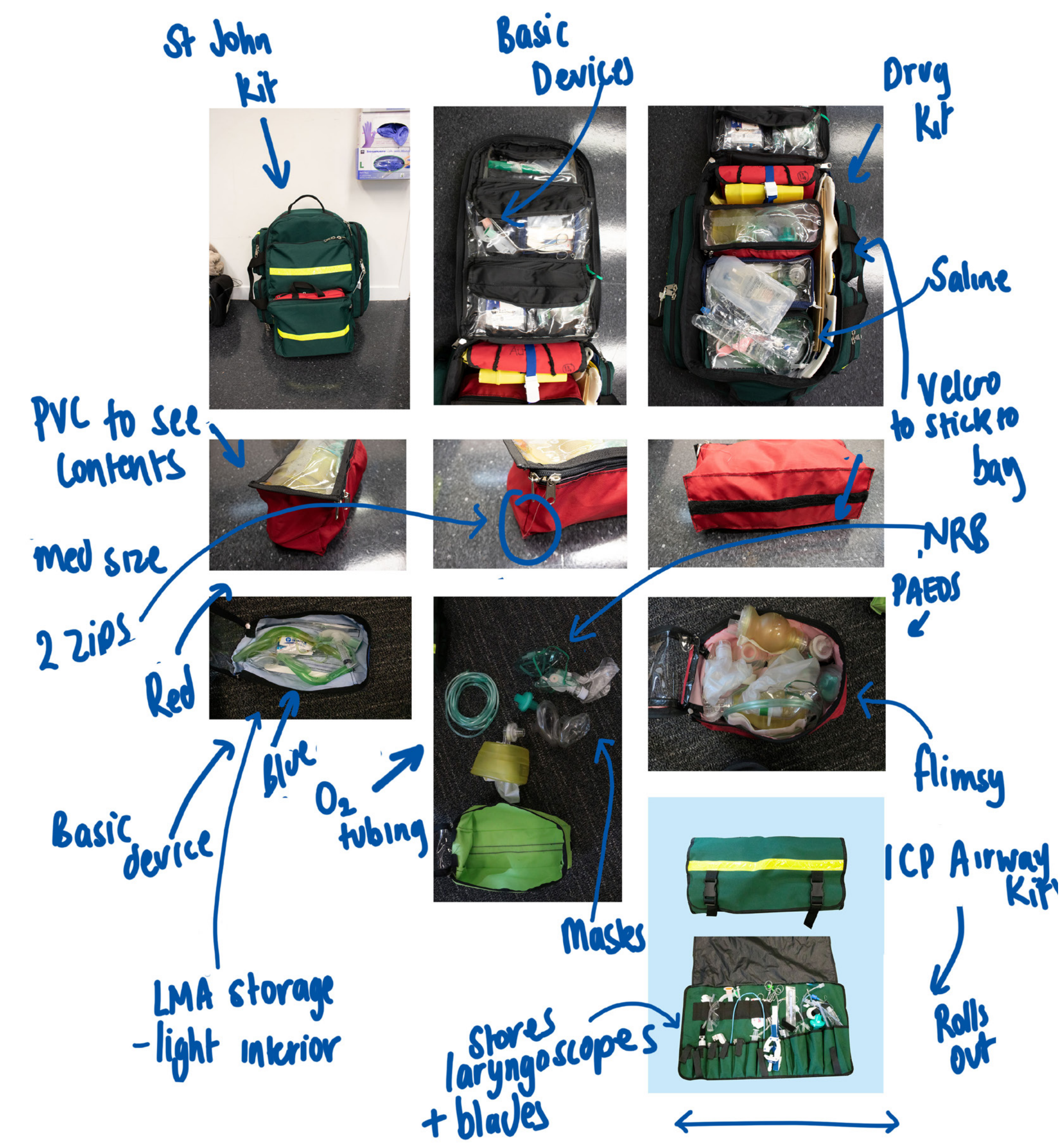
It was vital to view the current storage solution for airway management equipment. This indicated how the equipment was stored and stocked by paramedics.

I photographed each airway management pouch and analysed how it was constructed.

From this it was clear that these pouches were designed to store different medical equipment. This could be so the paramedic could organise the equipment themselves without a standardised storage guideline. For example, the Bag Valve Mask (BVM) storage was the same size and shape as the storage for the Laryngeal Mask Airway (LMA) devices. The only way to distinguish the two was to check the contents of the pouch using the clear PVC window. As observed during the ethnographic study participants would have to identify the contents of the pouch by looking at the PVC window to ensure they grabbed the correct airway management equipment. This storage solution seemed inefficient as time could be wasted identifying the contents of each pouch.

Compared with the hospital storage (see figure 138), this storage was quite chaotic as there were basic airway devices within the paramedic bag and within the smaller removable pouches.

The removable pouches were different colours but there was not a colour coded system in place as the airway management equipment was randomly stored in any coloured pouch.



INSIGHTS

-Chaotic, cluttered

-No organisation

-Basic airway stored in LMA pouch and Paramedic Bag

Figure 139. Product autopsy of the airway management equipment storage used by AUT Paramedicine department.

Materials

Paramedic response bags - polyester with a nylon interior (Palco, 2021)

Clear pouches (LMA and BVM storage- Nylon Oxford with Clear PVC window (Palco, 2021)
Intubation Airway Kit – Polyester (Palco, 2021)

These materials are durable, water proof, and easy to clean. The paramedic response bag and intubation kit were green which is the main colour for the St John brand.

Note: this equipment is used by AUT paramedicine students during their studies and the equipment is often reused and out of its original packaging. It has also been stocked to reflect the equipment bags St John paramedics use in the community.

Figure 140. Airways Trauma, Intubation bag (Palco, 2021).
Figure 141. Clear top pouches (Palco, 2021).
Figure 142.Thomas EMS Intubation kit (Medical Expo, 2021).
Figure 143.Guedel Colour coded set (Ferno, 2021).
Figure 144. Emergency respiratory bag for advanced life support (Medisave, 2021).

Market Analysis

Images have been removed by the author of this thesis for copyright reasons.

140. http://www.palco.co.nz/index.php?pr=391p__Airways_Trauma_Pack

141.http://www.palco.co.nz/597_and_598.php

142. https://www.medicalexpo.com/prod/thomas-ems/product-111116-746426.html

143.http://ferno.ca/index.php/product/guedel-colour-coded-8set-with-clear-plastic-carry-case/

144. https://www.medisave.co.nz/emergency-respiratory-bag.htm

Annotated market analysis of airway kits in New Zealand and international markets.

Images have been removed by the author of this thesis for copyright reasons.

145. http://ferno.ca/index.php/product/model-5100-airway-managementoxygen-bag/

146.http://ferno.ca/index.php/product/model-5100-airway-managementoxygen-bag/

147. https://doi.org/10.1186/s13049-018-0549-3

Figure 145. Model 5100 Airway Management/Oxygen Bag (Ferno, 2021).
Figure 146. Model 5100 Airway Management/Oxygen Bag (Ferno, 2021).
Figure 147. SCRAM bag (Swinton et al., 2018)

Annotated market analysis of airway kits in New Zealand and international markets.

Before I could start ideating the storage solutions, I needed to analyse existing storage solutions.

I found the pouches that St John paramedics use, online and analysed them by comparing it to international storage solutions for Paramedics. I primarily focused on airway management bags as these bags were specifically designed for airway management equipment.

The St John intubation bag (figure 140) had lettering to communicate the target user (Intensive Care Paramedics). However it was just placed on the front, there does not seem to be any thought put into the design as it covers the reflective tape. The SCRAM bag (figure 147) communicated the contents by stating "Emergency Airway Bag". The white lettering on the blue material makes the label stand out.

I noticed most of the storage options have a black interior or dark interior that may make it harder to see in low-light. The SCRAM bag (figure 147) was the only storage solution that used diagrams of the equipment to communicate where it should be placed. This appears to be a good idea as a Paramedic can more easily identify the shape of the equipment faster than the name.

The majority of these storage solutions are made from soft materials which makes it more light-weight for paramedics to carry. The only exception is a hard plastic case for the OPAs (see figure 143).

The colour of these products were mainly primary colours (red, blue, yellow) and are often associated with 'emergency' with some having reflective stripes. I found that the existing pouches currently used by St John Paramedics have zips that are quite small to handle and take time to open. As seen in the simulation, this resulted in the Paramedic ripping open the pouch without using the zip tag.

The St John airway bags were green to represent their brand identity as their uniforms branding on their website were also green.

From the ethnographic study it was clear that the design needed to store different sized LMAs, different sized basic airway devices, tube holder, Cobb's connector, syringe, Lubricant sachet (for LMA), and possibly the BVM.

From the Product Autopsy and Market Analysis I identified an opportunity to design a storage solution that is easier to open, makes it easier to identify the contents, and has a sense of organisation. Before I could start the ideation process, I needed to create a design criteria. This ensured that the design would meet certain specifications. These specifications were created after observing the simulations, the expert interviews, and analysing both storage used by St John and examples from overseas.

Design criteria

- Easy to use/access equipment
- Organized in a methodical way
- Reduces cognitive load
- Weather resistant
- Able to use in low-lighting
- Contains equipment for Airway Management
- Easily communicates content and/or how to use/assemble equipment

Ideation

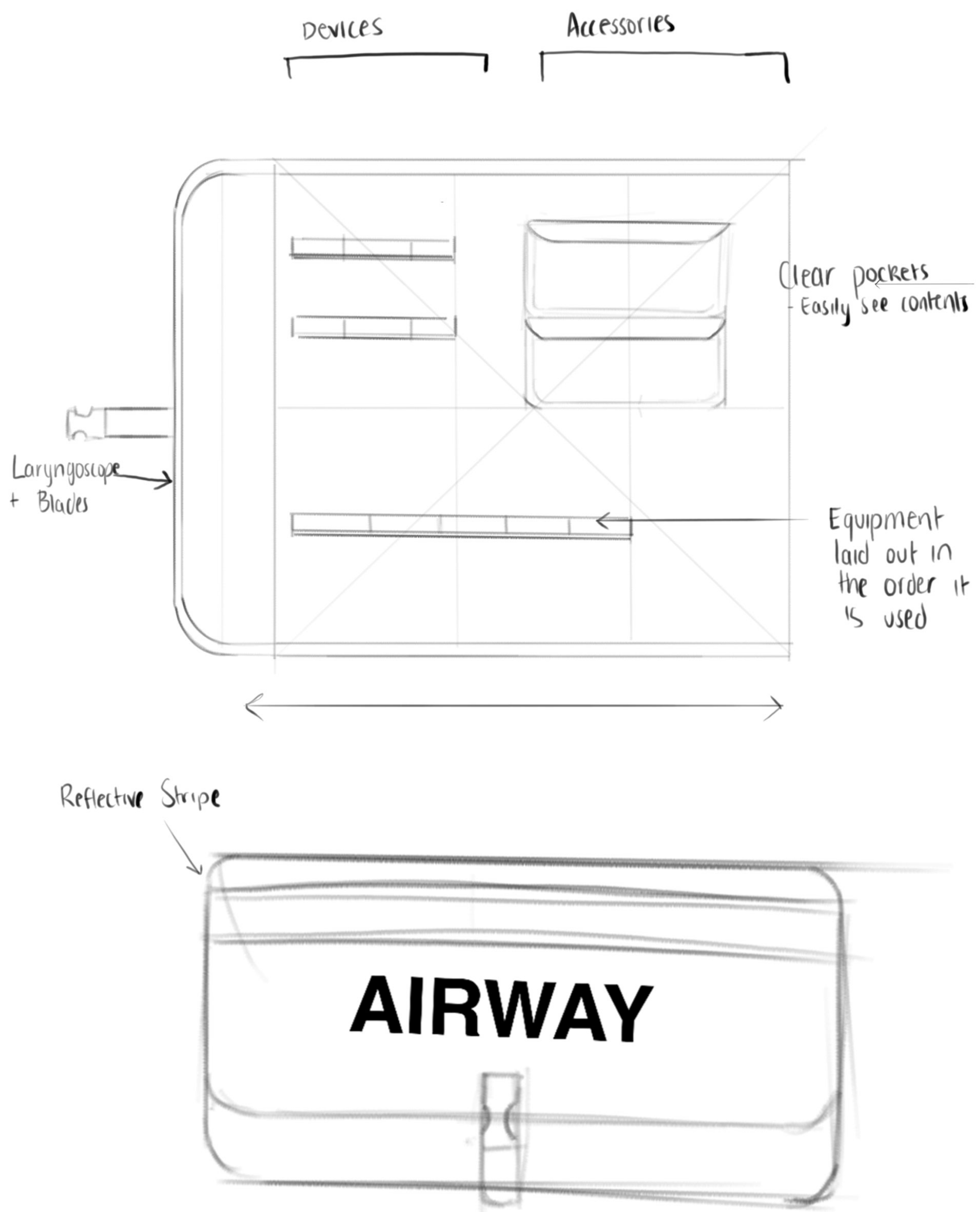


Figure 148. Ideation sketch of a potential storage solution for Airway Management equipment.

I started ideating storage concepts before I interviewed participants as gaining ethics approval was a slow and long process. Ideating before talking to the user group meant that my assumptions may have influenced the design. I prototyped two concepts out of cardboard.

This was an initial ideation sketch outlining how the storage solution may open up.

It included two areas that store the airway devices (Laryngeal Mask Airway, Endotracheal Tubes, Laryngoscope handles and blades) and airway accessories (Cobb's connector, Filter, Tube Holder).

I sketched in one buckle to secure th storage bag. I thought it would make it quicker to open up the bag especially in a time critical emergency.

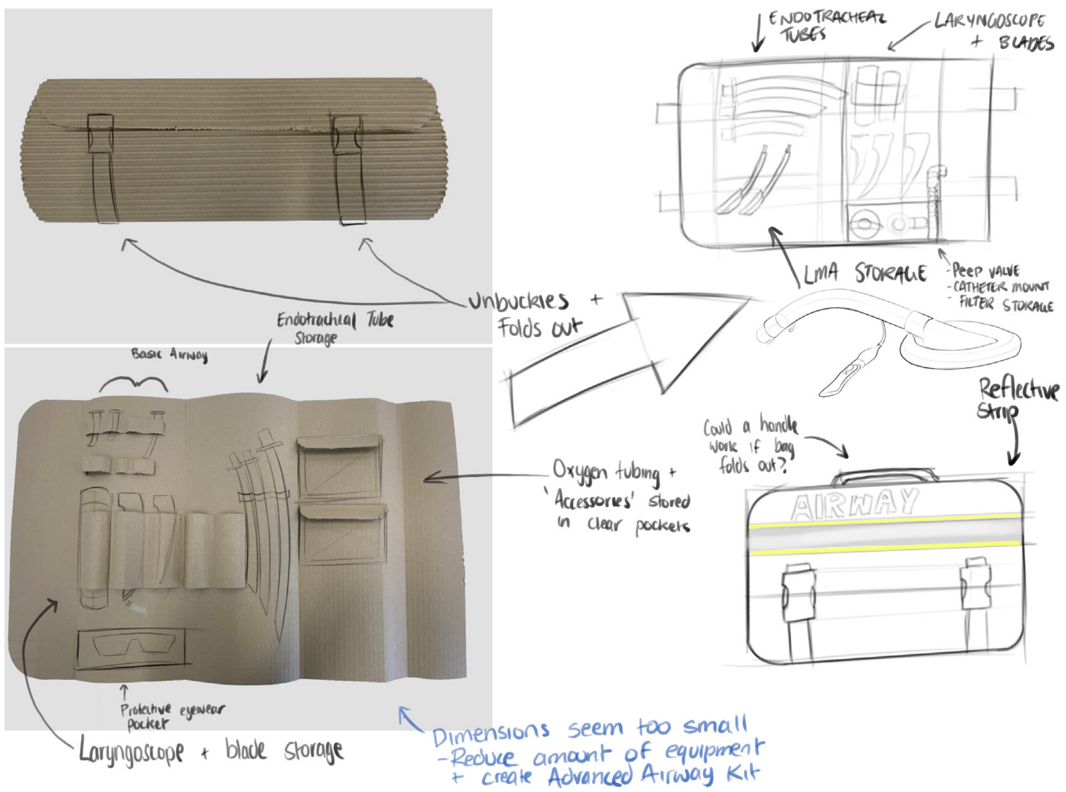


Figure 149. Ideation sketch of potential Airway Management equipment solution with pictures of a cardboard prototype made to test size.

