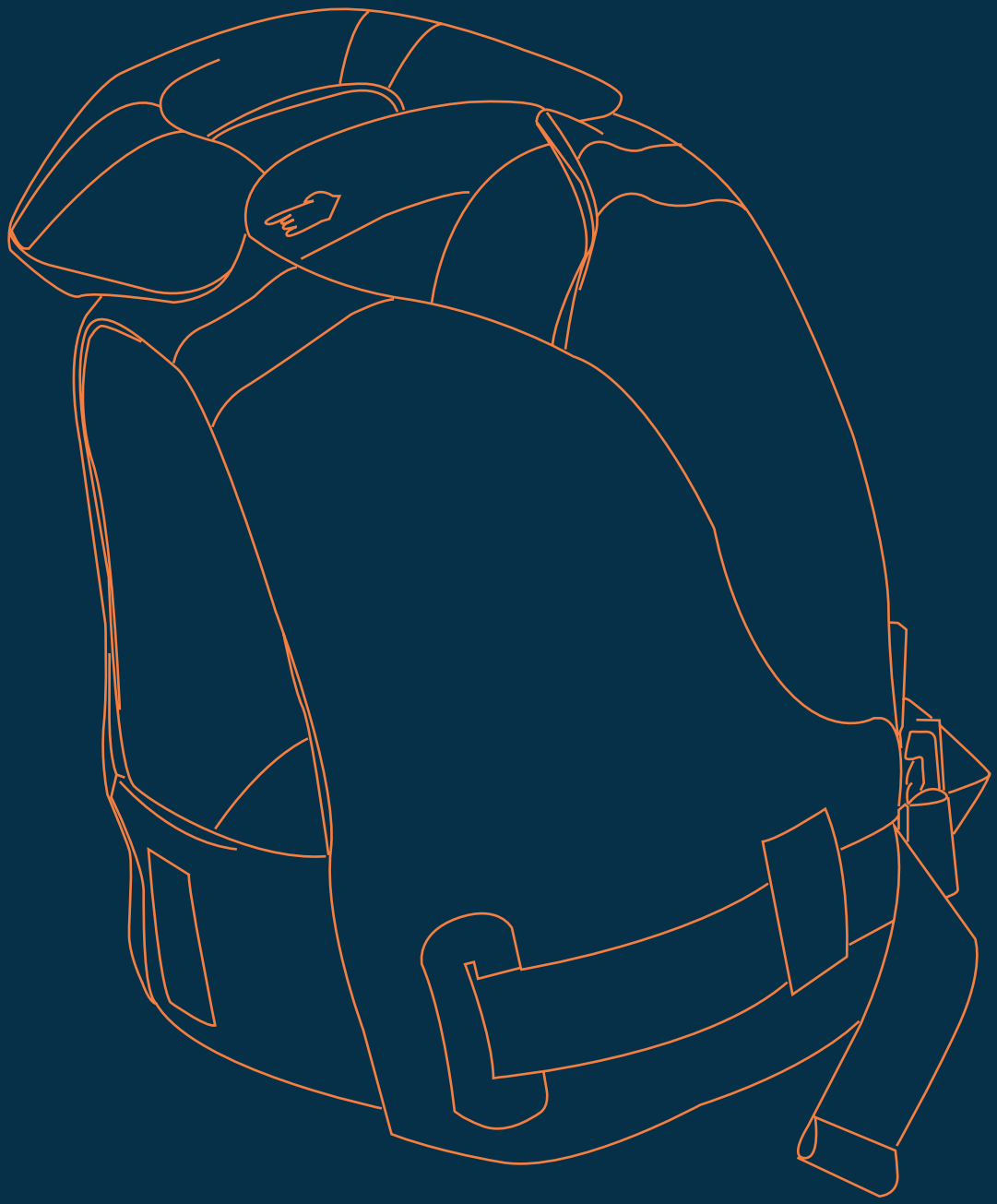
Slot n' Slide

A Concept Design for a Life Jacket for Flood Events in India

By Areef Shaik - 2022



An exegesis presented in partial fulfillment of
the
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Doctor of philosophy
in
Design

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New Zealand.

“जिस प्रकार रस्सी पर्वतारोहण के लिए जीवन रक्षक होती है, उसी प्रकार लाइफ जैकेट बाढ़ में रेस्क्यू करने के लिए होती है ”

“As a rope is the life saver for mountain climbing, a life jacket is for flood event rescue.”

-An Indian emergency responder

Abstract

India endures numerous flood events every year due to its tropical monsoon climate. River delta regions affected by these disaster events are often heavily populated and experience considerable damage and loss of life through drowning. The life jacket currently in use by first responders in India negatively impacts performance with unsatisfactory levels of protection, comfort and stowage. In addition, these products present fit and usability challenges and lack cultural sensitivity to end-users.

This research project addresses the suitability of this life jacket to respond efficiently in an emergency by using a practice-led prototyping investigation to develop a specific flood rescue product that is reflective of the context of use and responsive to the cultural context of India. The outcome of this creative practice research is a 'slot n slide' panel life jacket inspired by the traditional Indian sari. This conceptual design accommodates a diverse range of body anthropometry in a one-size-fits-all solution, achieved by an innovative inter-panel strapping system with integrated side adjustments. This concept provides new and perceivable benefits, including improvements in utility for first responders, single product deployment, efficient stowage and provisioning with easier donning and doffing, broad size accommodation, and a single adjustment strap, improving usability for end-users.

Acknowledgements

My heartfelt thanks to my supervisors, Professor Vicki Karaminas, Associate Professor Rodney Adank, and Senior Lecturer Deb Cumming. Thank you for giving me the opportunity to explore my PhD topic. Thank you for guiding me and inspiring me with your vast experience and wisdom. I am extremely lucky to have had such a superlative team.

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Special thanks to Dr. K. L. Ramesh and Jelani Mohammed, without your help I wouldn't have been able to obtain permission from NDRF personnel to conduct field study in India.

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I am deeply grateful to all the participants for their contribution to this research, generously sharing their time and insights. Because of your suggestions, the life jacket was grown from a small idea to a complete prototype.

Thank you mom and dad for setting me off on this journey, and my family and friends for all the unconditional support in the last four very intense academic years.

Last but not the least, I would like to acknowledge my partner Chang (Carol) Xu for supporting me throughout this doctoral journey and my life in general. Thank you is just a small word for everything you have done.

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Impacts of Covid - 19

The multiple lockdowns in New Zealand due to the COVID pandemic in 2020 and 2021 affected my PhD timeline in the following ways:

1. Losing access to studio space
As a practice-based study, access to studio and design labs on the university campus was necessary for me to advance this research project. Prototyping and testing of life jacket concepts was postponed due to a series of university lockdowns, reducing access to facilities, with multiple contingencies up-ended.

2. Sourcing materials
Creating mock-ups and prototypes of life jackets requires a substantial amount of textile materials: fabrics, sewing thread, foam, fasteners, Velcro, cords, webbing, and buckles. Sourcing these materials during the COVID pandemic was difficult and delayed progress. Suppliers were unable to deliver materials due to stock shortages or an inability to ship. Costs of materials and transport dramatically increased.

3. Aquatic spaces for life jackets testing.
The testing of life jacket concepts required access to managed aquatic environments. Although approvals and access were negotiated and gained, the consequent effects of Covid-19 closed access for my study for a significant period. Later due to lack of staffing affected by Covid, pool access was further reduced.

I made every attempt to advance my study during lockdown, but it nevertheless had a significant impact.

Preface

There was no electricity, and it was raining heavily with thunder and lightning. We were terrified with water all around us! Some of the villagers ran to the roofs of schools and concrete buildings, and some of them climbed trees and electric poles. For three days, we neither had water to drink nor food to eat!

Personal communication with a flood victim in the Runi village of Gujarat state, India, August 5, 2018

Every year, my hometown in India is greeted by tropical rains and cyclones due to its proximity to the eastern coast of the Bay of Bengal. I remember clearly when I was eight years old, in the month of July, the nearby Krishna River was severely flooded with incessant rainwater. The flood water entered our house up to knee level, and we had to shift all the household belongings to the upper level. We survived with what we had in the house for several days and could not get milk, rice, or other supplies. There was no electricity either. We could barely sleep at night as we feared the poisonous snakes in the water. The cleaning process after the flood water receded was a nightmare. All sorts of debris, including rubbish, metal, concrete, and animal carcasses, were brought into our house by the floodwater. The risk of being affected by successive flood events improved after moving to an urban location. Nevertheless, many people in my hometown still face the harsh consequences of floods every year.

I have travelled to many places in India that have been impacted by flood events. I have listened to the accounts of flood affected victims in person and developed a genuine interest in the flood event disasters experienced by the people of India. During one of my visits to the Indian state of Gujarat, I met a seventy-year-old man who was the sole survivor of a family of seventeen. He was living with his extended family at a flood response shelter arranged by the local authorities. I could feel the helplessness and desperation from his recount of the loss of his family. Sitting beside him, looking at the ruins left in his village I was overwhelmed and speechless and did not know how to convey my condolences and sympathy to him.