I created cardboard prototypes to test the size and layout of the storage solution.

This sketch also explores the placement of a label to communicate the contents. It also explored the placement of reflective stripes to make it easier to identify in low light.

Two straps were added to this design as it might be needed to hold all the equipment together. Even though it might not make it faster or easier to open up, it did secure the equipment so that it does not fall out when it is taken out of the larger paramedic bag.

The sketch overlay helped visualise how the equipment would fit on the cardboard prototype as I did not have access to the airway management equipment at that time.

I sketched another concept for the storage solution that opens up like a suitcase. I prototyped this concept but slightly changed the way it opens up by making a lid at the top instead of it opening from the middle and having equipment stored in the top half.

I prototyped this concept out of cardboard as this was the quickest way to test the size and proportion of the measurements. This concept includes space for a Bag Valve Mask (BVM) as I found that in the simulations, participants would grab two pouches—one that contained the BVM and one that contained the LMAs. I wanted to create a design that meant that only one pouch for airway management equipment needed to be retrieved during an emergency.

The BVM took up a lot of space. I prototyped this storage solution and found that the way it was stored did not allow for different sized LMAs, syringe or lubricant.

 I took the concept with a clear window to my first set of user feedback sessions. This is because this storage solution was more suitable for Paramedics using LMAs.

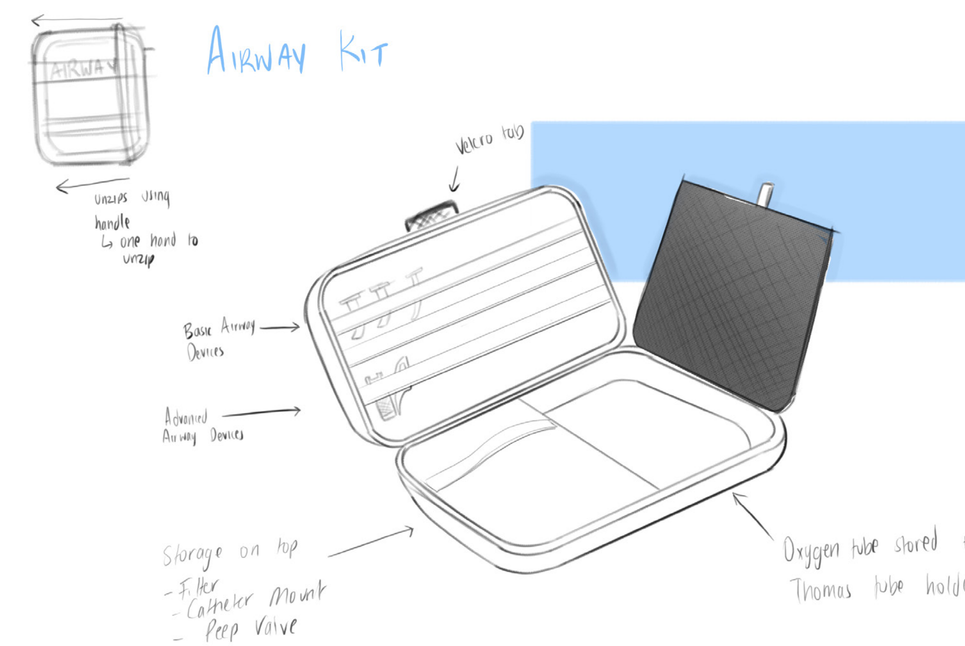


Figure 150. Sketch exploring a different storage concept. One that opens up like a suitcase to reveal the equipment.

Figure 151. Cardboard prototype of storage solution with a PVC window.

Figure 152. Cardboard prototype of storage solution showing the layout of the airway equipment.

Reflection

My initial assumption was that I was going to design an Airway Kit for all airway management equipment, which included Endotracheal Tubes and Laryngoscopes. Endotracheal Tubes, and Laryngoscopes are only used by Intensive Care Paramedics as they have the skills and qualification to perform the Airway Management procedure called Intubation. However, my ideal participant group (Postgraduate Paramedicine Students) had left the university, so I had to change the participant group to Third Year Paramedicine students. This changed what would be in the Airway Kit. Postgraduate Paramedicine students were learning how to intubate patient, which opened the scope of my project to include more Advanced Airway Devices. Intensive Care Paramedics are also trained to use LMAs.

Third Year Paramedicine students learned how to insert Laryngeal Mask Airway Devices (LMA) , while still an Advanced Airway Device it is not as challenging as Intubation. Therefore, the participant group influenced the area of Airway Management Devices I was researching.

It was only after interviewing third year paramedicine students and viewing the equipment I realised that there are different Airway Management Equipment for different Paramedics/skills (Paramedic vs. Intensive Care Paramedic).

I learned that it is best to gather information about the equipment first before starting to design as assumptions have a huge influence on form and usability.

Through the ethnographic study, I realised that there was an opportunity to design for Paramedics who use LMAs. Although, both Paramedics and Intensive Care Paramedics both have cognitively demanding airway management procedures to perform, the storage for LMAs needed to be improved.

User Testing Session One

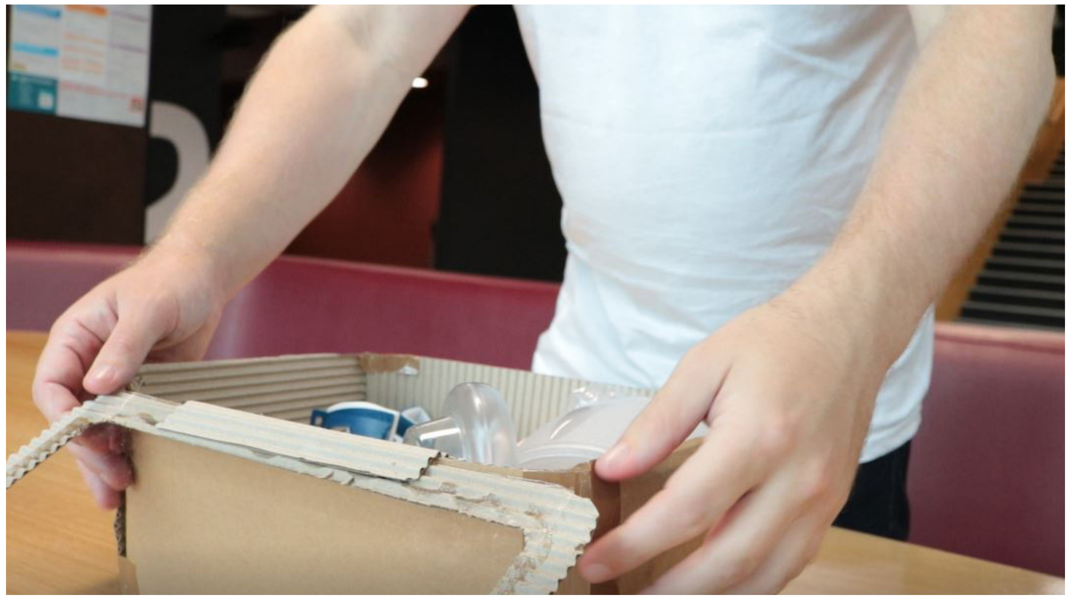


Figure 153. Participant opening storage solution and looking at the contents.

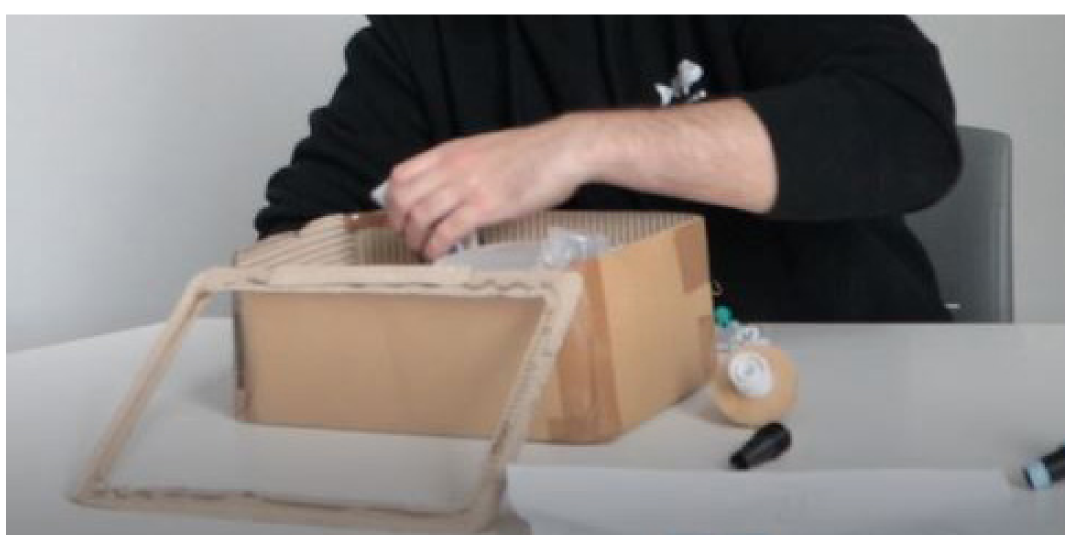


Figure 154. Participant opening the storage solution and accessing the contents.

Participant Feedback

In order to develop the storage solution further, I needed feedback and input from potential users.
I received conflicting feedback about the storage concept developed (see figure 153-154).

One participant liked the size and thought it would be great to have all the equipment in one bag. However, the other participant thought that there was too much space and the contents would get crushed.

Taking on both suggestions, I then focussed my attention on designing a better way to create storage that would not be easily crushed and store all airway management equipment.

The next steps...

Presenting concepts to participants really helped identify where the design needed to be improved. It was challenging receiving conflicting feedback as at first, I did not know which direction I should go in.

I compared the feedback from the participants and it occurred to me that there was a possibility of the contents getting crushed with the measurements. I decided to find a solution that avoided this. A storage solution that results in the equipment being damaged does not help the paramedic trying to revive a patient. This storage solution needed to be more resilient.

Development One

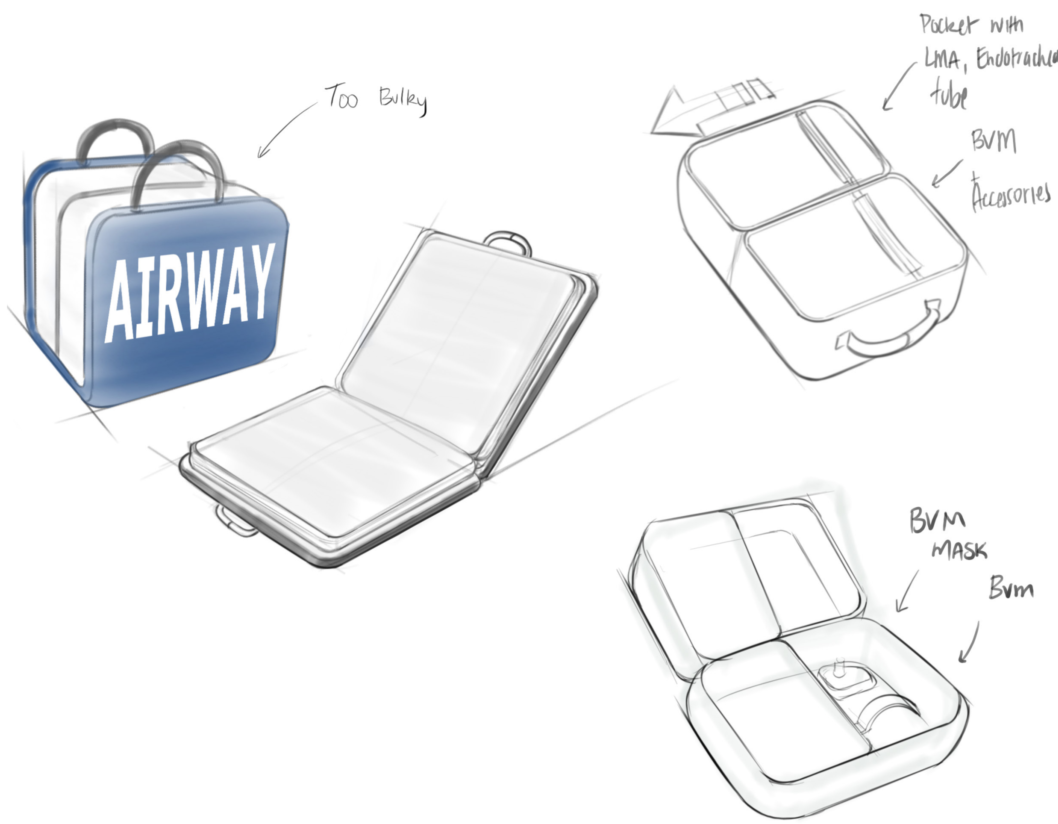


Figure 155. Storage solution ideation influenced by user feedback.

I kept exploring different storage solution designs. These sketches explored different forms of the storage solution, however it did not consider the size of each piece of equipment. The next stage was to start prototyping some of these concepts to explore how the equipment fits in relation to the size of the storage bag.

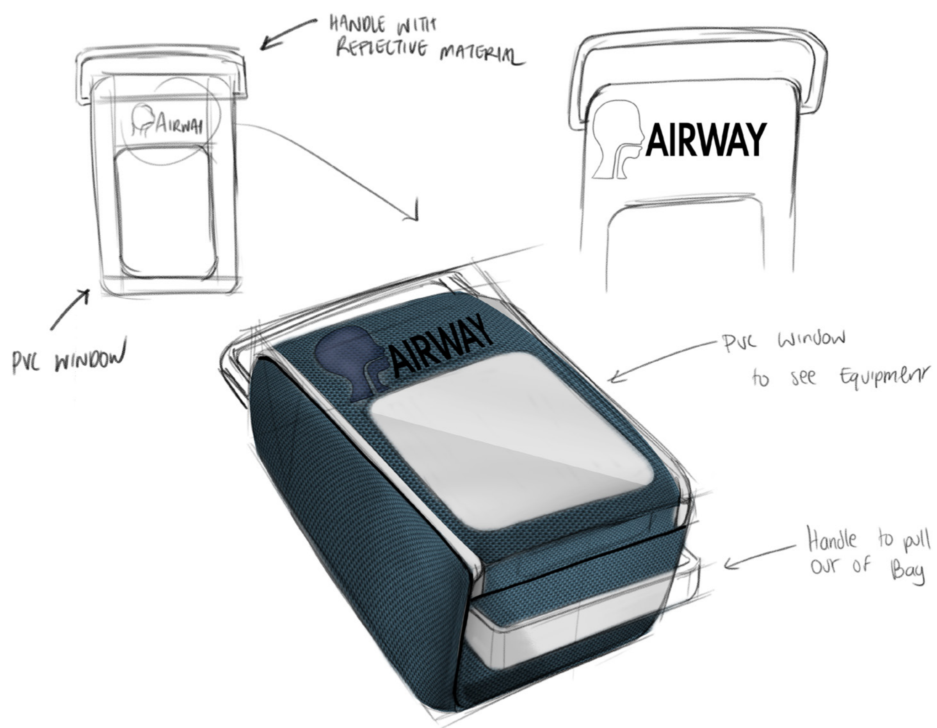


Figure 156. Storage solution ideation and material rendering exploring form and opening method as well as label for communication.