During my Master's in the United Kingdom, I had the opportunity to work on three live projects for autistic children, female prisoners, and Syrian refugees, respectively. I experienced a sense of fulfilment while working on the project for Syrian Refugees. I enjoyed the opportunity to focus on a global issue and humanitarian problem and be able to use design to help the plight of Syrian refugees. That was a significant turning point shifting my design focus to uplift the lives of people in need. At that time, some ideas I was interested in for my doctoral studies project were related to transformable clothing for refugees, life jackets for disaster events, and adaptive clothing for stroke patients. The decision to design life jackets for people affected by flood events was influenced by my personal lived experience. Through my travels in Asia, I met people living in coastal areas of Cambodia and Myanmar who like India are seasonally affected by flood events and with similar experiences: loss of family members to drowning, no access clean drinking water, inundation by disease transmitting water born pests, and the dangers of flood debris.

I cannot forget their plight and the desperation reflected in their eyes. I dedicate the outcome of my practice-based research into flood event life jacket design, to all the millions of people affected by floods in India and worldwide and to the brave rescuers who risk their lives in flood rescue activities.

Chapter 1: Introduction

1.1 The Frequent Event

Among all the natural disaster events happening worldwide, floods are the most frequent category. A recent report by the United Nations Office for Disaster Risk Reduction (UNDRR) and the Centre for Research on the Epidemiology of Disasters (CRED) reveals that, on average, 5,233 people die annually due to floods (CRED & UNDRR, 2021). Additionally, 8.6 million people are affected by floods annually every year in the 21st century (Yaghmaei, 2019).

In India, emergency responders, military personnel, national and international humanitarian agencies' volunteers are deployed to rescue and evacuate people during flood events. Life jackets and personal flotation devices, which are developed generally for military and marine environments, are appropriated when required for flood events in India. Design developments in related product areas for emergency needs, such as lifebuoys, life-rafts, mobile communication devices, generators, temporary shelters, water purifiers etc., have increased over the last decade. However, little design research has been done into life jackets for flood rescue in India. Consequently, there is a need for life jackets that are functionally appropriate, culturally acceptable, economically viable, and easily deployable by the Indian government disaster management authorities during flood events.

This research reviews and analyses the appropriateness of current life jackets for deployment in flood events in India and develops a life jacket specific for flood rescue events.

This life jacket allows the wearer to feel more comfortable and safer and is improved in terms of usability and performance for primary and secondary users of this product (those being rescued and the emergency responders).

Literature published on the types of flood rescue operations performed by the Indian emergency responders and the rescue equipment deployed by them, including life jackets, is limited. Hence, visual analysis of photographs of Indian flood events obtained from official websites of the Indian disaster management authorities was undertaken to provide a contextual understanding of the environment and conditions in which a flood life jacket would have to perform. Observations were made to identify the primary users of life jackets in flood events, rescue activities performed by Indian emergency responders and relief workers, and the types of life jackets deployed by them.

Most life jackets deployed by emergency responders in India are inherently buoyant types manufactured with Nylon or Polyester fabric as the outer layer, closed-cell polyethylene foam on the inside and flashlight or whistle accessories to aid with signalling for help. The closed-cell polyethylene foam is essentially a plastic packaging foam able to withstand impact and non-water absorption. The foam blocks inside the life jackets are bulky and primarily focused on aiding flotation. A bulky life jacket may restrict the wearer's movements in water and become arduous for wearers assisting others in distress. Some common functional features of the life jacket are culturally inappropriate to the context and conditions of the subcontinent of India. One of them is a crotch strap which is meant to stop a life jacket from riding up on the wearer, however the crotch strap does not fit over the traditional clothing worn in India, such as a women's Sari or a men's Dhoti.

Floodwater rescue, also referred to as swift water emergency rescue (Graham & Künneth, 2014), is associated with multiple hazards such as flood water exposure, contact with blood and body fluids, injuries from sharp jagged debris and so forth. New designs for life jackets that fulfil the collective needs of emergency responders and flood affected people are needed.

In any given flood, responsive rescue operations are vital in reducing the loss of lives and for safeguarding property. This study expands the understanding of the needs of flood victims involved in water rescue, and the challenges faced by emergency responders involved in flood rescue in India, both in relation to life jacket design. This research uses a practice-based design investigation to generate knowledge and understanding of this specific life jacket context and application. Primary research identified the currently used life jackets when used by first responders negatively impacted their abilities to perform with satisfactory levels of protection, comfort and efficient stowage. In addition, these life jackets presented fit and usability challenges, significantly with the ease of donning and doffing for end-users, due to sizing limits and the product's proportions. Secondary research provided a broad contextual understanding and reviewed existing innovative design concepts relevant to the context of study.

A set of design criteria based on the primary and secondary research was developed across the study to inform the progression and assessment of design concepts. An iterative series of physical prototyping was undertaken including evaluation in a controlled swimming pool environment. The outcome of this research is a conceptual life jacket inspired by the traditional wrap-around clothing of India. This 'slot n slide' panel life jacket, has been developed to accommodate a diverse range of body anthropometry in a one-size-fits-all solution, through an innovative inter-panel strapping system and integrated side adjustments.

1.2 Objectives and Research Questions

The objective of this practiced based research project was to design an appropriate flood rescue life jacket in response to India's context and conditions of flood events, and the regional authorities' frontline response.

Objectives:

1. To gain an understanding of the context and response to flood events in India with a particular focus on the role of the life jacket.
2. To assess the suitability of current life jackets deployed in flood rescue events.
3. To propose and test life jacket designs that would improve performance capabilities of the rescue efforts for rescuers as well as victims of flooding.

Research Questions:

The overarching research question for this research by creative practice was:

How could a life jacket be designed and optimised to meet the challenging nature of flood rescue events in India?

This question was supported by the following secondary research questions:

1. What challenges and issues are faced by flood affected people and emergency responders in flood events?
2. What are the activities performed by emergency responders during flood rescue operations in India?
3. What types of life jackets are currently used by emergency responders in Indian flood rescue operations, and what is their opinion of these products?
4. What life jacket improvements can be proposed for flood rescue in India?
5. What are the emergency responders' ideals for a future life jacket design with regards to its optimal function, usability and aesthetic properties?

Chapter 2: Methodology & Process

The research methodology uses a mixed-methods approach, understanding and synthesizing salient information from secondary data and literature, and subsequently building knowledge, understanding and innovation through creative practice.

Approaches such as visual analysis of published images provided valuable insights from the field of disaster management, informing a range of areas of knowledge development including: contextual understanding, roles played by various actors within a flood event, identification of life jacket types and usage, and the implications of dress. Focus groups and interviews undertaken during field research in India, provided a direct connection with lead end users, and were key in the development of innovative insights and validation of processes and procedures of Indian flood event response. Design activities included: iterative drawing and sampling, dryland user trials, prototyping, computer aided design development, and aquatic trials across a range of prototypes which provided rich user experience and usability insights.

2.1 The Double Diamond

The Double Diamond design process provided the framework for the study. This process was developed by the Design Council UK (2005) to "help designers and non-designers across the globe tackle social, economic and environmental problems". The process provides a four-stage model that designers and non-designers use to guide and challenge design problems. The four stages of the Double Diamond model are: Stage 1 - Discover, Stage 2 - Define, Stage 3 - Develop, and Stage 4 - Deliver.

- Stage 1 - Discover explores the challenge with a broad research perspective examining literature and secondary data in the early stage and initial rudimentary concepts.
- Stage 2 - Define, involves data generation through field work and its analysis informing the development of preliminary design criteria.
- Stage 3 - Develop, builds the creative investigation involving ideation, sketching, prototyping, iterating and testing.
- Stage 4 - Deliver is focused on refining the solution based on the feedback from testing and delivering the final product concept.

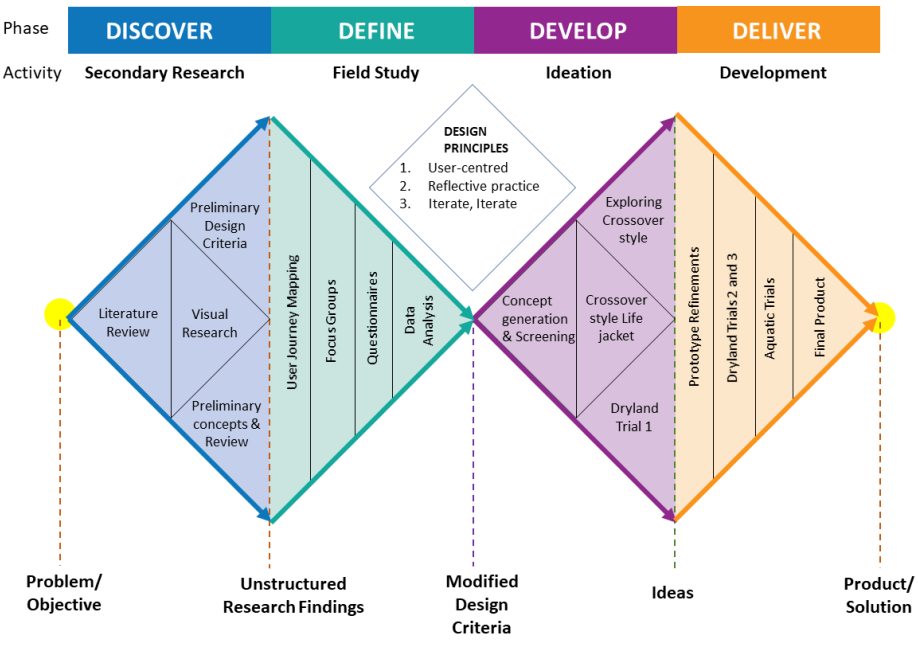


Figure 2.1: Double Diamond process translated for this study

Stage 1 - Discover

To achieve the objectives of this study, a literature review was carried out to review published material on Indian flood rescue operations, and to identify relevant life jackets and or novel life jacket concepts and innovations. Secondary research provided appropriate image resources for visual analysis of Indian flood events which provided a contextual understanding of the flood environment and identified the various stakeholders involved in a flood rescue situation. Preliminary design criteria were established based on the knowledge generated from the literature review and visual analysis. This initial knowledge base was used as a stimulus to generate first concepts.

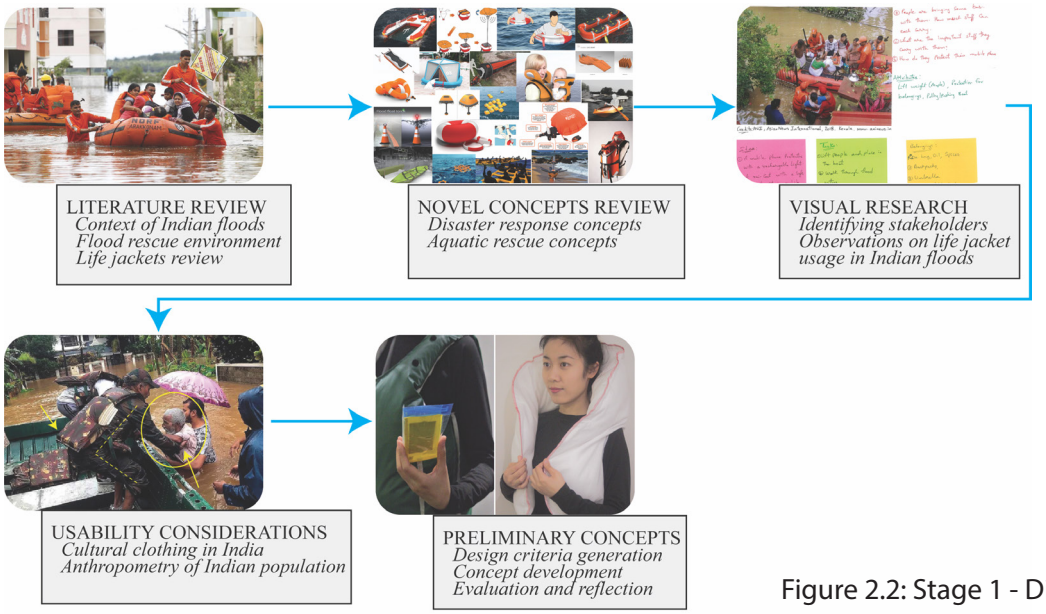


Figure 2.2: Stage 1 - Discover

Stage 2 - Define

In this stage, research was informed by field work in India which produced primary research material with emergency responders. Three focus groups and sixty questionnaires were completed with flood rescue personnel to generate primary information about the challenges faced by rescuers during floods. Issues with current life jacket designs and suggestions for an ideal life jacket that can be deployed in Indian flood events were elicited. Based on analysis of this data, and the previous information from literature review and visual research, a modified design criteria for designing life jackets specific to the context, conditions and user needs in India was drafted.

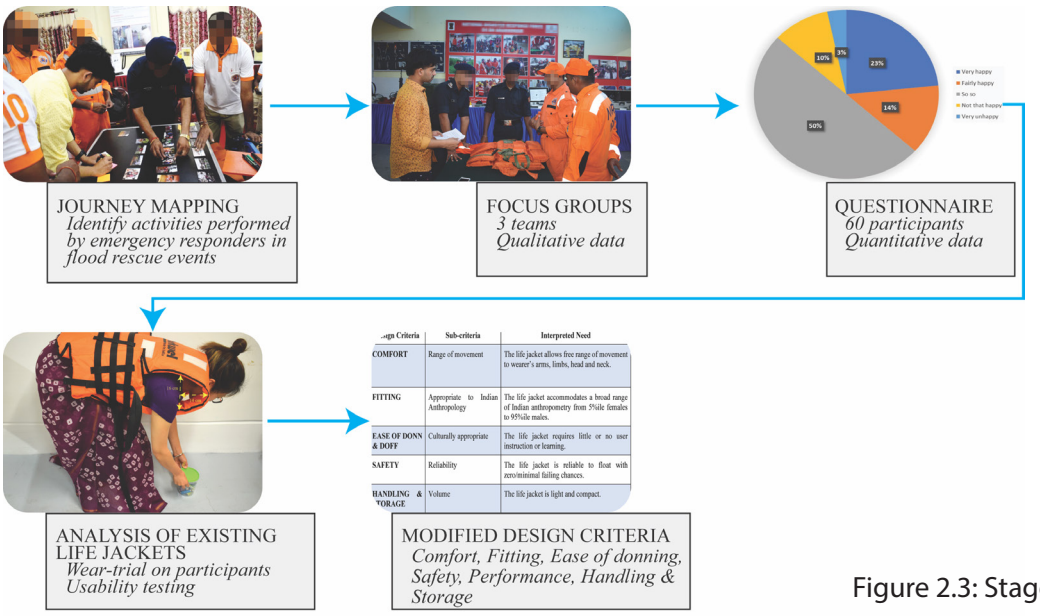


Figure 2.3: Stage 2 - Define

Stage 3 - Develop

Concepts were generated and reviewed based on the modified design criteria. The selected concept for development was inspired by the traditional wrap-around clothing in India, the sari and the Dhoti, a crossover style life jacket with sliding front panels that accommodated a large range of body anthropometry in a single size. A further, seven crossover style life jacket prototypes were developed and tested in a dryland (non-aquatic) environment to improve comfort, fit, usability, and reduce bulkiness. Favoured features from these prototype trials were incorporated into the final design in the following stage.

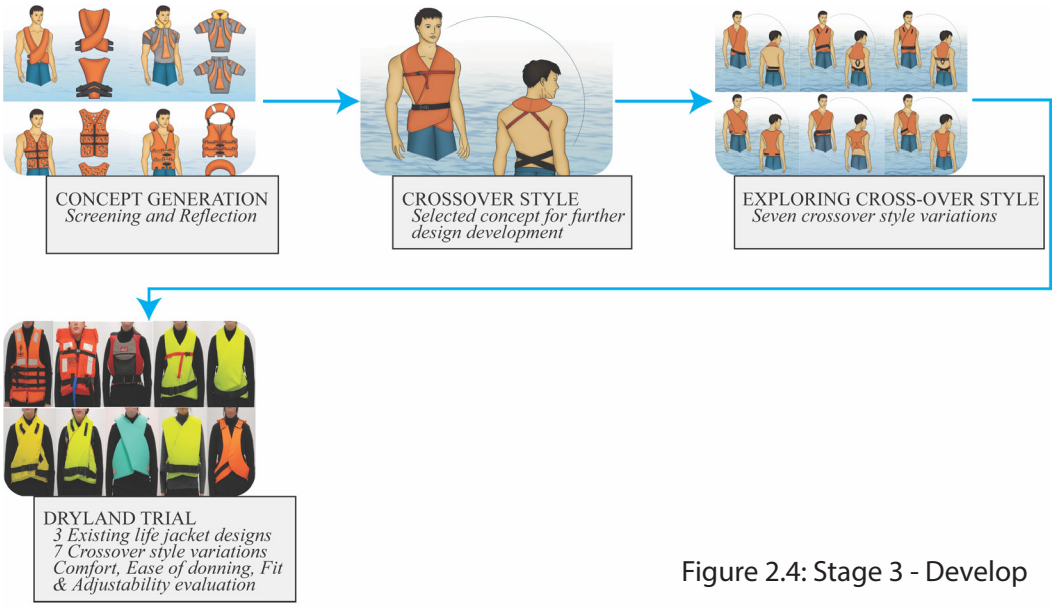


Figure 2.4: Stage 3 - Develop

Stage 4 - Deliver

The focus on design practice at this stage of development produced a design feature that enabled size range accommodation, through an inter-panel strapping system with integrated side adjustment. Human factors such as torso simulations across 5th percentile female to 95th percentile male was used in the development of this key single strap one-size-fits-all feature. An iterative and reflective design process was followed, to develop the final design through further wear-trials and fitting tests, followed by testing and evaluation in a controlled swimming pool environment. The final design was specified.

Figure 2.5: Stage 4 - Deliver

2.2 Ethical Processes

In Stage 2 - Define, a field study conducted in India involved the participation of emergency responders in contributing primary data on life jacket usage in Indian flood events. In Stage 3 - Develop and Stage 4 - Deliver, dryland trials, and aquatic trials involved participants who trialled life jackets that resulted from the design process. The participants provided qualitative feedback on parameters related to the life jacket prototypes, such as fit, comfort and performance and informed the refinement and subsequent design development.