This sketch was a rendering of a potential design solution using a material overlay to get a sense of what it may look like in a back-pack type fabric (kodra). It also helped with the understanding of where a seam, in the fabric, may be placed as pouches like this are fabricated in a certain way.

Development One

Figure 157. Fabric prototype of storage solution.

Figure 158. Equipment layout of fabric prototype. Airway devices on one side (top) while the 'accessories on the other side (bottom).

Figure 159. Airway device section of prototype illustrating how the devices would be secured using elastic.

Prototyping with cardboard was a good way to work out measurements, size and proportion. However, it was best that I prototyped with softer materials that were similar to the material the current pouches are constructed out of.

I sewed the storage prototypes myself as this allowed me to explore the limitations of fabric. I used cotton fabric as this was a cheap to use for the initial prototypes. Initially I thought it would be a beneficial storage concept as it stored the airway devices (basic and advanced), the airway accessories (tube holder, Cobb's connector, filter, syringe, lubricant) but found that this concept was a bit bulky and had wasted space once the equipment was in the bag.

Although this storage solution houses all the equipment in an ideal Airway Kit (from participants feedback), I found that some of the equipment could not fit as there was no space to fit in. I explored another concept that stores the equipment but does not waste space. From the ethnographic study, it was very important to create a design that makes it easier to open and retrieve the equipment.

Development two

Figure 160. Second fabric prototype that rolls out.

Figure 161. Layout of equipment in prototype with basic devices (left), Airway accessories (middle), and LMAs (right).

I went back to a previous concept that 'rolled out' and had the equipment laid in front of the paramedic (refer to figure 149).
I started to sew this concept and work out the measurements while trying to keep within the measurements of the existing Paramedic bag it would be stored in. Currently, St John paramedics carry a big bag that has smaller removable bags (see figure 139). This allows paramedics to bring the equipment closer to the patient. From anecdotal evidence from participants, there currently is not an organisational system present with the St John Paramedic bags.

Figure 162. Layout of equipment with airway accessories (top), LMAs (middle), and basic airway devices (bottom).

Figure 163. Third fabric prototype that rolls up. This prototype has a wider base.

I found that sewing this was insightful as it allowed me to think about how I would arrange the equipment so that it is not too bulky and has maximised the space. I was also interested in exploring how the storage solution would be opened and how the equipment would be accessed.

I explored how it would work if the storage folded out to reveal the equipment. I divided the equipment into three panels of basic airway devices, airway accessories, and advanced airway devices.

Using fabric demonstrated how the equipment would interact with a fabric storage solution. Figure 160, was tightly rolled because I did not allow for the bulkiness of each piece of equipment when rolling up the storage. This was something that I included in the designs moving forward. I wanted to keep refining this solution as I believed it introduced an organisational system that made it easier to identify the equipment and retrieve it.

This second 'roll-out' prototype tested increasing the space on each panel to allow for the storage to fold better and not be so tight. I changed the layout for this concept as I wanted to move the Laryngeal Mask Airway (LMA) devices to the middle so that it was next to the basic airway devices. I increased the size of the LMA panel which resulted in the storage having a bigger base when folded up (see figure 163). This meant it would sit unevenly within the Paramedic bag. I continued refining this concept by exploring different measurements and layouts.

I explored this concept further as it didn’t waste space like the other storage solution (figure 157). It also made it easier for the paramedic to see all the equipment and be able to retrieve the specific equipment they needed quickly. Reviewing the simulation video and the think aloud session, I found that the participants had to rummage around to find the right equipment. This could impact the time needed to set up equipment during an emergency, especially when dealing with a time critical patient.

Development two continued

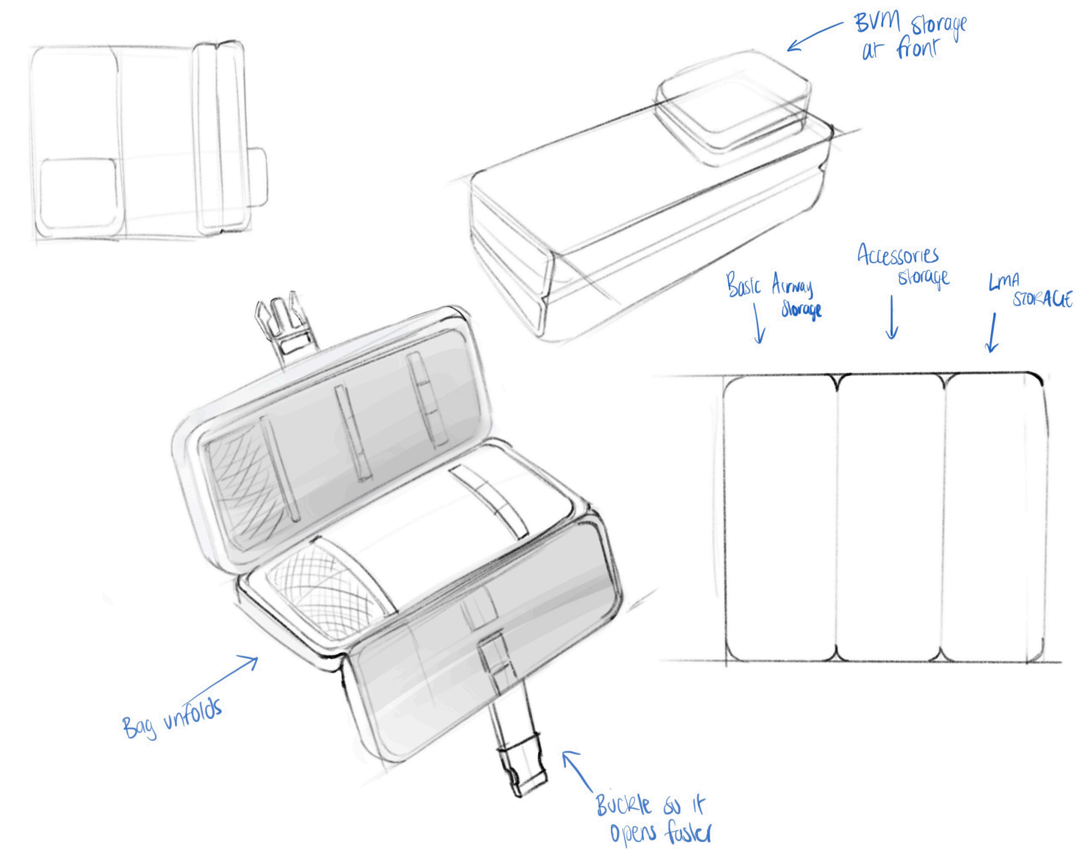


Figure 164. Sketch of storage solution that folds out. Exploration of where the Bag valve mask would be stored.

Figure 165. Fourth fabric prototype that explores BVM storage. Front view illustrated it was bulky.

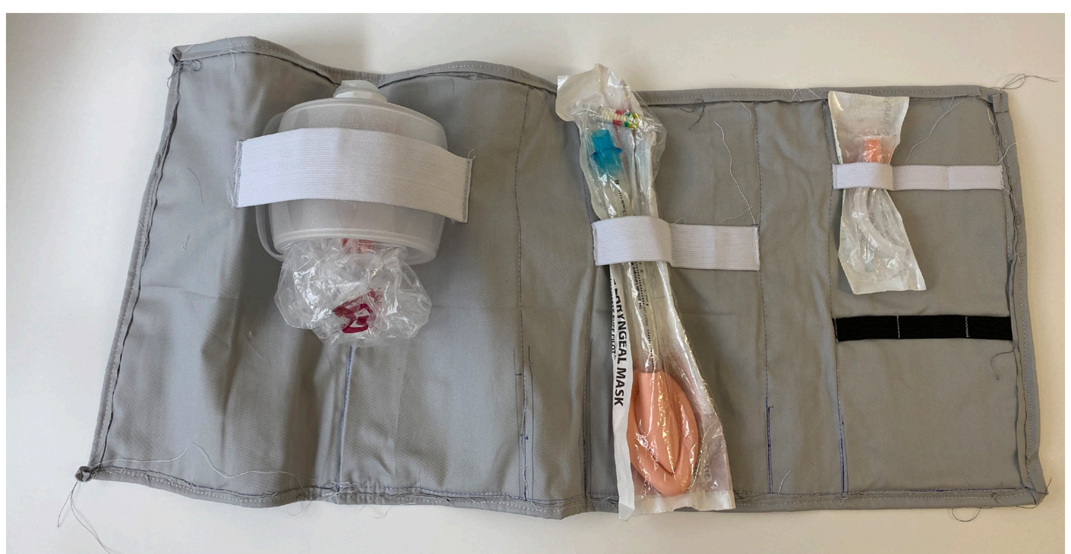


Figure 166. Layout of equipment with the BVM (left), LMA (middle), and basic airway devices (right).

I explored different sizes and configurations of equipment (figure 160-167). I explored the different configurations of equipment to figure out what would work best in a storage solution that rolled out. This was important as this influenced the measurements of the storage solution. I tried to incorporate a Bag Valve Mask (BVM) into this roll-out concept but found it to be too bulky when folded up which meant it would take up too much space in the existing Paramedic bag. Therefore, I thought it was best to create a separate storage solution to store the BVM.

Development Three

Figure 167. Fifth fabric prototype exploring a symbol to communicate contents.

Figure 168. BVM storage attached to Airway Storage .

Figure 169. Layout of storage with airway accessories (left), Basic devices (middle) and LMA (right).

The airway kit became too bulky when trying to store the BVM so to overcome this, I created a separate storage solution for the BVM. I thought it would be best to have the BVM storage attached on to the airway kit using Velcro so that both kits can be retrieved at the same time.

I wanted to test what it would look like to have a symbol to communicate the contents. I tested this because I found the space between the straps to be too small for text to be placed.

Figure 170. BVM storage prototype using a zip.

Figure 171. Contents of BVM storage (oxygen tubing, mask, and BVM).

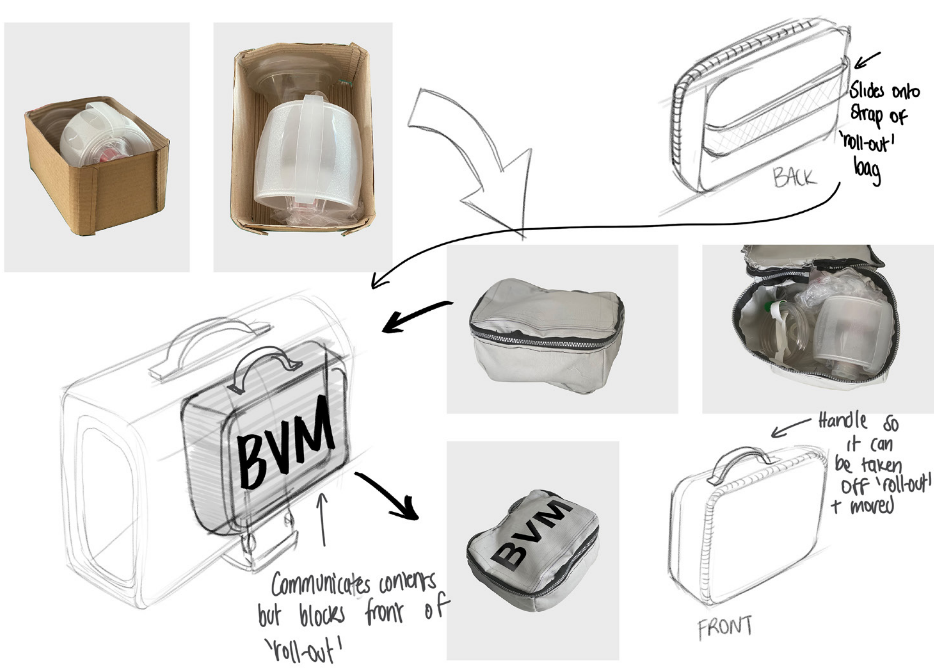


Figure 172. Sketches exploring the size of BVM storage and how it would attach to the Airway Kit.

I created another prototype for the BVM as I could not fit it into the Airway kit without it being too bulky. This bag would be attached to the Airway Kit storage using Velcro. By doing this, the paramedic takes both bags out at the same time from their Paramedic Response Bag.

I took this concept for the next user testing session (figure 168).

User Testing Session Two

Figure 173. Participant accessing equipment from the storage solution.

I took these two concepts to the next user testing session (figure 169). My intention with this concept, was to have the BVM storage attached to the LMA storage so both could be retrieved at the same time.

Participant Feedback

Keeping BVM storage separate to Airway Kit

Initially I thought it was a good idea to attach the BVM storage to the LMA storage so the paramedic to retrieves the set of bags together. When talking to this participant, it was clear that it's best to keep these storage bags separate as paramedics may need access to the BVM without using any airway devices. The participant stated, "there are times we use the BVM without the airway devices. Not heaps of times but there are times when it's the only bit you want access to." I've been viewing the storage of the equipment for Cardiac arrest emergencies when in fact there are other emergencies that need the airway management equipment. An example was a choking incident.

Airway Management process

What I found interesting was that the storage concept was a beneficial solution because it was viewed as 'phases' during the airway management process. The participant commented "the first person could start here this person could as you do CPR as you swap over you know your kind of at the second point in setting up for an LMA. Also if you go for an LMA and it doesn't work you've got immediate access to your basics [airway devices]." This gave an insight into the mind-set of paramedics during patient resuscitation. They are constantly planning and aware that they need to have a back-up plan.

During the airway management process, the airway is inserted during the 3rd cycle of CPR (AUT Paramedicine, 2019). Paramedics may swap tasks in between each cycle meaning that the Paramedic performing CPR may now be preparing the equipment for Airway Management. By viewing each panel as a 'phase' it allows the paramedic taking over to understand what stage they are at during the CPR cycles. It makes swapping tasks easier.

Reflection

It was challenging learning how to sew for each iteration of the storage solution but it was necessary as I believed I received better feedback with a fabric prototype compared with a cardboard prototype. To overcome this challenge I looked at existing bags and analysed how they were sewed which helped me think about how I would sew my concepts.

Receiving user feedback on this storage concept helped inform the next iteration. It also gave me a different perspective on how the storage would be viewed by a paramedic. Designing the storage to incorporate the 'team-work' aspect really highlighted the need for a design that makes it easier to swap tasks and communicate what needs to be done.

From participant feedback, I hadn't thought of the design as 'phases' of resuscitation when designing this concept. I designed it with the mindset of trying to make the equipment fit in a way that did not crush it or influence the shape of the storage and make it bulky. I think that viewing it as 'phases' during CPR would help lessen the cognitive burden as Paramedics would not have to think much about what else needs to be prepared before the Airway Device is inserted. My perspective of the layout differed to the expert in this field. It highlighted that I designed the storage for an ideal version of how it might be used. However, people tend to perceive things differently based on their own experiences.

Development Four
Fastening Strap and BVM Storage

Figure 174. Fabric prototype exploring one buckle for securing the equipment.

Figure 175. 'Y' strap that allows for one buckle to secure the storage.

Figure 176. Layout of equipment with basic airway devices (left), airway accessories (middle) , equipment preparation sheet (right), and LMAs (far right last panel).