Ethics applications relating to each stage were all approved by the Massey University Human Ethics Committee. All participants were willing to participate in the project, and informed consent forms for each activity were provided prior. The Ethics application details for each of the activities mentioned above along with their approval status is documented in Appendix A.

2.3 Structure of Exegesis

The following chapters in the exegesis bring together content generated across the Double Diamond process. Subsequent chapters discuss the research outcomes and draw conclusions with regards to contributions and further design research directions.

Chapter 3: Flood Event Landscape of India
This chapter summarizes the context and conditions of flood events in India. It identifies the major types of floods and their causes, and how flood rescue is undertaken in India and by whom.

Chapter 4: Life Jackets and India
This chapter reviews salient secondary information related to the research project and crosses a range of topics including, types of life jackets, standards required, and those life jackets specific to the Indian disaster event management. It provides contextual insights through a visual analysis approach of images from flood events in India. In addition, it presents information on dress conventions in India that impacts on the performance of life jackets. Finally, it provides insights and precedents from the field of disaster design related to flood events.

Chapter 5: Indian Field Research and Product Trial
This chapter presents primary research undertaken in India with Emergency Responders. Three locations were chosen from varied geographical locations, population densities, climatic zones, and having had experience with major flood events in the past. These locations included Ghaziabad in the North, Vijayawada in the Central, and Arakkonam in the South of India. Focus groups, journey mapped the process and procedures undertaken during a flood event, and along with a separate questionnaire study, identified challenges faced, opinions and aspects of the ideal flood event life jacket. The research approach used conventional focus groups and interviews to validate and adjust insights from secondary research with lead users and experts from the field of flood disaster response. A preferred existing life jacket model was reviewed in a dryland trial that provided experiential insights into a conceptual design for a life jacket that caters for the needs of responders in the Indian subcontinent.

Chapter 6: Design and Development
This chapter provides documentation of the creative practice undertaken in the development of the Flood Event Life Jacket. The design content was tested and developed against modified design criteria starting from idea and concept generation and development through to prototyping trials and user testing on dryland and in aquatic environments.

Chapter 3: The Flood Event Landscape of India

3.1 The Human Scale of Flood Events

Over the last two decades, floods have affected nearly 300 million people in India, causing more than 28,596 deaths (Guha-Sapir et al, n.d.) resulting in 1,400 to 1,500 deaths in floods every year (see Figure 3.1). The sudden peak in the mortality graph below represents the 6,453 people who died in the Uttarakhand flash floods in 2013 caused by a sudden cloudburst.

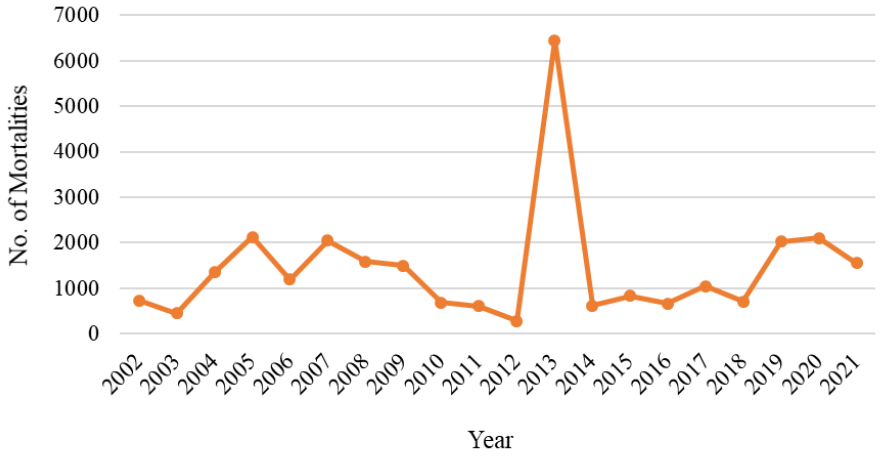


Figure 3.1: Mortalities caused by floods in India (2002-2021)

The number of people affected by floods each year in India fluctuates with a reduction in the period from 2008-2014 and an upsurge from 2015 to 2018 (see Figure 3.2). On average, 15 to 20 million people are affected by floods in India in any 5-year span.

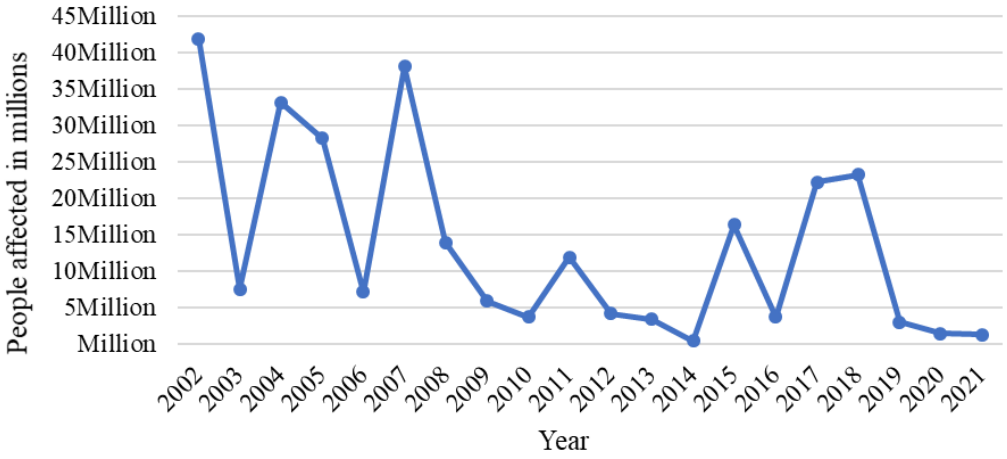


Figure 3.2 Number of people affected by floods in India (2002 - 2021)

Key Statistics:

1400
to
1500
deaths
annually due to floods

300
million
people affected by floods in past two decades

15-20
million
estimated people affected by floods every five years

The major types of floods in India are: Coastal flooding (rise in sea levels caused by extreme weather and high tides), Riverine flooding (overflow of a river onto inland areas caused by intense rainfall), and Urban flash flooding (flooding of urban areas caused when the ground cannot absorb the water from heavy and sudden rainfall) (NDMA, 2008, p.1).

> "Riverine flooding is the most critical climate-related hazard in India. Heavy monsoon rainfall, inadequate capacity of rivers to carry the high flood discharge, inadequate drainage to carry away the rainwater quickly to streams/rivers are the main causes of floods in India"
>
> Natural Disaster Management Authority of India (NDMA, 2016).

River delta regions in India that experience incidents of severe floods are often heavily populated and experience considerable damage and loss of life through drowning (NDMA, 2008). Responsive rescue operations are vital in reducing the loss of lives and safeguarding property.

3.2 Flood Rescue in India

The NDMA defines search-and-rescue as the first and vital stage of a flood scenario, followed by immediate relief and rehabilitation (NDMA, 2005, pg.2). Search-and-rescue involves evacuating people trapped in locations surrounded by floodwater and relocating them to safer zones. In India, armed forces personnel and civil protection servicemen such as police and firemen are generally deployed by the government authorities in the case of a 'major or severe level' flooding (NDMA, 2010, pg.34). Of these, the National Disaster Response Force (NDRF), a subdivision of the Indian armed forces was formed "for the purpose of specialist response to threatening disaster situations," performs essential search-and-rescue operations during floods each year (NDRF, n.d.). Local community members also undertake immediate search-and-rescue activities when outside help takes longer to arrive. Although disaster management in India has organised policies and structured programmes, the high mortality rate due to floods indicates the ineffectiveness of rescue operations and flood risk management policies. The sheer population living close by the river and coastal flood locations is a major contributing factor to the high mortality rate (Mandych, 2009). Limited numbers of emergency responders can be quickly overwhelmed in major flood events in highly populated areas (Briones et al., 2019).

Search-and-rescue activities are performed in harsh and unfamiliar environments during flood rescue and evacuation and are associated with multiple hazards such as flood water exposure, contact with blood/body fluids and injuries from sharp jagged debris (Graham & Künneth, 2014; pg.487). Houses and streets are filled with water (see Figure 3.3) that consists of all kinds of debris and obstacles such as concrete, metal, fences and trees which can cause damage to property and human lives.

Figure 3.3: A family is rescued by NDRF team from a flooded residential area (Source: Xinhua, 2015).

Emergency responders may not be familiar with the situations as they do not have the opportunity to train in flood areas with vehicles flowing in stagnant water and swift water ways. Working in swift water is more dangerous and challenging than in stagnant water because of the speed of the moving water which damages impacts from debris and increases difficulty in performing rescue activities. The risk of harm to flood victims and rescuers alike, is very high in swift water (Ray, 2014; Szpilman et al., 2012).

Sometimes emergency responders work in dark and dangerous conditions without torches or handheld lamps (see Figure 3.4). Handling rescue equipment like ropes, torches, and lamps can be complex when assisting people to evacuate flooded houses. Often there may not be enough life jackets to distribute and no poles to measure/test water depth. Rescue activities can take hours or even days to complete. In such cases, having no access to clean drinking water can lead to the dehydration of emergency responders and flood affected people (George & Brons, 2014).

Figure 3.4: An elderly woman is carried to safety from her flooded house at night (Source: Spokesperson Navy, 2015)

Distribution and effectiveness of life jackets represent a key tool in frontline search and rescue operations. Before departing on a flood rescue operation, emergency responders are required to wear personal protective equipment, including a "personal flotation device (life jacket), thermal protection, helmet, gloves, and foot protection" (Ray, 2014). NDRF personnel in India wear a half or full-sleeved T-shirt and shorts underneath a life jacket (see Figure 3.5) while performing flood rescue activities. The T-shirt and shorts, made of a breathable mesh nylon fabric, are accompanied by waterproof footwear. Other first responders such as firefighters, police, and military personnel work in their service uniforms, while non-governmental organisations (NGO), volunteers and civilians wear everyday clothing: shirts, t-shirts, pants, raincoats etc. Although this type of clothing does not protect the rescuers from the many dangers that they are exposed to in flood events, this type of clothing is chosen for its comfort, ventilation and quick-dry nature in response to the scorching and humid tropical weather in most parts of India.

Figure 3.5: NDRF personnel wear T-shirts and shorts made of a breathable mesh nylon fabric during flood rescue operations (Source: Santosh Kumar/ Hindustan Times via Getty Images).

Emergency personnel perform several types of activities during a flood rescue event. Activities such as rowing boats, assisting people to evacuate flooded houses and getting into life-rafts or boats, and rescuing people who are drowning are performed in aquatic environments. Rescue activities that are performed on land include carrying the disabled, assisting the elderly, supporting pregnant women and children to safer locations, cleaning debris, and distributing aid.

Current life jackets designs do not consider how they negatively impact on the wearer's performance during various rescue activities. In Figure 3.6, two emergency responders are carrying an older woman on a chair. The life jackets donned by them have a bulky collar restricting their vision to the sides. The foam on the front obstructs the hand's reach to the opposite side. Similar obstruction can happen whilst in rowing boats, where responders sit side-ways on the edge of a boat and need to reach on the opposite side for the oar.

Figure 3.6: Emergency responders carrying an elderly woman on a chair while wearing life jackets with collar (Source: Kiran Manjunath/AFP via Getty Images, 2017).

An arduous task that responders repeatedly perform during flood rescue is lifting people onto a boat. In Figure 3.7, military personnel are seen lifting an older man into the boat by holding him under the upper arm while another person is assisting from behind. The life jackets worn by the military personnel, with a length up to his upper thigh, blocks the waist flexion movement by creating a fold in between the waist and thigh, and creates contact with the back when bending forward. The proposed life jacket design should accommodate the action of lifting a person by holding them under the arms.

Figure 3.7: An army personnel lifting a flood victim into a boat. (Source: PTI Photo, 2018).

An improperly fitted life jacket has a high chance to make the wearer slip through the life jacket or the life jacket to rise onto the wearer's face. A woman dressed in a Sari or a man wearing a dhoti cannot fasten the crotch strap over their inner clothing. This puts the wearer at a risk of slipping out of the life jacket when being held and pulled up.

Current life jackets designs are worn like a vest by entering hands through the armholes and then secured on the front using a zipper, hook n' Loops or buckles. Indian populations, although aware of western wearing styles of fasteners can find it puzzling to wear a life jacket and fit it, appropriately to their body. In Figure 3.8, an old woman can be seen wearing a life jacket over a sari that improperly fits her size, whilst an infant is seen wearing an adult size life jacket.

Figure 3.8: People rescued from flood affected areas in India wear improperly fitted life jackets (Source: Biju Boro/ AFP Photo, 2017).

3.3 Summary

There is limited published information on the types of search-and-rescue operations performed by the Indian emergency responders and the rescue equipment used in their flood rescue operations. Emergency responders include professionally trained personnel from military, police and civil defence organisations, along with civilian volunteers involved affected by the disaster event. Search-and-rescue activities are performed in dangerous and challenging environments commonly associated with multiple hazards.

Life jackets used by emergency responders and deployed for the mitigation of flood events, often have perfunctory functionality and low levels of usability. Fit and adjustment of life jackets is affected by clothing archetypes worn in India. This makes securing a life jacket particularly difficult for women.

Floods affect 15 to 20 million people on average every year in India. These significant figures evidence the sustained and regular cycle of flood events in India, the vulnerable heavily populated river delta areas, and the need for preparedness by national and regional governments in response. The high mortality rates from predictable annual flood events can be seen to indicate ineffectiveness in disaster event management and operations which support an argument for developing flood event response equipment specific to the challenge, and not appropriated from some other source or purpose.

Chapter 4: Life Jackets & India

4.1 Personal Flotation Devices, Life Jackets and Buoyancy Aids

The European standard relating to personal flotation devices (PFD) classifies all PFDs into two types (ISO 12402-5:2006): life jackets and buoyancy aids. It defines a life jacket as a device that will protect the airway of an unconscious person, regardless of the sea conditions, whereas a buoyancy aid will only provide support to a conscious person who swims to keep the airway clear (ISO, 2006). Life jackets and buoyancy aids are categorised into further classes based on the level of support provided by the PFD, types of buoyancy, activation methods for inflatable devices, and PFDs with added survival equipment like whistles, reflectors, locating beacon, cell phone pocket and hydration pouch.

Life jackets are used as life-saving mechanisms in marine and river environments. Life jackets provide strategic buoyancy to enable flotation and correct body position for survival in water (Brooks, 2014).
They do not necessarily enable other activities or improve swimming performance. Even with a life jacket, survival in a flood event is affected by other injuries, hypothermia, dehydration, water ingression to nasal and mouth passages, and injuries causing blood loss or unconsciousness (Jonkman, 2014).

The critical difference between a life jacket and buoyancy aid is that a life jacket will provide adequate buoyancy to a person's chest, and more importantly raise the head above the water so that the airway has an acceptable freeboard. Whereas, if a person wearing a buoyancy aid becomes exhausted or unconscious, they will slump forward, the airway will become submerged, and they will drown. Typically, a life jacket has a collar around the neck filled with foam which raises the wearer's head above the water so that the airway has an acceptable freeboard. Buoyancy aids tend to have no collar and have non-restrictive neckline and armholes, which allow for a greater range of motion for the head and arms.

Examples of a life jacket and buoyancy aid are shown in Figures 4.1 and 4.2 respectively.

Figure 4.1: Example of a life jacket
(Source: Hutchwilco, 2022)

Figure 4.2: Example of a buoyancy aid
(Source: Hutchwilco, 2022)

The Indian Standard (IS-6685) for life jackets, which incorporates the requirements under the International Maritime Organization (IMO) resolutions and Safety of Life At Sea (SOLAS) regulations, defines a life jacket as a safety device for all persons whose occupation or recreation is connected with water (Bureau of Indian Standards, 2009). The IS-6685 does not incorporate the term personal flotation devices (PFD) in its specification, and no further classification is provided on the types of life jackets. The Indian Standard (IS-6685) recommends a minimum buoyancy of 100 Newton for an adult life jacket and 60N for a children's life jacket. To maintain uniformity with the terminology in the life jacket standard of India, the term 'life jackets' will be used here on in, to define the above mentioned two types of PFD's, describing them with or without a collar where necessary to identify their expected level of performance and differentiation of types commonly used in India.

Leading brands in the manufacturing of life jackets include Onyx, Stohlquist, Astral, O'Neil, Mustang, NRS and Coleman in the USA; Survitec, CrewSaver, Musto and Palm Equipment in the UK; Baltic and Lalizas in Europe; Menance, Jarvis Walker, Burke Marine, Torpedo7, Hutchwilco and BLA in Australia and New Zealand. In India, local manufacturers and suppliers such as India National Safety Solution, SHM group, Galvanisers India, Majestic Marine and Engineering, and Mahima Industries prevail. No notable specific Indian designs of life jackets are found in published literature or e-commerce websites.

4.2 Life Jackets Deployed in Indian Flood Events

The life jackets most deployed by military personnel and National Disaster Response Force (NDRF) teams in India were reviewed for this study. These are 'inherently buoyant' types made with closed cell polyvinyl chloride or polyethylene foam, jacketed in nylon and or polyester fabrics. The foam is impervious to water and with the jacketing material, can withstand physical impacts. Life jackets, both with and without a collar, are used in India. Examples of life jackets deployed in India during rescue activities are shown in Figures 4.3 and 4.4 (see Figures 3.6 and 3.8 for the life jackets being in use in Indian flood events).

Figure 4.3: Markwel life jacket with collar

Figure 4.4: Galvenisers life jacket without collar

4.3 Visual Research Developing Contextual Understanding

Secondary visual research using photographs of five major Indian flood events that occurred during 2012-2020, was analysed to understand the flood disaster context in India and to refine the objectives and aims for this research. Information on the human impact of Indian flood events that occurred during this time was obtained from the Emergency Events Database (EM-DAT). The twenty flood events with the highest mortality rate and number of people affected were first selected. Multiple events were screened in this group from states or zones to identify those with the highest rates of flood affected regions. Five flood events were chosen in this way from varying geographical locations, multiple states/ zones of India with dissimilar population types. The chosen five flood events and their details are presented in Table 4.1.