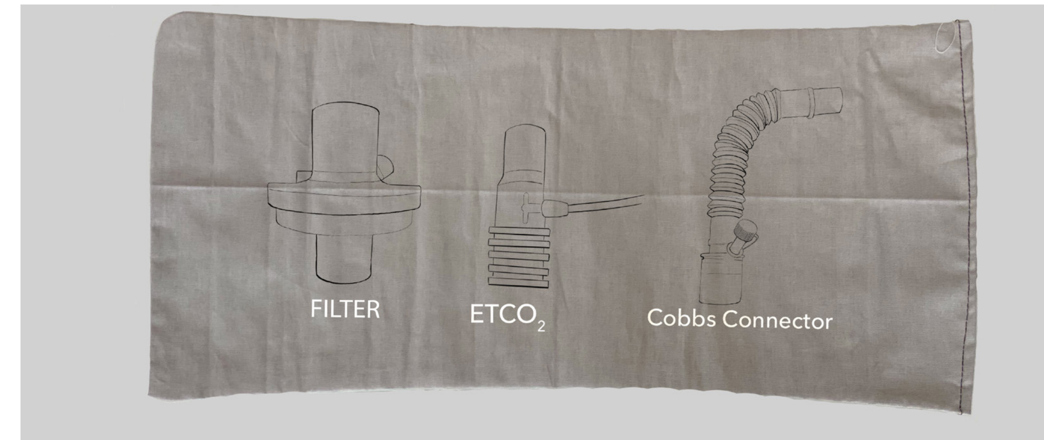


Figure 179. Sterile work sheet that displays a diagram of the equipment.

Figure 177. BVM storage exploring opening it from the middle and not the top.

Figure 178. BVM storage with contents in the 'lid' and the bottom.

After the second user testing session I wanted to refine the storage concept more. I explored using one buckle to fasten the storage solution as this may make it easier and faster to open during an emergency.

From the initial ideation (figure 149), the fastening of the storage solution changed from one buckle to two buckles. However, I wanted to test one buckle as I think it would be quicker and easier to open as opposed to two buckles. I tested this idea (figure 174-175) but found that the space between the 'Y' strap meant it could get caught on other contents in the larger paramedic response bag. This could mean time is wasted trying to untangle it which is not ideal in a time critical resuscitation. Therefore I changed this design back to two buckles.

This concept has a fabric sheet that would be used as a clean work surface (figure 177). I noticed that paramedics tend to prepare the equipment on a towel. Instead of having to grab a towel from their response bags, I thought it might be best to have it included in the airway management bag. This would save time grabbing an extra item to prepare the equipment. I also thought it was a good opportunity to create a cognitive artefact out of this design by having a diagram of the equipment for preparation.

The BVM storage explored storing the 'accessories' (mask and oxygen tubing) in the top layer of the bag with the BVM itself being stored in the bottom layer. This would allow for some organisation in the bag so that paramedics can grab what they need to assemble the BVM.

Having one buckle on the concept made it faster to open but also increased the chances of the 'Y' strap getting caught on other bags within the Paramedic kit. I switched back to two buckles located on either side the bag.

Development Five
Equipment Layout

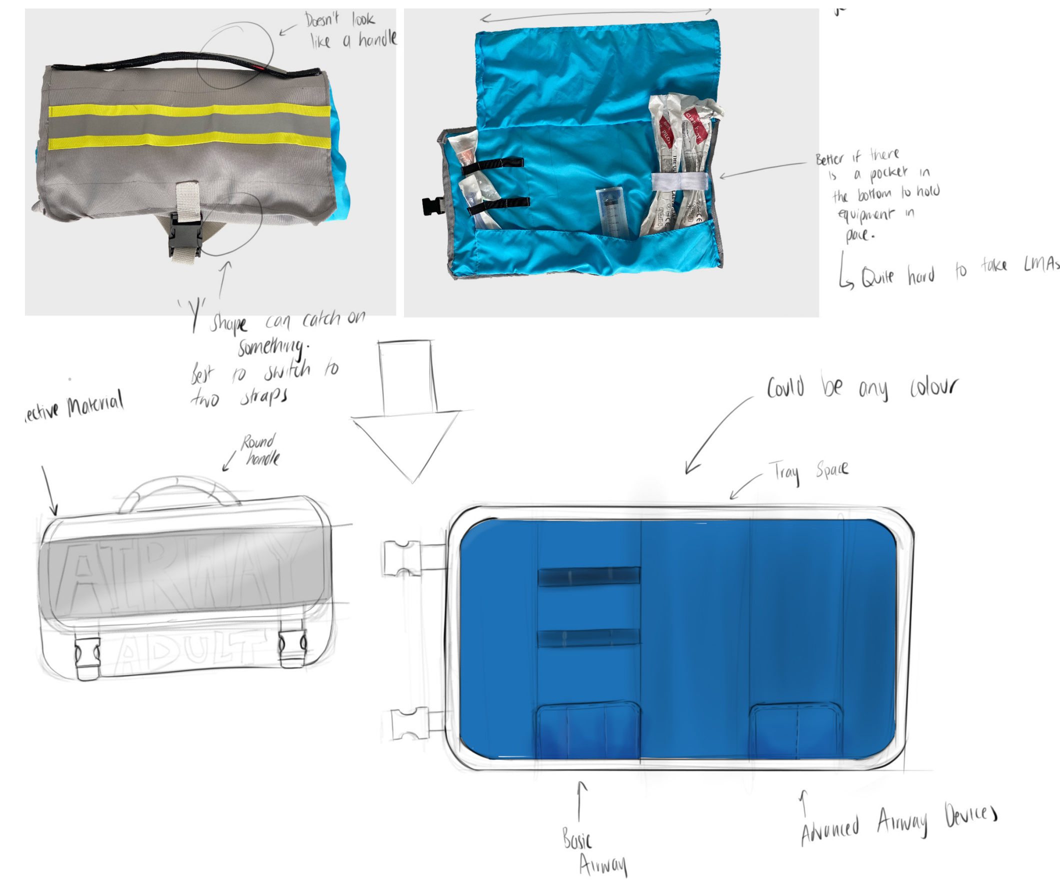


Figure 180. Sketch exploring the placement of a handle, label, and space for a 'tray' to use as a surface to prepare equipment on.

Through these sketches I explored the possible placement for the name of the kit and placement of reflective material. It needed to be easy to read.

These sketches also explored the placement for the clean surface area for equipment preparation.

Development Six
Cognitive Aid

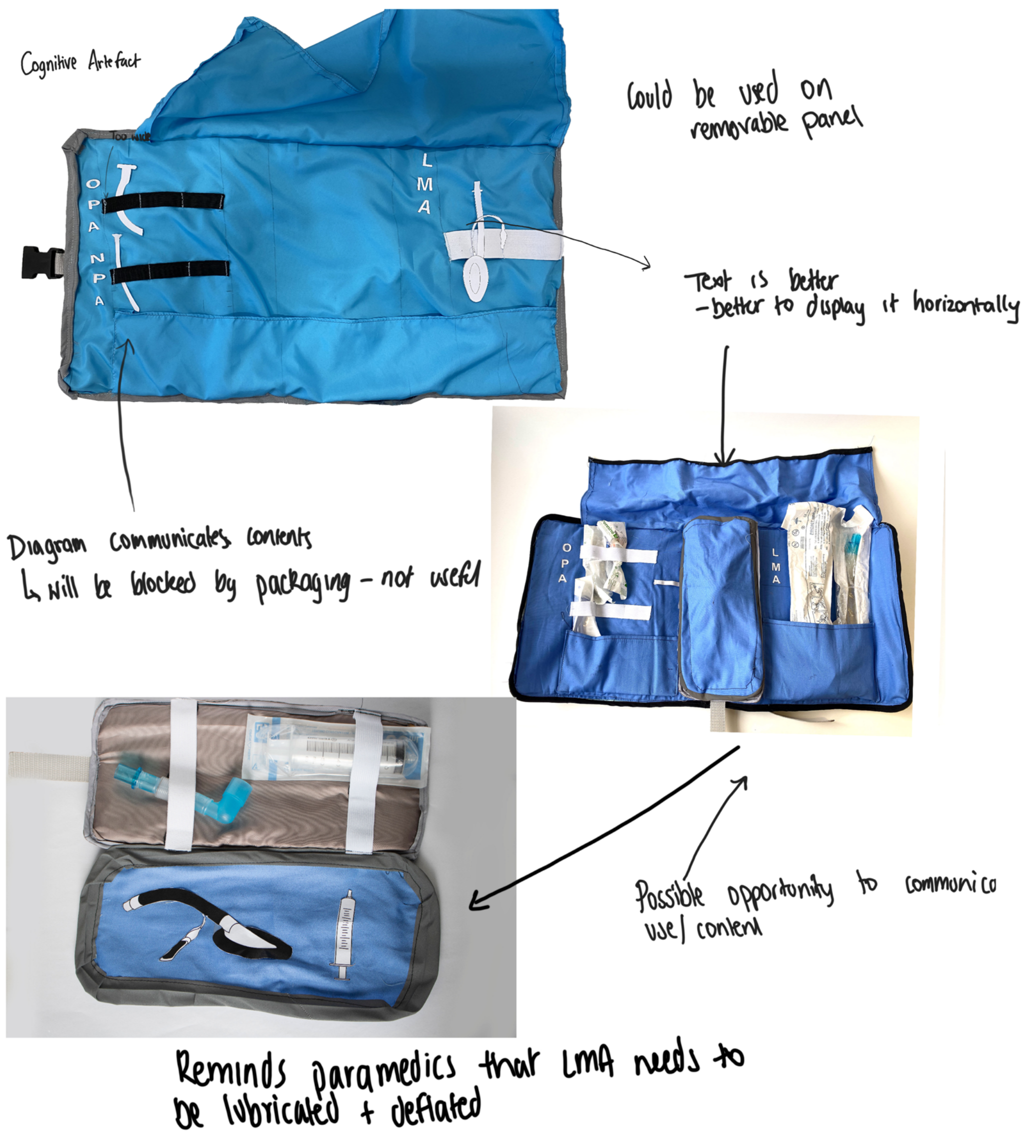


Figure 181. Photos of prototypes exploring placement of lettering to communicate the contents and placement of the clean surface for equipment preparation.

I tested lettering and images of the equipment to communicate the contents of storage. I found that the images would not be seen so were useless. However, the lettering was easy to see so this was the best choice for communicating the contents. The lettering on figure 181 (top left) was too long and stretched. I changed this so it was easier to read.

I identified an opportunity to turn the removable clean equipment preparation area into a cognitive aid/artefact. From the expert interview, I learned that participants would find it challenging to remember the sequence of the airway management equipment accessories (filter, $ETCO_2$, Cobb's connector). I thought a diagram of this could be included on the equipment preparation panel.

After reviewing the ethnographic study simulations, I realized it was best to design the equipment preparation area to remind paramedics of what equipment needs to be prepared. This was similar to how a previous participant viewed the storage as 'phases' in the airway management process.

I created illustrations of the LMA and syringe to place on the panel of the equipment preparation area. I also moved the airway accessories to this part of the storage so all paramedics need to grab is the size of the LMA and the equipment preparation panel.

Development Six
Prototypes

Figure 182. Front view of prototyped Airway Management storage.

Figure 183. Side view of Airway Management solution illustrating would not fall out.

Figure 184. Layout of equipment in Airway Management storage kit with top flap to keep equipment contained.

Figure 187. Fully opened Airway Management storage solution with round corners.

Figure 185. BVM storage with an elastic handle to open both zips at the same time.

Figure 186. BVM storage with newer measurements, with a reflective handle to open both zips at once.

I slightly changed the measurements of the BVM storage between participants in the next user testing session.

As illustrated in figure 182, I reverted to two buckles to secure the storage prototype. Unlike previous concepts, this iteration of the Airway Management equipment storage has rounded corners and a black binding which frames the contents of the bag.

The BVM storage was modified in between user testing sessions with participants to reflect the feedback given. I also modified it so it worked as I found previous iteration (figure 185) to be challenging to open.

I presented these concepts to the next user testing session.

User Testing Session Three

Figure 188. Participant opening BVM storage.

Figure 189. Participant ripping open Airway Management storage.

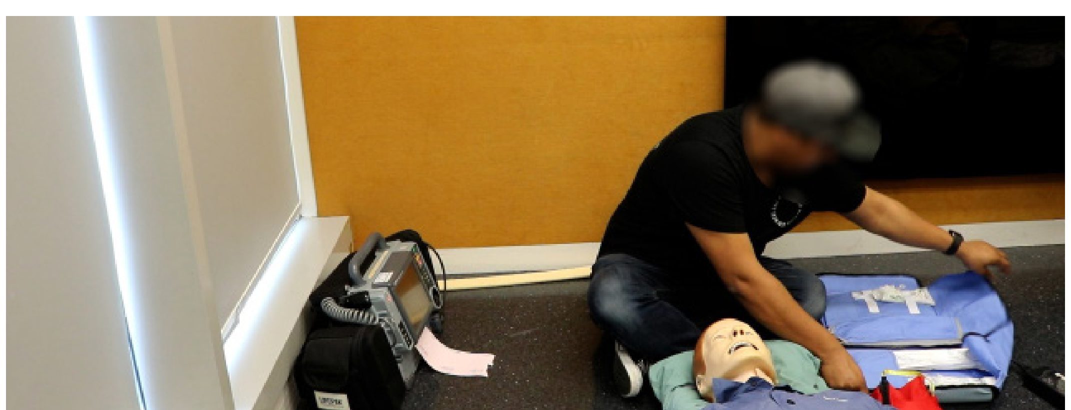


Figure 190. Participant opening flap on airway management storage.

Figure 191. Participant opening BVM storage with one hand.

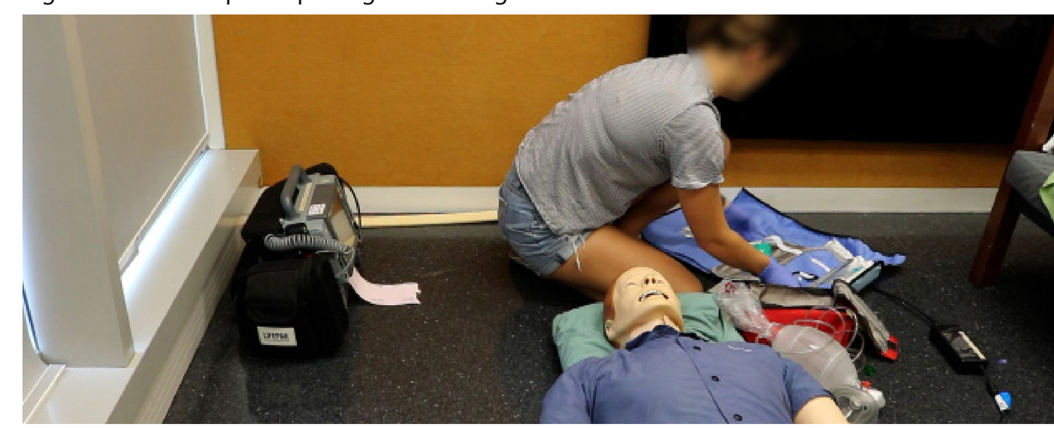


Figure 192. Participant opening equipment preparation area.

Participant Feedback

LMA storage

The airway kit—which stores the basic and advanced devices— was considered better than their current solution. The participants liked that they could have easy access to the basic airway devices if their advanced airway device failed during an emergency. One participant stated, “having this [basic devices] in this

is all ideal instead of having different pockets and another bag". This emphasized the need to make the airway management equipment easy to retrieve.
They also liked having a removable, clean workspace as opposed to a towel to lay their equipment on. It was also viewed as a reminder of where the equipment should be placed for preparation. This may make it easier for paramedics to identify what other airway management equipment needs to be prepared.
The intention of this design was to have two airway kits—adult and paediatrics/neonate. I asked participants which colour would be associated with each age group. The general consensus was blue for adults and pink for paediatrics/neonates as their Clinical Procedure Guidelines are pink for children.

BVM Storage
The participants liked that they could open the Bag Valve Mask storage in one movement which saves time during an emergency. However, they all thought the size was too small (even for just an adult kit) as there is more equipment that needs to go into the kit, such as different sized masks and a Non-Rebreather mask (see figure 139).

It was interesting that I received conflicting feedback about pre-assembling the BVM (pre-attaching the O2 tube and pre-attaching the mask). One third year paramedicine student said, "Usually all these things [BVM, Mask, and Oxygen tubing] are attached in the kit… it'll be set up as possible".

Keeping this idea of preparing the BVM by pre-attaching the oxygen tubing, I asked one postgraduate student if this was a good idea. Their response was "a big thing on the road people connecting the oxygen tubing and it's kinked by the time it comes out" and in response to being asked about pre-attaching the masks they said, "No so it will always, plus we have different sized masks, so we'll have a 5 and a 6 and they'll be in bags".

This contradiction was not a huge issue regarding the BVM storage design. It meant that I needed create a design that was big enough to store the necessary equipment that usually is stored with the BVM. Keeping this in mind, it was the Paramedic's decision to pre-attach masks or oxygen tubing to the BVM which was out of my control as this solely relied on the preference of the Paramedic. It also highlighted the fact that I could design the storage with one purpose in mind, but the intended user would most likely use it to suit their preference or need.

Reflection

One issue I encountered was that the LMA's I was using to base my design around were not actually the same ones St John used. I discovered St John use a different LMA which was packaged differently. This impacted how the design was laid out. I needed to rethink how the design stores all the equipment.

This further emphasised that I was designing for a specific ambulance service in Auckland. The other ambulance organisation (Wellington Free Ambulance), within New Zealand, may have different equipment brands that are stocked for their paramedics.

My design needed to consider that other medical equipment brands could be used so it should not be tailored to a specific packaging size. Therefore I made the decision to design for the medical products used by St John but the design could be used by other ambulance services who do not specifically use that brand.
One recurring theme of having user testing sessions with participants with different experience levels was receiving conflicting feedback. I received conflicting feedback during this session regarding pre-attaching the equipment. To overcome this I decided to listen to the postgraduate participant as they have experience being a paramedic out on the road. However, the paramedicine student's feedback regarding pre-attaching the BVM and mask to be prepared was still a valid point. If I had more time I would explore a design concept that allows this to happen without damaging the equipment.

Development Seven

Design detailing

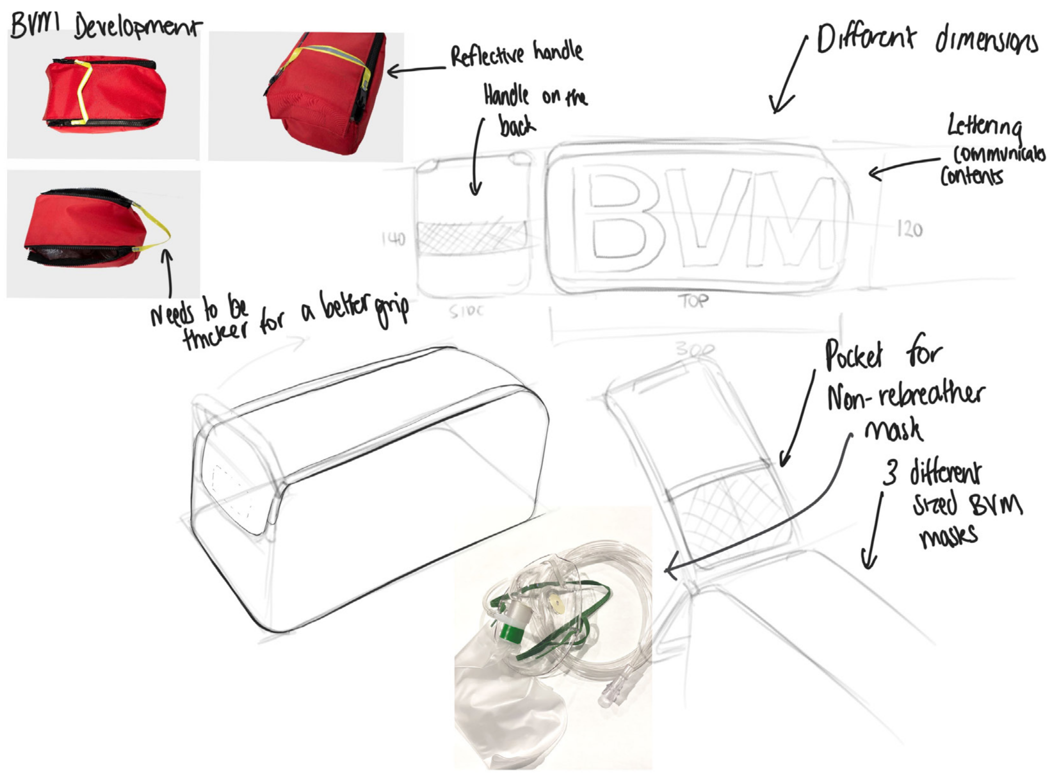


Figure 193. Sketches exploring the label placement on the storage solution as well as the measurements for the bag.

As I discovered that the packaging of the LMA's used by St John paramedics are different to the one is I was using, I needed to rethink the layout of the equipment. I developed the BVM storage further and changed the measurements to enable more equipment (different sized masks and a Non-Rebreather mask) to be stored. For the airway kit with the airway management devices, I created lettering that communicated each section of the airway storage.

The sketches in figure 193, explored how the lettering might be placed onto the BVM storage solution. It also explored the storage of the additional equipment carried by paramedics (Non-Rebreather mask see figure 193).

Development Seven
Design detailing

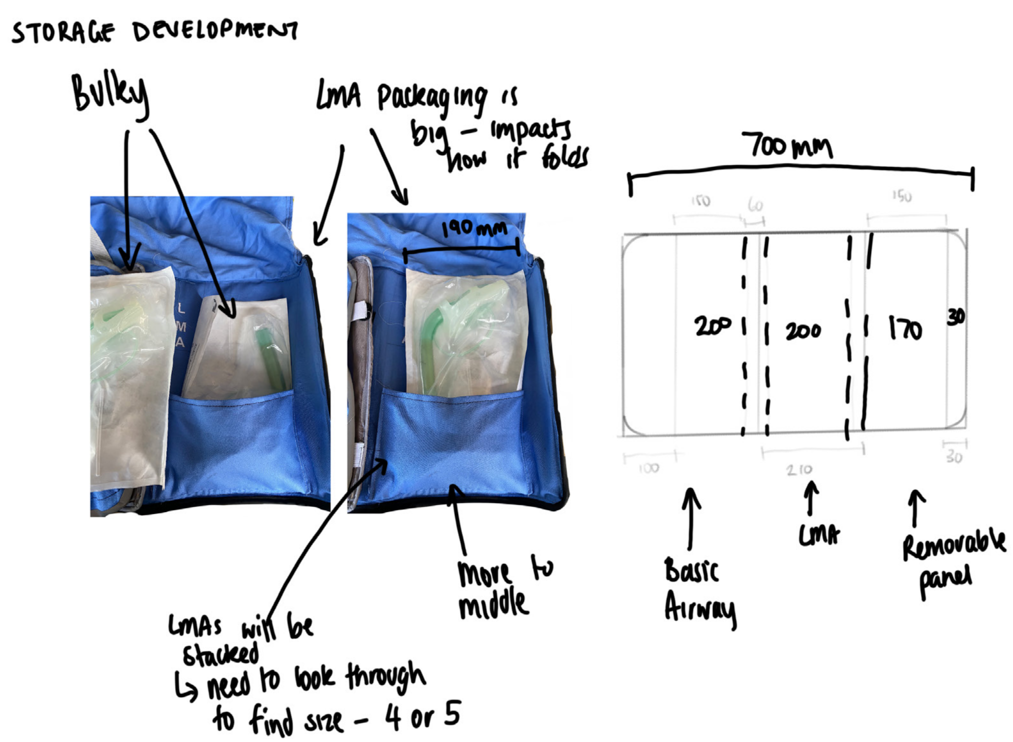


Figure 194. Exploration of measurements of the Airway Management storage to account for the different sized packaging for the LMA.

From the previous user testing session, I discovered St John use a certain brand of LMA. This brand happens to have a wider packaging footprint compared with the LMAs I was initially working with.

Due to the wider packaging, the measurements needed to change so that the LMA actually fitted in the storage solution.

I discovered the width of the packaging impacts how the storage was folded, resulting in the front not folding over properly.

I had to move the Equipment Preparation Area (clean work surface) to the end of the storage solution to make room for the LMA. As I've observed a participant ripping the storage open with a sense of urgency, storing the LMA in the last panel may cause it to fall out if someone were to rip the storage open. Because of this, I decided to move the LMAs to the middle. I also did not want to add elastic bands to hold it in place as this would lead to paramedics wasting time trying to remove it from the storage as it may get caught on the elastic.

Development Seven

Design Detailing Clean Removable workspace

These sketches exploring the measurements of the removable clean work area. I also wanted to explore if there was an opportunity to turn each panel into steps of the airway management process when equipment needed to be prepared. However, I thought this might complicate things so I changed it to panels that fold out and have a symbol to communicate that the equipment should be prepared on the last panel.

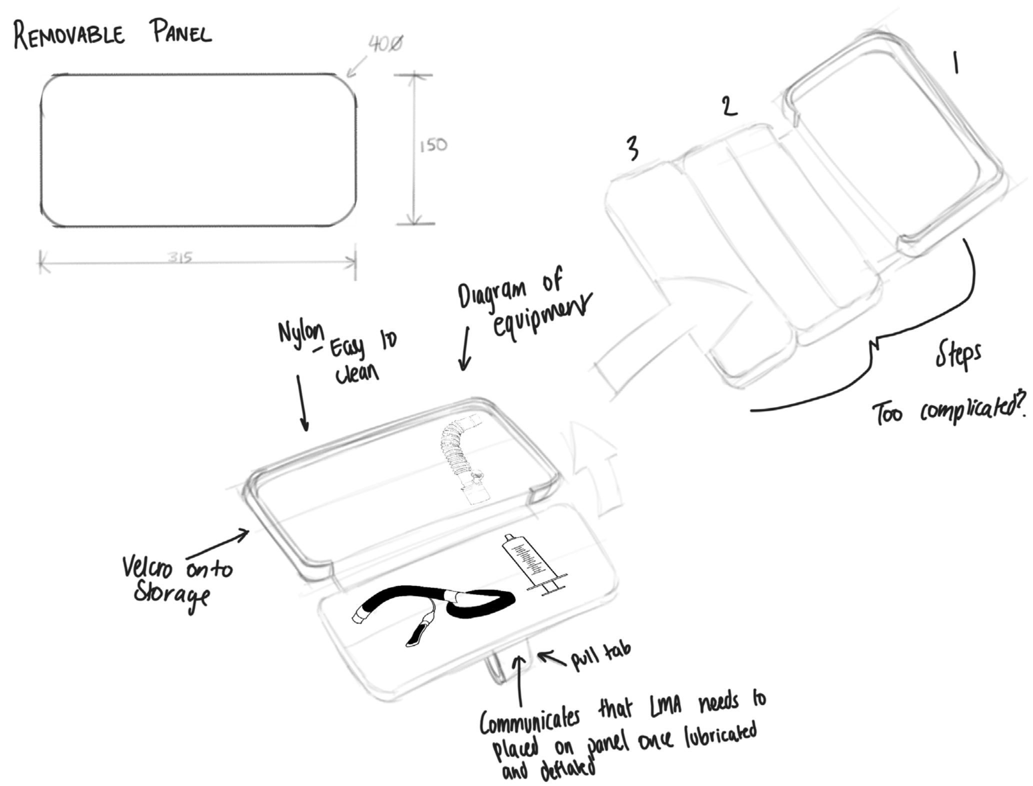


Figure 195. Sketches figuring out the layout of the equipment preparation area.

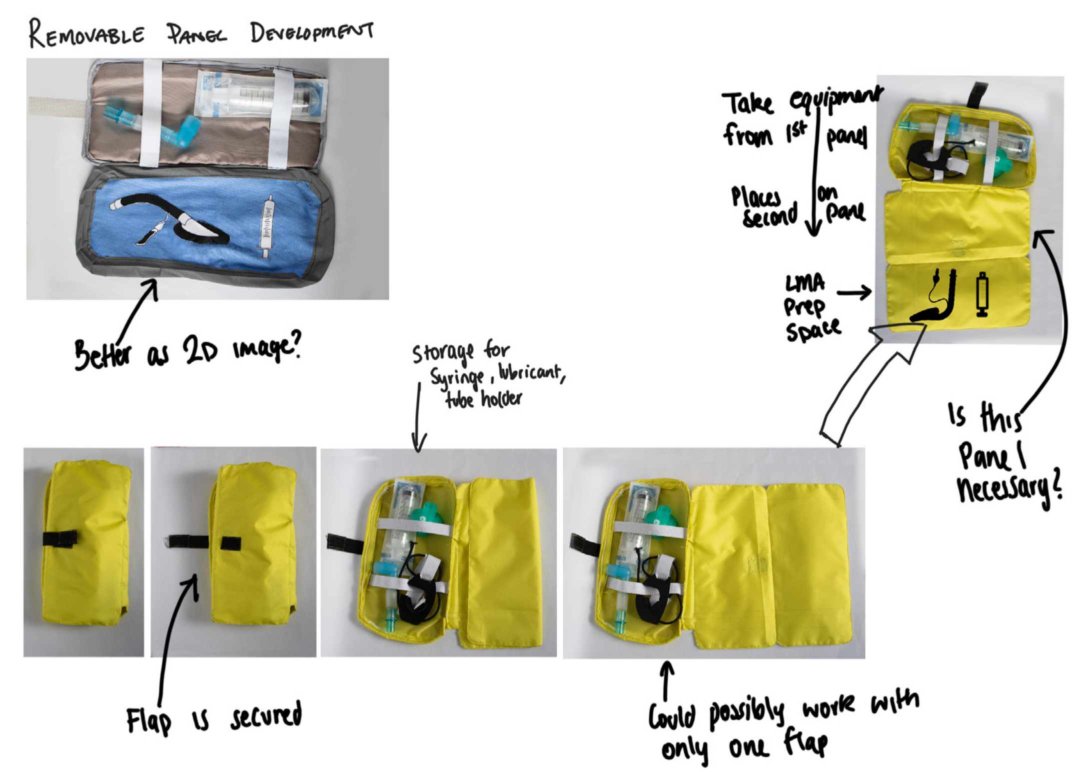


Figure 196. Analysing photos of prototyped Equipment Preparation Area. Prototyping the appropriate position for the diagram of equipment.

I analysed the prototype I made and wondered if the third panel was necessary. This was something I needed to ask participants about as they know how much space would be needed to prepare equipment on.

I also changed the image of the LMA to reflect the type of LMA they use. The 2D illustration works out better than the 3D illustration. The 2D illustration was much easier to identify as an LMA.

Prototypes for user testing sessions

Figure 197.Layout of equipment basic devices (left), LMAs (middle), and equipment preparation panel (right).

Figure 198. Final prototype to be taken to user testing session.

Figure 199. BVM storage with reflective handle.
Figure 200. BVM storage opened to reveal contents.

Figure 201. Equipment preparation area opened to reveal equipment (left) and images for placement of equipment during preparation.

Figure 202. Equipment preparation area that contains 'airway accessories'.

I used slightly different materials for these prototypes. I used a cheap nylon for the BVM storage (figure 199) and the interior of the LMA storage (figure 198). I wanted to replicate the material that the final model would be made out of as this material is easy to clean.

The BVM had slightly changed measurements to reflect the feedback given from the previous iteration. This was to account for storing more masks and a Non-Rebreather mask paramedics may use during emergencies. I found the handle at the front did not add anything to the design. When pulling the zips back it did not help with that movement. So it was best to get rid of that after the next user testing session.

For this iteration, the Equipment Preparation Area (figure 201), was bright yellow. I wanted to test whether this made a good cognitive aid and whether it would be easily identified as something that was removed from the storage during patient resuscitations.

I took these final models to the final user testing session.

Final User Testing Session

Figure 203. Participant preparing equipment on equipment preparation area while another participant performs CPR.

Figure 204. Participant opening equipment preparation area without removing from airway kit.

Figure 205. Participant using equipment preparation area, about to place LMA on surface.