Table 4.1: List of Indian Floods from 2012-2019 chosen for Visual Research
(Source: Guha-Sapir. D, Below. R, Hoyois. Ph - EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium)

	Disaster Name	Disaster Type	Cause of the Flood	Total Deaths	Total Affected
1	Kerala Floods 2018	Flash Flood	Heavy Rainfall, Broken dam / burst bank, Landslides	504	23,220,000
2	Assam, Gujarat, Uttar Pradesh and West Bengal Floods 2016- 2017	Riverine Flood	Monsoon Rain, Inundation of floodplain	1,343	25,755,000
3	South Indian Floods 2015	Urban Flood	Heavy rainfall, poorly planned urbanisation	325	1,801,000
4	India and Pakistan Floods 2014	Riverine Flood	Heavy Monsoon rain, landslides	298	275,000
5	North Indian Floods 2013	Flash Flood	Torrential rains, Clouds	6,054	504,473

1. Defined the roles of various participants in a flood rescue activity,
2. Identified the rescue equipment currently deployed and analyse their appropriateness for Indian sub-continent,
3. Highlighted the challenges faced by emergency responders during rescue activities,
4. Understood the lifestyle of flood affected people in rural and urban areas.

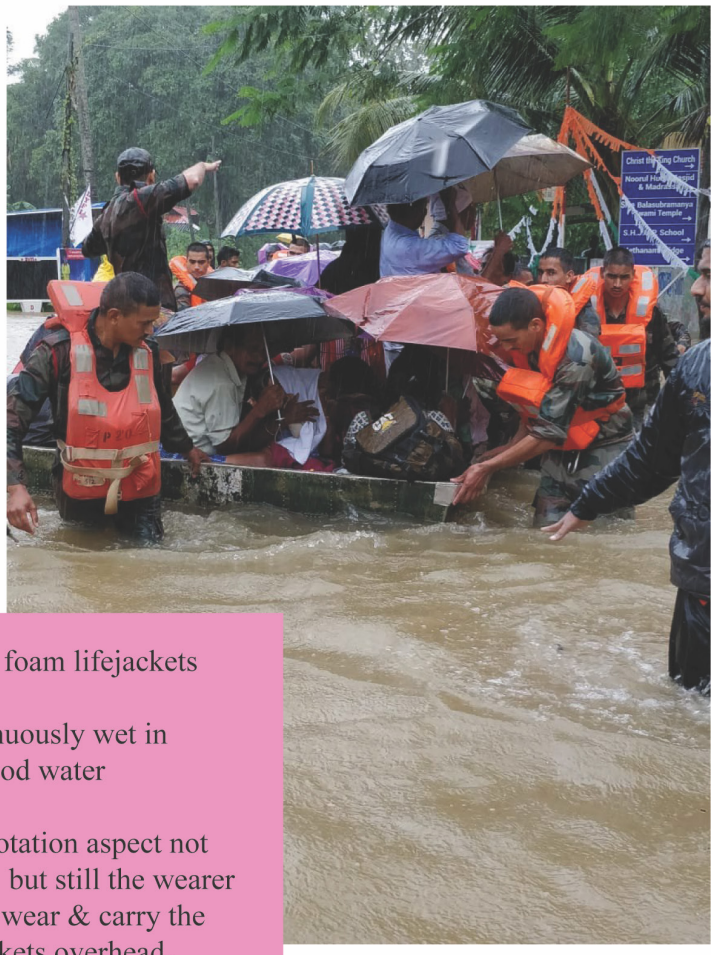
The Visual Research Diary used in this project has been scanned electronically and presented in Appendix B. A digitally coded sample of the visual research diary is displayed in Figures 4.5 and 4.6.

Scenario:
Indian army pulling a boat through flood waters with rescue people in the boat.

Equipment:
Lifejackets (Type I), Metal-boat (Gemini marine Boats),

Problems:
1. People wear rain coats, but not rescue personnel
2. Rescue personnel get wet in rains. Their hands are not free to carry umbrellas.

Attributes: Bulky, Heavy,
Not in use position, Not one for one,
Raining



1. Bulky foam lifejackets
2. Continuously wet in the flood water
3. The flotation aspect not in use, but still the wearer has to wear & carry the lifejackets overhead.

Figure 4.5: Digitally coded sample 1 of the visual research diary

Credits: Defence Ministry of India, 2018. Kerala, India. www.ptinews.com/ptigallery

Credits: ANI, Asia News International, 2018. Kerala. www.aninews.in

Scenario: People rescued from flooded houses and taken to relief camps.

Equipment: Life-rafts, Human power, Lifejackets (Type-II), Lifebuoy Buckets

Problems:

1. Elderly, disabled and kids are to be lifted by rescue personnel to get into boats.
2. Life rafts can't come to the entrance of the house. Walking through flood waters is unavoidable to get into life raft or boat
3. People are bringing some basic needs with them. how much stuff can each carry
4. What are the important stuff they carry with them?
5. How do they protect their mobile phone?

Attributes:
Lift weight (people), Protection for belongings, Pulling/Pushing boat

Idea:

1. A mobile phone protector with a rechargable light.
2. A rain coat with a safe pocket for storing mobile phone and some important documents.

Tasks:

1. Lift people and place in the boat.
2. Walk through flood waters.

Belongings:

1. Rice bag, Oil, Spices
2. Backpacks
3. Umbrellas
4. Plastic / polythene covers (waterproof)

Figure 4.6: Digitally coded sample 2 of the visual research diary

4.3.1 Findings From Visual Research

This visual research approach enabled the classification of flood event participants, stakeholders and affected others. It aided the identification of the various activities performed during the search-and-rescue phase and in trying to understand the challenges faced by emergency responders and affected people during flood events, consequently providing insights to innovation. It provided an understanding of the environmental context in which flood event rescues happen.

There were two types of participants used in this study, based on their roles and needs in a flood rescue activity.

1. The first group were the 'emergency responders' which included military rescue-teams, firefighters, aid-distributors, and volunteers of relief-aid organizations. The role of the emergency responders is to locate and evacuate people, and to distribute emergency aid to people located in flooded areas.
2. The second group were the 'affected people' who are inhabitants of the flood affected area. The definition given on Emergency Events Database (EM-DAT) website for people affected is: "People requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance". Flood affected people may need assistance in evacuating their flooded houses, relocating to safer locations with their family members and belongings, while having to pass through flood waters.

Although the roles of emergency responders and affected people were different, at times they are interchangeable. When deployed in a flood rescue operation, emergency responders are at some risk of loss of life and hence, they need to make sure of one's own safety also. Similarly, when support is delayed or unavailable from emergency responders, local community's take-up roles as zero-responders to rescue other flood affected people (Briones et al., 2019). A detailed classification of the participants in an Indian flood event is shown in Figure 4.7.