Participant Feedback

This was my last chance to gain feedback on my storage solutions for airway management equipment. This feedback would allow me to make changes for the final design.

BVM Storage

Feedback for the BVM storage was that the zips may fail. One participant suggested a suitcase-like design with all the airway management equipment and ventilation equipment (BVM) so that it is easier to access.

In the scope of a master's project, there was not enough time to explore a concept like this. I was also constrained with the existing bag St John uses for their medical equipment.
With the BVM storage, one participant stated that some of the ambulance vehicles may already have the handle on the zips for easy access.

LMA Storage

Three participants liked the fact that Velcro was used to secure the LMA storage as this made it faster to open.
The LMA storage received positive feedback because they could see the basic airway equipment and advanced airway equipment. One participant did not initially remove the Equipment Preparation Area and folded it out as an extension of the design.

An interesting insight was, when I asked a participant about the handle on the LMA storage, they thought that it does not matter as the airway kit would be grabbed and thrown on the ground.

Clean Work Space

One participant suggested having Velcro may make it stick to carpet and might be annoying to remove but also stated some people might like to have it sticking to the ground so it does not move. This was the case as it stuck to the carpet when they tried to move it closer to the patient.
One participant believed the colour of the clean work space (yellow) was good as it would remind paramedics not to leave it on scene.

Another participant suggested the clean workspace needed to be easily cleaned in the event of having to remove the airway device from a patient and the device being soiled with vomit or blood. This meant I need to think about how this design can be better adapted to the likelihood of being exposed to bodily fluids, blood and possibly vomit. One participant also suggested having the clean workspace fold out to be longer so that if it were used by Intensive Care Paramedics (ICPs), they would have the room to prepare their equipment. This was because ICPs have more airway management equipment to prepare for patient intubation.

Reflection

I believed sewing prototypes was essential as it gave participants a glimpse of how the storage may look and work, it was really time consuming. During my process I would sketch the storage solution first before sewing it as I was a beginner when using a sewing machine. Having a working prototype allowed participants to give better feedback.

Taking on board the feedback participants provided, I developed each storage design further. There were little usability aspects I needed to think more about. I think it was essential to remember that this design would be used in different environments/locations and under different circumstances as no two emergencies would ever be the same.

I found it interesting that one participant did not remove the Equipment Preparation Area and unfolded it as an extension of the storage. This could be the paramedics' preference but I did not think of having it unfold as an extension. It was fascinating as it gave me an insight into how it may actually be used with some paramedics preferring to leave it attached to the storage solution. I think it was essential to have that ability to be able to move the Equipment Preparation Area if they wanted to.

I still wanted to complete a few more user testing sessions as I think the design could be further refined to work out usability issues. I think it would also be beneficial to 'test' this within the current St John bags to see how paramedics access the equipment.

Final Development

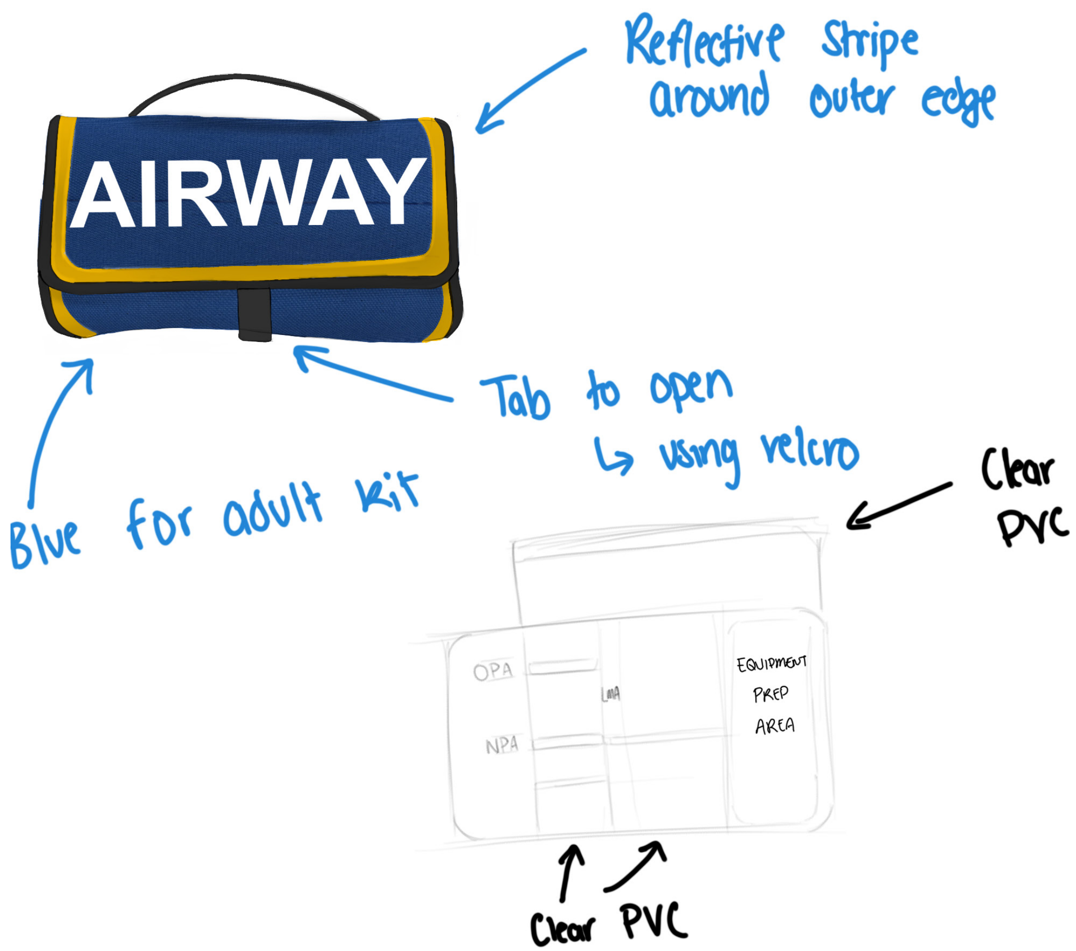


Figure 206. Sketch of the final developments for this storage solution.

I rendered a sketch of what the airway kit may potentially look like. I needed to explore how it would look with the reflective stripe around the edge of the bag. With the previous concepts, it made it harder to position the lettering onto the front as there was a reflective strip. This way the strip does not effect the lettering. However, it did mean that there would not be any reflective strip on the handle as that would mean there was too much reflective material.

I created more space between the basic airway panel and advanced airway panel to allow for lettering to communicate the contents. This also allows the front to have a folded flap that looks better than the previous iteration.

The BVM storage essentially has not changed. Except for moving the handle to the back of the bag instead of the front (figure 199).

Final Design

Final design: LMA storage and BVM storage.

I re-designed the airway management storage solution as participants found the current designs to be more time consuming when trying to find the correct sized airway management device or trying to find the airway management accessories (Filter, Cobb's connector). Through the interviews, I found the basic devices were scattered throughout the paramedic response bag with some devices located in the same storage pouch for the LMAs. I wanted to create a design that made it easier to retrieve and access the airway management equipment. My design stores both the basic airway equipment, advanced airway equipment and the airway management accessories. Both bags would be colour coded to communicate that it either contains 'Neo-Nate/Paediatric' sizes or 'Adult' sizes.

The storage for the Bag Valve Mask (BVM) was designed to be easier to open. I noticed during the simulation and the think-aloud session, participants would not bother using the zip tags to open the bag. They would just rip it open. This led me to design a handle that could be pulled in one motion to allow for quick access. The BVM storage will be colour coded the same as the LMA storage solution (adult and neonate/paediatric).

There was a label placed on the front to communicate the contents and this would be in a luminous material so that it can be seen in low-lit environments.

Within the bag there was a clean work area for paramedics to use to prepare the equipment. It folds out to reveal the airway management 'accessories' needed to prepare the equipment before use.

CHAPTER SEVEN

DISCUSSION

Introduction

In this research, I aimed to explore the gap in knowledge surrounding design and research for paramedics working in the pre-hospital setting. Human-Centred design methods and an Action Research approach were used to engage with paramedics and paramedicine students to explore their experience with airway management equipment during the resuscitation of cardiac arrest patients. As I am a designer, and not a paramedic, their knowledge and experience with airway management equipment and patient resuscitation were crucial in informing the final design concepts. This research aimed to show how a Human-Centred design approach can benefit paramedics using airway management equipment.

This study aimed to examine the importance of Human-Centred design to optimise paramedic performance during patient resuscitation. My aims for the design outputs from this research were:

To create a design solution that alleviates Paramedic stress and reduces cognitive load during patient resuscitation.

To design a solution that makes Airway Management equipment easy to find and retrieve in an emergency.

The objective of this project was to highlight areas where design can benefit paramedics using airway management equipment during patient resuscitation. The experience of participants helped shape, inform, and refine each design solution so that they were better tailored to their needs. To achieve this, it was important to gain a better understanding into how the airway management equipment was accessed and used in the pre-hospital setting.

I used a Human-Centred design approach as I wanted to create designs that considered the needs of the user and how it would be used in the pre-hospital setting. Each design concept aimed to benefit paramedics by reducing cognitive load, stress and by optimising their performance.

Paramedics adapt to poor design

Through expert interviews with participants, it was apparent that the pre-hospital environment can be unpredictable and filled with uncertainty. An example of this was when a participant described how they felt attending cardiac arrest emergencies stating, "the first initial 3-4 minutes are hectic ". This response suggested that cardiac arrest resuscitation can be chaotic which may increase cognitive load, due to the amount of information needed to be processed which could exacerbate feelings of stress. This view was echoed by other participants that described the factors that make a resuscitation stressful. Anderson et al.'s (2018) study exploring the challenges New Zealand Ambulance personnel face during decision making highlighted stress as a factor that impacted them. Paramedics are trained to overcome these feelings of stress, but when responding to a life-or-death emergency, there are factors (noise, keeping track of time, age of patient etc.) that contribute to stress and cognitive load (LeBlanc et al., 2012; Anderson et al., 2018).

An important example of paramedics adapting to poor design was highlighted during the ethnographic study simulations and think-aloud sessions for this research. I observed participants access and use the airway management equipment. I noticed, in the simulations, that participants would attach the airway management accessories (filter, $ETCO_2$ device, and Cobb's connector) in an incorrect sequence that suited them at the time. A possible explanation for this might be that the participants felt the time pressure during the cardiac arrest simulation and needed to attach the equipment (in any order) to ventilate the patient on time (after 30 chest compressions). The findings from the interviews suggested participants knew that there was a standard guideline to follow when assembling the airway management equipment but often forgot the correct sequence. This underlined how paramedics adapt to poor design as they connect the pieces of airway management equipment in a different sequence to the guideline. This further emphasized the understanding that paramedics often adapt to certain tasks to get the work done (McNab & Rutherford, 2020). The ISO connectors each piece of airway management equipment used allows the equipment to be attached in different ways. I tested this by attaching the equipment in different sequences. I found four possible combinations for the equipment to be attached. If the system were better designed, there would only be one way to attach all the equipment together which would reduce the chance of error. Simmons & Graves (2008) noted that the Luer connector that has been linked to tubing misconnections (IV lines, feeding tubes, tracheostomy inflation cuffs) was a result of systems error rather than human error. Like the Leur connectors, the ISO connectors on the airway management equipment allows for the equipment to be assembled in different sequences. Similar to the events leading up to tubing misconnections (cognitive slips), paramedics are susceptible to having cognitive slips as they work in a cognitively demanding environment (Misaisi & Keebler, 2017) This emphasized the need to create a design solution that considers human behaviour so that the product is not easily misused .

Cognitive load

Through the cardiac arrest simulations that were conducted for this research, it was made clear that paramedics process an overwhelming influx of information. When giving feedback for the design concepts, participants would often refer to their cognitive load during an emergency as they needed to think about how it would impact them. The designs that would reduce their cognitive load received positive feedback as participants could imagine using the design in a real-world emergency. My initial assumption was that paramedicine is a cognitively demanding job. It was only until I mapped the user's journey, that I discovered how cognitively demanding patient resuscitation and airway management was because there were a lot of tasks to complete and a lot of equipment to prepare.

Cognitive load was a factor that paramedics train to manage during emergencies. Cognitive aids have been designed and have worked for paramedics in the pre-hospital setting (Woods et al., 2019; Swinton et al., 2018) . As part of the storage solution, I created a removable panel that acts as a cognitive aid. Participants liked this idea as it held all the airway management accessories in one place and had a reminder of what equipment needs to be prepared. During the research, participants reported the challenges of finding the correct airway management equipment during patient resuscitations. This emphasised the importance of designing to support paramedics both physically and cognitively. Another participant believed it would be a good reminder for rural paramedics who do not use airway equipment as often as their urban counter parts. This research further underlined the need for medical equipment to be better designed with the consideration of the paramedic's cognitive load. The SCRAM bag was a notable example of integrating a cognitive aid into an Airway Management kit (Swinton et al., 2018). By creating a system that had pre-prepared equipment in the kit, it reduced the cognitive load of the paramedic using it (Swinton et al., 2018). Swinton et al. (2018) discovered that there was a relationship between cognitive load and the presentation of equipment as organising equipment to reflect the steps of a procedure leads to the reduction of the cognitive burden. During my research, this was evident when the storage solution was presented to participants as the layout of the equipment was viewed as 'phases' within the airway management process. These 'phases' were related to 'steps' that may be needed to complete during the preparation of the airway management equipment especially when swapping tasks with other paramedics.

Stress and Standardisation

Stress is a factor that cannot be removed in an emergency (Anderson et al., 2018). The first minutes when attending a cardiac arrest are stressful because of the need to commence advanced life support. This was evident during the expert interviews as participants would emphasise the stress associated with patient resuscitations. My initial assumption was that cardiac arrest resuscitations were stressful due to the need to revive the patient. This assumption was affirmed during the cardiac arrest simulation as the fast-paced scenario showed the stress present within the emergency. For example, I noted how the paramedics would keep track of the time as they were performing chest compression and would communicate this to their partner who would be preparing the airway management equipment. Even though these were students using their clinical skills in a simulation, it was similar to findings from a study that interviewed New Zealand Ambulance Personnel to investigate their experience of challenging resuscitations (Anderson et al., 2018). Anderson et al. (2018) noted that cardiac arrest resuscitations can be stressful due a number of reasons including, it being the paramedic's first resuscitation, the age of the patient, and secondary arrests.

The stress experienced during the simulation, could be attributed to the time-pressure that paramedics face as they need to perform the airway management procedure within a certain time frame as the patient's life depends on it.

During the interviews and user testing sessions, I discovered that there was no standardisation regarding the storage of all the medical equipment they carry. In the UK, ambulances have become standardised as there was a need to reduce risk to patient safety due to the variation of equipment storage in each ambulance vehicle (Hignett, 2017).

As mentioned in the documentation of research section (figure 139), the storage solution that St John' s paramedics used were multi-coloured, standard sized, pouches that had a PVC window and two zips. This allowed paramedics to stock their equipment in whatever pouch suited them and the equipment. As I discovered, all the medical equipment was packed in different sized packaging. There was no colour coded system in place so this would vary from ambulance stations around Auckland and New Zealand. A study in Canada trialled new paramedic response bags that organised equipment methodically so that it would assist paramedics in following treatment protocols more efficiently (Bitan et al.,2019). 62% of the Paramedics preferred the new designs because it was easier to find the equipment (Bitan et al., 2019).

The cardiac arrest simulation provided valuable insights into how paramedics access and retrieve equipment. I observed how participants would rummage around to find the correct sized airway device because the equipment was stacked all together in the existing pouches.

The storage solution I presented to participants had the basic airway devices separated. The advanced airway devices, and the airway management accessories were organised into distinct panels. This received positive feedback as they knew the equipment would always be organised in the same way even if they worked at different ambulance stations across Auckland. This indicated that the pouches used by St John can vary with the equipment stored in it. A possible explanation for this feedback was familiarity with the layout may help alleviate stress because it was determined that time would not be wasted by searching for the necessary airway management equipment.

Introducing a standardised organisational system could help alleviate feelings of stress experienced at an emergency. Schyma et al. (2020) highlighted in their study that equipment that was difficult to locate or unfamiliar may lead to delayed airway management interventions in a stressful situation. The SCRAM bag was designed to overcome this as it included a standardised layout of equipment (Schyma et al., 2020; Swinton et al., 2018). The re-designed storage solution, as part of this study, aimed to create a standardised layout of equipment to reduce stress and cognitive load. Further user testing, in high fidelity simulations, needed to be done to establish whether the standardisation of airway management equipment alleviates stress.

Design and Paramedicine

The focus of design and paramedicine has primarily been on stretchers, ambulance designs, and paramedic response bags (Du Bronson et al., 2019; Mathews et al., 2013; Hignett, 2017; Bitan et al., 2019). This was a result of many studies focused on the physical injuries sustained by paramedics due to carrying heavy equipment, patient handling and working in cramped spaces (Conrad et al., 2008; Gray & Collie, 2017; Jennings, 2019; Wang et al., 2009). This study focused on airway management equipment to be specifically tailored to paramedics in the pre-hospital environment. The findings suggest that there was a need to design medical equipment specifically tailored to paramedics. For example, the Filter/$ETCO_2$ device was specially tailored for paramedic use in the pre-hospital setting as the filter was not used in the hospital setting. The findings from the user testing sessions suggested that participants believed it would reduce their cognitive load. This further supports the idea of designing for paramedic's cognitive load. Cognitive aids are good examples of designing for cognitive support (Woods et al., 2019; Swinton et al., 2018) however, this research has important implications for further developing medical equipment to provide cognitive support.

Past literature highlighted that the pre-hospital setting is dangerous, evolving, and unpredictable (Pruchnicki & Dekker, 2017; Bitan, 2020). Bitan's (2020) framework for designing for emergencies (human operator, equipment, and environment) was crucial as it helped identify factors that impact paramedics in the pre-hospital setting. It allowed me to gain a deeper understanding of how they might work, adapt, and react to these factors which helped inform the design decisions that I have made. For example, through the simulations and think-aloud sessions, I gained a better understanding of how equipment was accessed, by paramedics, which helped me create a storage solution that was easier to open, and stored the necessary equipment needed for airway management. This meant the storage solution was better tailored to their needs during a cardiac arrest. It was through the interviews, that I discovered that the airway management procedures do not go as planned so paramedics need to think about back-up solutions to overcome this challenge. In response to that insight, the storage solution I designed made it easier to access the basic devices if the intended airway management device (LMA) fails.

Bitan (2020) emphasised designing equipment to be resilient through gaining a better understanding of how it would interact with the human operator (paramedic) and the pre-hospital setting. Designing for resilience meant anticipating where human error can occur and designing to prevent the error from occurring (Bitan, 2020). A Human-Centred design (HCD) approach helped shape the designs to be better suited for the intended users. Their input helped highlight areas for improvement within the designs. Through the user testing sessions, I conducted with participants, I identified usability issues with the Tube Holder and Filter/ETCO2 device that could have resulted in the designs malfunctioning or being misused. The findings from this study have important implications for developing medical equipment specifically for paramedics in the pre-hospital setting.

Designing within the current systems

Designing for one of the ambulance organisations in New Zealand meant that the storage must be designed around the equipment that was used by that organisation. St John's selection of equipment from manufacturers affected how the airway management equipment is stored and accessed. For example, the Ambu one LMA used by St John, had packaging that was wider compared with other brands which affected the measurement of the storage solution. This finding has important implications for developing storage solutions for paramedics as each ambulance service would stock different medical equipment brands.

It would be beneficial to research how other ambulance service organisations (Wellington Free Ambulance) in New Zealand store their medical equipment and what manufacturers they are purchased from. This may influence the storage design as a major component was the medical equipment that needed to fit. It does explain the lack of a colour coded system within the current pouches used to store the equipment as these seem to have been designed to stack and pack any equipment for each pouch. It did give paramedics an opportunity to organise it to their preference, but it did create inconsistencies between ambulance vehicles and stations.

Challenges of Designing Individual items in Healthcare

Initially I wanted to change the design of each of the ISO connectors that the airway management equipment used so that it was impossible for the equipment to be connected in an incorrect way. After the first user testing session, I decided to design around the current system as creating a new system meant that it would need to consider how it would work within the pre-hospital and hospital setting. The Filter/ETCO2 device fits within the current system and reduces cognitive load for paramedics using it. I interviewed an anaesthesiologist to understand the purpose of the filter and Cobb's connector. As in previous findings, it was made clear that the hospital does not use filters as the current breathing circuits are sterilised and the Cobb's connector creates extra dead space which means the patient would not be receiving oxygen. Whereas the paramedic participant indicated that the Cobb's Connector was used for extrication of a patient. This emphasised that the pre-hospital airway management process differs to the hospital airway management process. However, these two systems interact with one another when a patient is handed over to the hospital. Therefore, it was ideal to design within the ISO connector system as redesigning the pre-hospital equipment could mean an incompatibility with the hospital system. My choice to design within the current ISO connectors may have constrained the design outcome but it also makes it easier to implement with the equipment paramedics currently have.

Past literature examined how in the hospital setting tubing misconnections have led to patient death (Simmons & Graves, 2008; Simmons et al., 2011). This was due to the design of a Luer connector system being compatible with other systems that should not be able to connect (intravenous catheters, feeding tubes, etc.) (Simmons & Graves, 2008). Simmons & Harrington (2021) have stated that poorly designed connectors in healthcare compromise patient safety. This research project encountered a similar issue regarding the sequence of airway management accessories being able to connect in different combinations. There has not been any literature exploring patient outcomes because of the airway management being assembled differently. However, the findings of this research suggest that the system was designed to allow for this to happen. As previously stated, the connectors are standard sized that adhere to ISO (International Organisation for Standard) (Cook, 2012). A possible solution to this issue would be to re-design the whole system. However, this would render the subsequent design outcomes incompatible with the hospital system. For design to be successful in both the pre-hospital and hospital setting a 'Systems Thinking' approach needs to be taken which would allow for improvements to be made to reduce the risk of patient harm (McNab & Rutherford, 2020). Simmons & Harrington (2021) had expressed that it has been two decades of advocating for safer designs regarding tube misconnections but this has not been acted upon. This highlighted the difficulties re-designing a new system within healthcare. Simmons and Graves (2008) further emphasized the healthcare industry's reluctance to change whole systems and would rather rely on human vigilance.

My redesigned Filter/ETCO2 device only focused on a small part of the system—emergency airway management. Although the Filter and Cobb's connector were not used in the hospital setting, other airway management equipment (Laryngeal Mask Airway, Endotracheal Tube, and Bag Valve Mask) were used in both pre-hospital and hospital settings. The redesign of these connectors needed to consider manufacturing standards and both the hospital and pre-hospital setting which was out of the scope of this Master's project.

Limitations

Recruitment

Gaining ethics approval was an unnecessarily long and slow process that resulted in the ideal participant group (Postgraduate paramedicine students) finishing their studies and leaving the university. This led to a change in the participant group to third-year paramedicine students as there were more of them on campus. However, the timing was still not ideal as recruitment took place during the exam period for third year students. This resulted in lower recruitment, likely because once students finished their exams, they did not return to campus. Consequently, I only recruited three third-year paramedicine students.

St John had their own process to receive approval to interview staff members. This took two months to gain approval. Once the request was approved, only one paramedic responded to the advertisements (placed on St John's notice board) and participated. It was challenging to recruit participants because of timing and participants having work commitments and personal commitments. Overall, eight participants were involved in this research. Three were third-year paramedicine students, two paramedics, and three were postgraduate paramedicine students. Their feedback and input were crucial in developing each design solution.

At the beginning of the project, I aimed to recruit five to six students (undergraduate and postgraduate) so that I could get a variety of perspectives (beginner to experienced).

Participants who were recruited were based in the Auckland area and may not represent the population of paramedics throughout New Zealand. Paramedics in rural areas may have different experiences with airway management equipment and patient resuscitation compared with their urban counterpart. For example, paramedics in rural areas have an increased average response time of 12 minutes compared with an average of 8 minutes for urban areas (St John, 2021). Very little was found in the literature on the amount of cardiac arrest patients in rural areas as the data report provided by St John tended to focus on response times (St John, 2021). One participant noted during a user-testing session in rural areas they may access airway management equipment "once or twice a year". This may be an assumption made by the participant, but further research needs to be done with rural paramedics.

Covid Lockdowns

The level 3 lock-downs as a result of covid community cases delayed planned sessions to conduct a role-play of the airway management equipment. This was meant to be conducted with the assistance of an AUT lecturer to provide guidance on the airway management procedure. As a result, after Auckland moved to level 1, I had to conduct a role-play using a training manikin, by myself and had to rely on tutorial videos of inserting airway devices into patients.

During the prototyping phase, the university had closed which meant I could not prototype my designs using a 3D printer. Consequently, there were two weeks where I could not develop the designs further. This impacted the timeline of the project as I could not test my ideas.

Recommendations

HCD Approach to medical device design

The findings of this research indicate the opportunities associated with applying HCD approaches to paramedicine equipment. Further research should be undertaken to investigate the benefits of a Human-Centred design approach to other medical equipment used in the pre-hospital setting. For example, the design of laryngoscopes for intubation or the additional medical equipment that needs to be carried to every emergency (oxygen tank, suction unit, AED etc.). Further research with participants of varying levels of experience should also be considered. Through this research, participants with different experience levels had different perspectives that influenced how they provide feedback on the design concepts. An HCD approach aims to tailor products and services to the users' needs (Jeffcott, 2020). Paramedicine students who have just learned different medical procedures should be considered in further research as their perspective may be different to experienced paramedics who may have learned to adapt to poorly designed systems and products. Paramedicine students' perspectives may contribute to better designed systems as they have not needed to adapt to poorly designed products. Their perspective of just learning how to use a product may provide insight into how to improve a product or system.

High fidelity simulations for user testing

Further user testing with experienced paramedics with each design outcome would be necessary to further refine each of the design solutions. Testing these solutions in a high-fidelity simulation may result in feedback that enriches further development of the design solutions.

Further work is required to establish the feasibility of the redesigned Filter/ $ETCO_2$ device used in the process of resuscitation. This could be done by further user testing in a high-fidelity simulation to determine where in the process of resuscitation the Filter/ETCO2 device may most effectively be used. For example, it may be pre-attached to the BVM and used to oxygenate the patient. It is only when the LMA is inserted into the patient, it is calibrated for use. The next steps for this research would be to determine how this design would be used during patient resuscitation as they currently have a set process of when they use the filter.

Introducing a standardised organisational system

From the interviews with participants, it was evident that there was not an organisational system regarding the storage of medical equipment in the Paramedic Response Bags. Hignett (2017), and Bitan et al. (2019) have explored a standardised Paramedic Response Bag to increase patient safety by preventing paramedics accessing the incorrect equipment or drugs. Further research should be undertaken to investigate the benefits of standardisation for equipment storage and ambulance design in New Zealand. From the feedback provided at the user testing sessions, it is possible that introducing a standardised storage solution across all ambulance vehicles could reduce cognitive load for paramedics working from vehicle to vehicle.

Medical Equipment that fits the population

Some participants referred to experiences of having to adapt their patient position because the airway management equipment did not 'fit' the patient. The participants attributed this to the current medical equipment designs only being designed to fit patients of certain sizes. A further study with more focus on patients with different body types and anatomy is therefore suggested. An example of designing for the greater population was an ambulance designed to carry bariatric patients that has been implemented by St John in Auckland (Johnston, 2009).

Future research could expand on looking at the airway management devices itself and re-designing them to be more efficient to access, prepare, and use on patients that have different body-types or anatomy.

Postscript

Final Reflection on Solutions Explored

Feasibility of product solutions

Feedback indicates that the storage solution can be easily manufactured by the current supplier of St John's paramedic bags. St John currently have over 1000 active ambulance vehicles (St John, 2021). The airway kit would be stocked in each ambulance as well as the Wellington Free Ambulance fleet and potentially the Westpac helicopters.

St John attend around 2000 cardiac arrest emergencies per year (Dicker et al., 2021) and have over 1000 ambulances that are regularly stocked. It would be feasible to manufacture the filter/ETCO$_2$ device and tube holder. Although this would likely need to be done using an overseas company as there currently don't appear to be any New Zealand companies that manufacture pre-hospital equipment. There is potential for these devices to be implemented worldwide, as this equipment is used universally. Due to constraints associated with a master's project, exploring the pathway of cost of manufacturing in New Zealand was outside of the scope of this research.

Viability

I presented these design concepts to AUT's Paramedicine department and received positive feedback regarding the solutions proposed. Members of the paramedicine department believed that they would use these products during patient resuscitations if they were available and that they appeared to be tangible solutions to some of the problems that were identified during the research. They especially liked, that with the Airway kit, they could easily swap tasks and communicate to the next person what equipment needed to be prepared. They also stated that the Equipment Preparation Area would be extremely helpful for novice paramedics or newer paramedics, who may forget what equipment needs to be prepped— especially when under pressure in an emergency.

The Filter/ETCO$_2$ device was also well received as a concept, as the paramedics, liked that they didn't need to search for the ETCO$_2$ device and didn't need to remember was equipment needed to be attached onto the ETCO$_2$ device.

The tube holder was viewed as a faster and more intuitive alternative to the Thomas tube holder (current solution), as they could easily secure the tube using the strap.

Sustainability

The airway kit would be used multiple times as it stores the equipment, and the material (canvas) makes it easy to clean. It can be wiped down with anti-bacterial wipes for infection control purposes.

The Filter/ETCO$_2$ device and the tube holder are single use items as they would need to strictly follow infection control guidelines to be reused. The Filter/ETCO$_2$ device is part filter which can only be once during patient resuscitation as it traps bacteria to prevent contamination of equipment. For it to be reused, it would need to be sterilised and have the pleated membrane replaced. This would be possible but an organisation, like St John, would need to establish this system.

The tube holder could not be reused because once the patient is transferred to the hospital, the tube holder is discarded by hospital staff. The prehospital setting and hospital setting and two different systems that do not share equipment. For example, once the patient is handed over, the LMA inserted by the paramedic is replaced by an endotracheal tube from the hospital. To create a more sustainable system for sterilisation of the equipment, review of the whole system needs to take place. This was out of the scope of this master's project, but is an area that has potential for future research. Incorporating sterilisation into the existing process needs to be robust and strongly adhere to infection control protocols.

Once the filter and tube holder are exposed to bodily fluids (blood), or vomit it is considered biomedical waste and needs to adhere to certain disposal protocols (BMP Medical, 2019). The potential of more sustainable solutions for these designs is an area that could be explored further in the future.

Reference List

Al-Shaikh, B., & Stacey, S. (Eds.) (2013). Essentials of anaesthetic equipment. Elsevier.

Anderson, N.E., Gott, M., & Slark, J. (2018). Grey Areas: New Zealand Ambulance Personnel's Experiences of Challenging Resuscitation Decision-Making. International Emergency Nursing 39, 62-67. https://doi.org/10.1016/j.ienj.2017.08.002.