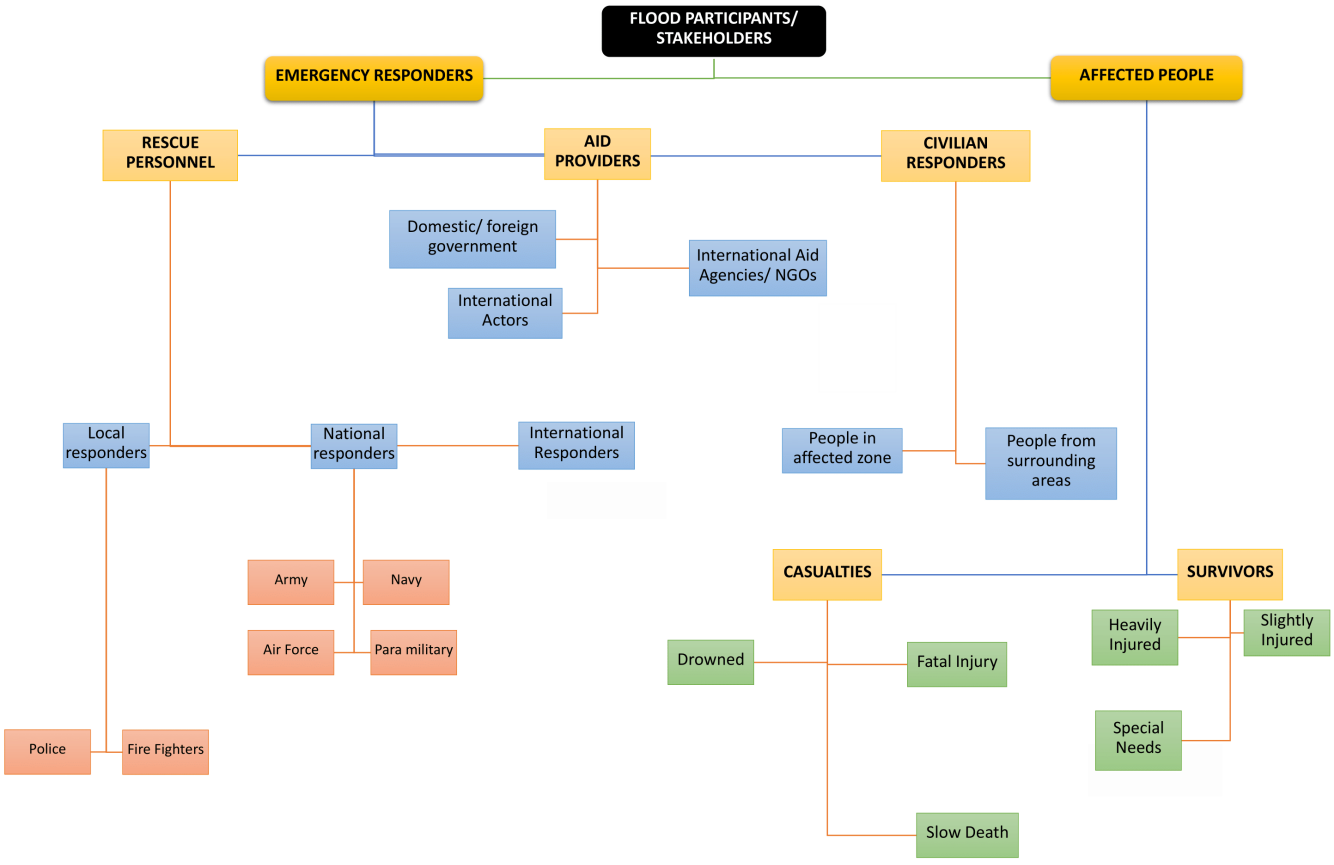


Figure 4.7: Classification of flood participants/ stakeholders

Flaws and opportunities for innovation in the current life jackets deployed by Indian emergency responders was observed. Both types of life jackets deployed (with and without a collar), were observed. Foam life jackets used by most emergency responders observed, were bulky and appeared uncomfortable if used for extended periods of time, due to movement restrictions. Bulky life jacket collars can reduce head movement and vision of the wearer to the sides, and in some instances restrict arm movements affecting usability. Bulky life jackets are inefficient to stow, impacting the number that can be carried on a rescue craft or transport. When not in use they take up considerable space for rescue teams or individual households. However, foam type life jackets provide a degree of insulation from cold water, heat loss and hypothermia.

Rescuers assist other people to walk, cross flood waters, get in and out of rescue boats, evacuate flooded houses and rescue drowning people. Most activities are performed in water levels without needing to float. Buoyancy/ floatability features of the life jackets are not always used.

Similarly, life jackets are not always worn in flood events, even when provided. There are multiple reasons for this including: unavailability of life jackets for each person on a rescue boat, ill-fitted and wrong sized life jackets, the life jackets being bulky and interfering with the activities of the wearer. A woman dressed in a Sari, or a man wearing a dhoti cannot fasten the crotch strap over their clothing. This puts the wearer at a risk of slipping out of the life jackets when lifted out of the water.

4.4 Clothing Archetypes of India

India is a land of ethnic diversity, with various traditions, cultures, and religions followed since early civilizations. Men's and women's clothing varies widely and is closely associated with the regional culture, climate and religion (Sandhu, 2015). In urban locations and to some extent in rural areas, mens wear formal and casual western clothing like shirts, pants, t-shirts, jeans, trousers, shorts, coats, and jackets. Traditional clothing for men includes kurta pajama, dhoti, and lungi. Dhoti and lungi are 10 to 12 feet long piece of textiles that are wrapped around the body and tucked in at the waist with the help of a belt (Ghurye, 1966). The difference between the dhoti (see Figure 4.8) and the lungi (see Figure 4.9) is that a dhoti is wrapped around the body and goes under the legs, whereas a lungi is wrapped like a hollow cylinder around the body.

Figure 4.8: An example of a dhoti

Figure 4.9: An example of a lungi

Indian women irrespective of their caste, creed and culture wear a sari (see Figure 4.10). A sari (saree) is a 12 to 15 feet long unstitched garment draped in different styles and worn on an upper stitched garment called choli/blouse (Chishti, 2010). Besides the sari, women also wear other traditional clothing like the salwar kameez (see Figure 4.11) and the churidar, as well as western clothing that includes shirts, pants, jeans, skirts, blouses and coats.

Figure 4.10: An example of a sari

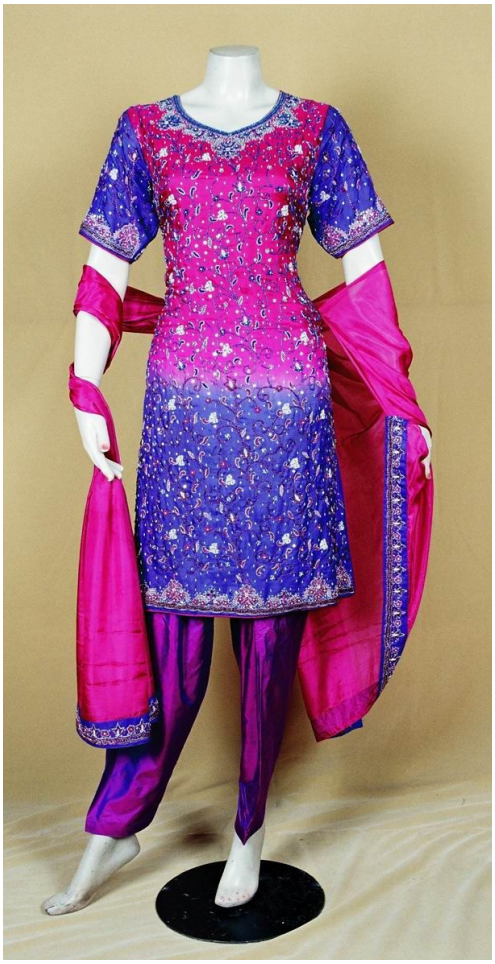


Figure 4.11: An example of a salwar kameez

Traditional Indian clothing such as the dhoti, lungi, sari, and salwar kameez do not require fasteners like zippers, snap buttons, hook n' loop's, or a button-hole to secure the garments on the body. Dhotis and saris are wrapped around the body and held with a safety pin or a belt, while a salwar kameez and churidar have drawstrings to tighten across the waist. Published literature pertinent to the impact of clothing worn with a life jacket is lacking. Clothing such as the sari and the dhoti, which use considerable lengths of fabric, can impact the safety level of the life jacket by altering its fit and buoyancy. Unlike Western style garments, traditional Indian clothing can be adjusted to the wearer's size and doesn't require the garments to be of a specific size to fit the wearer. This is a particularly interesting aspect of some Indian clothing in relation to a life jacket design, in that it is universally adjustable – one size fits all.

4.5 Existing Disaster Design Concepts

In the preliminary stages of research, novel concepts and products designed for various disaster scenarios including floods were gathered from websites and news articles, design forums and awards (Red-dot and IF Awards) published from 2015 to 2020. The motive behind reviewing concepts and products designed for all types of disaster scenarios was to understand how design can propose innovative solutions in the context of the disaster management. Sixty-five design concepts for mitigation of various disaster event applications were reviewed. These design concepts addressed a range of emergency needs such as evacuation tools, rescue equipment, clothing needs, portable light and heat source gadgets, rapid deployment, temporary shelters etc. A chronological list of the 65 products discussed in this section is presented in Appendix C.

The 70 design concepts/ products were divided into two categories:

30

in the category of general disaster response designs / products

35

in the category of aquatic hazard response, the latter being the focus of interest for this research

4.5.1 General Disaster Concepts

This category of design concepts and products addresses the general consequences of major disasters: earthquakes, storms and human conflict. The design concepts and products were chosen to include a variety of areas to comprehend a holistic understanding of peoples' needs in emergency situations. These include rescue devices, apparatus, stretchers, backpacks, rapid deployment temporary shelters, communication devices, portable solar-powered light, and a portable toilet (see Figure 4.12). Very few of these were able to be advanced to full-scale manufacturing and distribution in a practical world. A notable example is the 'Better Shelter Tent' (top right fig 4.12) designed by IKEA and funded by United Nations High Commissioner for Refugees (UNHCR). This cost-effective, modular shelter has been installed in multiple locations across the globe for displaced refugees (IKEA & UNHCR, 2016). The 'Better Shelter Tent' presented a highly utilitarian solution with a broad application across a diverse range of contexts. It's utility, is a significant factor in its success in this sector. A solution that accommodates diversity in use and application would also hold benefits for a life jacket design for flood events in India.

Figure 4.12: General disaster response concepts/products reviewed

4.5.2 Aquatic and Flood Disaster Concepts

Novel concepts and products designed for aquatic dangers, such as hazards at sea, oceans, and riverine and urban floods provided more focused insights into design innovation related to water-related contexts (see Figures 4.13 and 4.14). Of these designs:

- Twelve were designed for marine-rescue aid.
- Nine were designed for miscellaneous purposes: a swimming aid, a net for grabbing people drowning in water, floatable stretchers, life jackets with a baby carrier, convertible life-rafts and a conceptual floating shelter.
- Fourteen were life jackets designed for niche markets and five were life jackets designed for potential flood-rescue applications.