AUT Paramedicine. (2019, March 27) The Aotearoa New Zealand Model of High Performance CPR [Video]. YouTube. https://www.youtube.com/watch?v=7L45-AsO4bA

Bitan, Y., Ramey, S., Philip, G., Uukkivi, T. (2015). Working with Paramedics on Implementing Human Factors Improvements to Their Response Bags. Proceedings of the International Symposium of Human Factors and Ergonomics in Healthcare, 4(1), 170-181. https://doi.org/ 10.1177/2327857915041016

Bitan, Y., Ramey, S., Philip, G., & Milgram, P. (2016). Evaluation of Ergonomically Redesigned Paramedic Bags— a Usability Study. Proceedings of the International Symposium of Human Factors and Ergonomics in Healthcare, 5(1), 61-64. http:// doi.org/10.1177/2327857916051013

Bitan, Y., Moran, P., & Harris, J. (2018). Evaluating safety culture changes over time with the Emergency Medical Services Safety Attitudes Questionnaire. Australasian Journal of Paramedicine 16, 1-6. https://doi.org/10.33151/ajp.16.628

Bitan, Y., Ramey, S., & Milgram, P. (2019a). Ergonomic Design of New Paramedic Response Bags. Applied Ergonomic 81, 1-8.

Bitan, Y., Shreiber, S., Zafron, G., & Jaffe, E. (2019b) Designing a First Responders' Emergency Response Kit for Motor-Vehicle Collisions. Ergonomics in Design, 28(4), 11-17.https://doi.org/ 0.1177/1064804619886936

Bitan, Y. (2020). Design for Emergencies. In A.Sethumadhavan, & F. Sasangohar,. (Eds.).Design for health : Applications of human factors, (pp. 147-160). Elsevier Science & Technology

Bland, H., Borton, C., & Jafri, Syed. (2012). The supply of anaesthetic and other medical gasses. In A. Diba & A. Davey (Eds.). Ward's Anaesthetic Equipment, (pp. 1-26). Elsevier.

Brinton, J., Fenton, W., & Meadley, B. (2019). Clinical Skills. In K. Curtis, C. Ramsden, J. Considine, & M.Fry, (Eds.). Emergency and Trauma Care for Nurse and Paramedics (pp. 329-406). Elsevier.

Chamberlain, P., Wolstenholme, D., & Dexter, M. (2015). The state of the art of design theory and practice in health: an expert-led review of the extent of the art and design theory and practice in health and social care. Sheffield Hallam University.

Cook, T. (2012). Airway Management equipment. In In A. Diba & A. Davey (Eds.). Ward's Anaesthetic Equipment, (pp. 139-205). Elsevier.

Conrad, K.M., Reichelt, P.A., Lavender, S.A., Gacki-Smith, J., & Hattle, S. (2008). Designing ergonomic interventions for EMS workers: Concept generation of patient-handling devices. Applied Ergonomics 39 (6), 792-802. https://doi.org/ 10.1016/j.apergo.2007.12.001

Considine, J., & Shaban, R.Z. (2019). Resuscitation. In K. Curtis, C. Ramsden, J. Considine, & M.Fry, (Eds.). Emergency and Trauma Care for Nurse and Paramedics (pp. 281-305). Elsevier.

Dicker, B., Todd, V., Howie, G., Wilkinson, N., Stewart, G., Swain, A., & Ranjan, A. (2021). Out-Of-Hospital Cardiac Arrest Registry Aotearoa New Zealand, National 2019/20Report. St John New Zealand. https://www.stjohn.org.nz/news--info/our-performance/cardiac-arrest-annual-report/

Du Bronson, M.B., Wierts, K., Hignett, S., Fischer, S., & Yazdani, A. (2019). Existing Science on Human Factors and Ergonomic in the Design of Ambulances and EMS Equipment. Prehospital Emergency Care 23(5), 631-646.

Fenlon, S. (2012). Equipment for paediatric anaesthesia. In In A. Diba & A. Davey (Eds.). Ward's Anaesthetic Equipment, (pp. 289-309). Elsevier.

Fletcher, K.A., & Bedwell, W. (2017) Cognitive Aids in Emergency Medical Services. In J. Keebler, E.H. Lazzara, & P. Misasi, (Eds.). Human Factors and Ergonomics of Prehospital Emergency Care, (pp.123-139). Taylor & Francis Group

French, A., Taylor, L.K., & Lemke, M. (2019). Task analysis. In M.B. Privitera (Eds.). Applied Human Factors in Medical Device Design (pp.63-81). Elsevier Science & Technology. https://doi.org/10.1016/B978-0-12-816163-0.00001-3

Friess, E. (2010). The Sword of Data: Does Human-Centered Design Fulfill Its Rhetorical Responsibility? Design Issues, 26(3), 40-50. https://doi.org/10.1162/DESI_a_00028

Gray,C., & Malins, J. (2016). Visualizing Research : A Guide to the Research Process in Art and Design. Routledge.

Gray, D.E. (2018). Doing research in the real world. SAGE.

Gray, S.E., & Collie, A. (2017). The nature and burden of occupational injury among first responder occupations: A retrospective cohort study in Australian workers. Injury 48(11), 2470-2477. https://doi.org/ 10.1016/j.injury.2017.09.019

Groeneveld, B., Dekkers, T., Boon, B., & D'Olivo, P. (2018). Challenges for Design Researchers in Healthcare. Design for Health 2(2), 305-326.

Harte, R., Glynn, L., Rodriguez-Molinero, A., Baker, P.MA., Scharf, T., Quinlan, L.R., & O'Laighin, G. (2017). A Human-Centered Design Methodology to Ehance Usability, Human Factors and User Experience of Connected Health Systems: A Three-Phase Methodology. JMIR HUMAN FACTORS 4(1), 1-8. https://doi.org. 10.2196/humanfactors.5443

Hignett, S. (2017). Products: Product design in acute health. In E. Tsekleves & R. Cooper (Eds.). Design for Health (pp.154-169). Taylor & Francis Group.

Hallgrimsson, B. (2012) Prototyping and Modelmaking for Product design. Laurence King Publishing.

King, T.A., & Cooke, R.PD. (2012). Cleaning, disinfection and sterilization. In In A. Diba & A. Davey (Eds.). Ward's Anaesthetic Equipment, (pp. 429-437). Elsevier.

Kovacs, G., & Law, A.J. (2012). Airway management in emergencies. McGraw-Hill Medical.

Kushniruk, A. W., & Parush, A. (2020). Editorial: Visualizing user experience and stories: From customer journeys to patient experience mapping. Knowledge Management & E-Learning, 12(4), 380–386. https://doi.org/10.34105/j.kmel.2020.12.020

Johnston,M. (2009, June 27). Ambulance kitted out to carry very obese patients. In New Zealand. New Zealand Hearld. https://www.nzherald.co.nz/nz/ambulance-kitted-out-to-carry-very-obese-patients/ALZZYVYGXOHM65KOVP5NR7BMSA/

Laerdal. (2010). Airway Family – Brochure. Laerdal. https://laerdalcdn.blob.core.windows.net/downloads/f995/Brochure_4988_AirwayFamily-995.pdf

LeBlanc, V.R., Regehr, C., Tavares, W., Scott, A.K., MacDonald, R., & King, K. (2012). The Impact of Stress on Paramedic Performance During Simulated Critical Events. Prehospital and Disaster Medicine 27(4), 369-374. https:/.doi.org/10.1017/S1049023X12001021

MacGill, M. (2017, December 11). What do anaesthesiologists do? Medical News Today. https://www.medicalnewstoday.com/articles/287857#specializations

Margolis, G. (2004). Paramedic, airway management. Jones and Bartlett.

Matthews, E., Fusari, G., Muhammad, Y., Harrow, D., Stevens, P., Winsor, R., Benger, J., Dean, D., Darzi, L.A., & King, D. (2013). Redesigning the UK Emergency Ambulance. ASME. J. Med. Devices, 7(3). https://doi.org/10.1115/1.4024484

MEDICAL, B. (2019). What are the Benefits of Disposable Medical Supplies vs. Reusable?. BMP Medical. Retrieved 8 April 2021, from https://www.bmpmedical.com/news/reasons-to-switch-to-single-use-medical-devices-and-disposable-medical-supplies/.

Mills, A.J., Durepos, G., & Wiebe, E. (2012). Thematic Analysis. In A.J. Mills, G. Durepos & E. Wiebe (Eds.). Encyclopaedia of Case Study Research (926-927). https://doi.org/10.4135/9781412957397

Milton, A., & Rogers, P. (2013). Research Methods for Product Design. Laurence King Publishing.

Misasi, P., & Keebler, J. (2017). Introduction to Human Factors and Ergonomics of Emergency Medical Services. In J. Keebler, E.H. Lazzara, & P. Misasi, (Eds.). Human Factors and Ergonomics of Prehospital Emergency Care, (pp.1-12). Taylor & Francis Group

Munroe, B., & Hutchinson, C. (2019). Patient Assessment and essentials of care. In K. Curtis, C. Ramsden, J. Considine, & M.Fry, (Eds.). Emergency and Trauma Care for Nurse and Paramedics (pp. 243-279). Elsevier.

Nuamah, J.K., & Mehta, R.K. (2020). Design for stress, fatigue, and workload management. In A.Sethumadhavan, & F. Sasangohar,. (Eds.).Design for health : Applications of human factors, (pp. 201-226). Elsevier Science & Technology

Ostermayer, D.G., & Gausche-Hill, M. (2014). Supraglottic Airways: The History and Current State of Prehospital Airway Adjuncts. Prehospital Emergency Care, 18(1), 106-115. Hhttps://doi.org/10.3109/10903127.2013.825351

Palmer, E.MH.(2020). Cognitive Factors in Emergency Medical Services. In J. Keebler, E.H. Lazzara, & P. Misasi, (Eds.). Human Factors and Ergonomics of Prehospital Emergency Care, (pp. 15-24). Taylor & Francis Group.

Paramedic Science. (2017, May 6). Clinical Skills - Airway management Step-wise [Video].YouTube. https://www.youtube.com/watch?v=yc-Qs27YVE60&t=242s

Privitera, M.B. (2013). Playing with Doctors. Innovation in Unexpected Places 32(1), 40-43. https://issuu.com/idsa.innovation/docs/innovation_spring2013_issuu

Privitera, M.B. (2015). Introduction to Contextual Inquiry. In M.B. Privitera (Eds.). Applied Human Factors in Medical Device Design (pp.1-21). Elsevier Science & Technology. http://dx.doi.org/10.1016/B978-0-12-801852-1.00011-3

Privitera, M.B. (2015). Contextual Inquiry methods. In M.B. Privitera (Eds.). Applied Human Factors in Medical Device Design (pp.47-71). Elsevier Science & Technology. http://doi.org/10.1016/B978-0-12-801852-1.00011-3

Privitera, M.B. (2015). Using CI to Inform Design Development of an Incision and Drain Packing Device for Use in Emergency Medicine. In M.B. Privitera (Eds.). Applied Human Factors in Medical Device Design (pp.243-260). Elsevier Science & Technology. http://dx.doi.org/10.1016/B978-0-12-801852-1.00011-3

Privitera, M.B., & Culverhouse, I. (2019). Contextual Inquiry Methods. In M.B. Privitera (Eds.). Applied Human Factors in Medical Device Design (pp.46-61). Elsevier Science & Technology. https://doi.org/10.1016/B978-0-12-816163-0.00001-3

Pruchnicki, S., & Dekker, S. (2017). Resilience Engineering in Prehospital Emergency Medical Services. In J. Keebler, E.H. Lazzara, & P. Misasi, (Eds.). Human Factors and Ergonomics of Prehospital Emergency Care, (pp. 203-219). Taylor & Francis Group.

Rowe, A. (2020). Participatory Action Research and Design Pedagogy: Perspectives for Design Education. Art, Design & Communication in Higher Education 19(1). https://doi.org/
10.1386/adch_00013_1

Rutherford, G. (2020). 'Human Error'. In G. Rutherford (Eds.). Human Factors in Paramedic Practice (pp.49-57). Class Publishing.

Sanders, E.-N., & Stappers, P. (2008). Co-creation and the new landscapes of design. CoDesign, 4(1), 5–18. https://doi-org /10.1080/15710880701875068

Sanders. E.B-N., & Stappers, P.J. (2015). Probes, Toolkits and Prototypes: Three Approaches to Making in Codesigning. CoDesign 10(1), 5-14.

Schoups, A. (2017, May 22). An Introduction to Assumptions Mapping with David J. Bland: Webinar Recap. Mural. https://www.mural.co/blog/intro-assumptions-mapping

Schubel, L.C., Muthu, N., Karavite, D.J., Arnold, R., & Miller, K.M. (2020) Design for Cognitive Support. In A.Sethumadhavan, & F. Sasangohar,. (Eds.).Design for health : Applications of human factors, (pp. 227-250). Elsevier Science & Technology

Schyma, B.M., Wood, A.E., Sothisrihari, S., & Swinton,P. (2020). Optimising remote airway management kit dump using the SCRAM bag—a randomised controlled trial. Perioperative Medicine, 9 (11), 1-6. https://doi.org/10.1186/s13741-020-00140

Shippey, B., & Rutherford, G. (2020). Situational Awareness and Decision Making. In G. Rutherford (Eds.). Human Factors in Paramedic Practice (pp.161-196). Class Publishing.

Shuman, EK., & Chenoweth, CE. (2012). Reuse of medical devices: implications for infection control. Infectious disease clinics of North America 26(1), 165-172. https://doi.org/10.1016/j.idc.2011.09.010

Silicone Rubber: What Is Medical Grade Silicone?. Casco Bay Molding. (2021). https://www.cascobaymolding.com/silicone.

Simmons, D., & Graves, K. (2008). Tubing Misconnections a Systems Failure with Human Factors: Lessons for Nursing Practice. Urologic Nursing. Official Journal of the American Urological Association Allied 28 (6), 460–64.

Simmons, D., Symes, L., Guenter, P.,& Graves, K. (2011). Tubing Misconnections: Normalization of Deviance. Nutrition in Clinical Practice, 26 (3), 286-293. https://doi.org/10.1177/0884533611406134

Simmons, D., & Harrington, L. (2021). Failure to Act: Tubing Misconnections in the United States. AACN Advanced Critical Care, 32(1), 11-13. https://doi.org/10.4037/aacnacc2021920

Siricharoen, W. (2020, November 26-17). Using Empathy Mapping in Design Thinking Process for Personas Discovering [Paper presentation] International Conference on Context-Aware Systems and Applications. https://doi.org/ 10.1007/978-3-030-67101-3_15.

Söderholm, H.M., Andersson, H., Hagiwara, M.A., Backlund, P., Bergman, J., Lundberg, L., & Sjögvist B.A.(2019). Research challenges in prehospital care: the need for a simulation-based prehospital research laboratory. Advances in Simulation, 1(1). https://doi.org/10.1186/s41077-019-0090-0

St John New Zealand. (2019). Clinical Procedures and Guidelines- Comprehensive edition. https://www.stjohn.org.nz/globalassets/documents/health-practitioners/clinical-procedures-and-guidelines---comprehensive-edition.pdf

Swann, C. (2002). Action Research and the Practice of Design. Design Issues, 18(2), 49-61. https://doi.org/
10.1162/07479360252756287

Swinton, P., Corfield, A.R., Moultrie, C., Percival, D., Proctor, J., Sinclair, N., & Perkins, Z.B. (2018). Impact of drug equipment preparation on pre-hospital emergency Anaesthesia (PHEA) procedural time, error rate and cognitive load. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine, 26 (82), 1-10. https://doi.org/10.1186/s13049-018-0549-3

Wang, H.E., Weaver, M.D., Abo, B.N., Kaliappan, R., & Fairbanks, R.J. (2009). Ambulance stretcher adverse events. Quality & Safety in Health Care 18(3), 213-216. https://doi.org/10.1136/qshc.2007.024562

Woods, B., Lang, B., Blayney, C., O'Mahony, L., Tuig, A.V., Rea, T., Carlbom, D., Sayre, M., & King, M. (2019). Medic One Pediatric (Moped) Cards: Standardising Paramedic Pediatric Resuscitation. BJM Open Quality 8(3), 1-7. https://doi.org/ 10.1136/bmjoq-2018-000534