Figure 4.13: Marine-rescue aid concepts/products reviewed

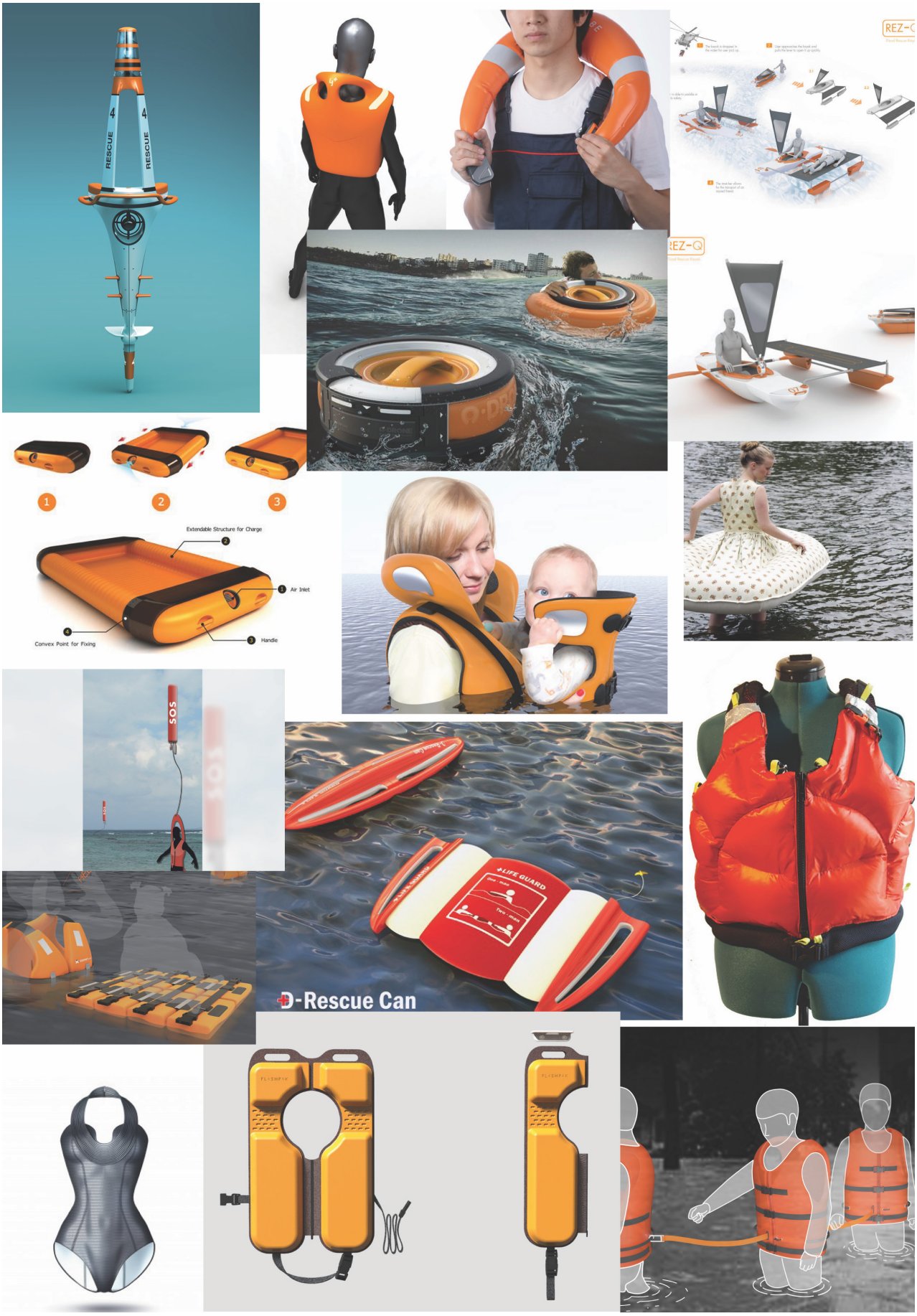


Figure 4.14: Marine-rescue aid concepts/products reviewed

The life jacket design concepts and products were more pertinent to this research as concepts addressed aspects of rescue activities experienced in flood events.

'Life Jacket Plus'

The 'Life Jacket Plus' (see Figure 4.15), incorporates two handles around the collar, making it easy to grasp and hold the wearer while being pulled out of a flood event. Its construction from a self-skinning foam, provides a pleasing sculptured form. Fit and adjustment for a range of sizes would still appear to be a challenge, although it would be a level fit for a specific individual.

Figure 4.15: Life jacket plus (Source: Zhang Bin, Lin Xingmin and Jiang Ying, 2012).

'OPOST'

'OPOST' is a flotation device explicitly designed to cater to emergency responders' needs in flood situations. This device, which comes with a carrying bag, has less bulky foam than traditional life jackets to provide broader arm movement to the wearer (see Figure 4.16). It can be adjusted to fit a wide range of sizes with the help of straps around the waist and over the shoulders (see Figure 4.17). 'OPOST' provides only 70 Newtons of buoyancy which is below the minimum requirement of 100 Newtons buoyancy prescribed by the European and Indian life jackets specifications.

Figure 4.16 & 4.17: OPOST life jacket can be adjusted over the shoulders and around the waist using Hook n Loop straps (Source: Maxime Loubert, 2020).

‘Connect’

‘Connect’ (see Figure 4.18) is a conceptual life jacket design with lower sections that can be split off. These sections can then be recombined for specific purposes, such as a life raft or a floating buoy. Connect attempts to highlight sharing potentials between people in need that may have different requirements such as the elderly, children, or animals.

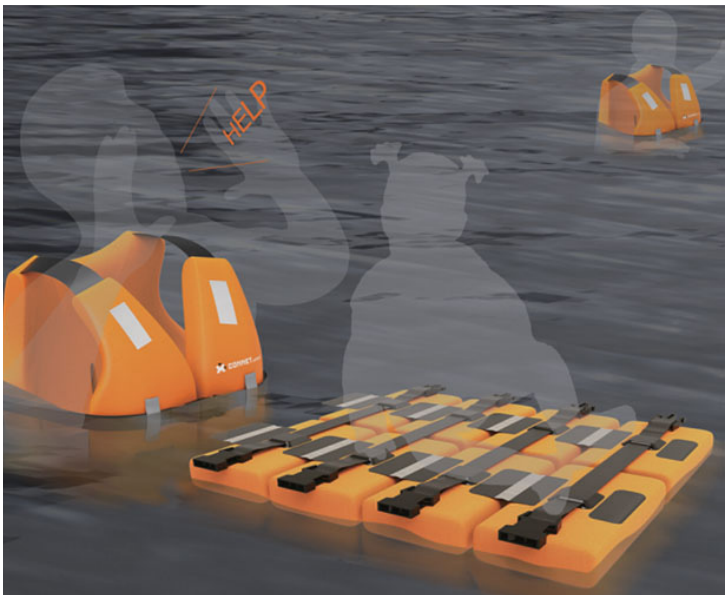


Figure 4.18 Connect: A life jacket and floating device in one (Source: Zhang Chaojun, 2016)

‘Connect the Life jackets’

Whereas ‘Connect the Life jackets’ (see Figure 4.19) is a combination of rope and life jackets that links everyone to reduce the risk of being swept away. These life jacket concepts allude to added functionality and benefit; however, the practical usability of their design remains untested.

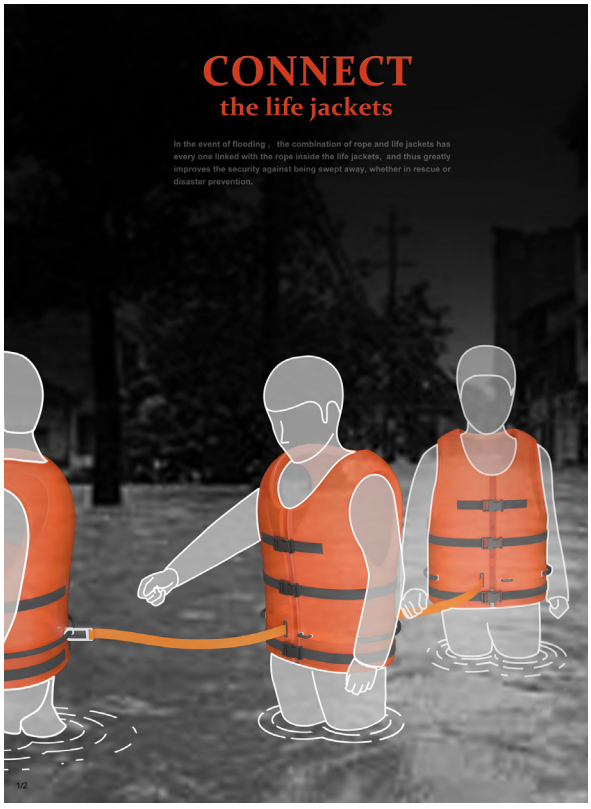


Figure 4.19: Connect the Life jackets (Source: Zhejiang University, 2018).

'VEST'

'VEST' is a conceptual design (see Figure 4.20), developed by Kinga Krężel for the 'Innovations in Life Jacket Design Competition 2015'. The VEST buoyancy aid concept is a simple wrap design inspired by a shawl, draped and then tied around the body. Its development incorporates an upper single position lug/locking feature that fixes the mid position of the product, locking the overlapping flotation foam panels together. The lower strap provides adjustment for sizes.

Figure 4.20: VEST buoyancy aid (Source: Kinga Krężel, 2015)

The design of this buoyancy aid is reduced to a considerable amount of foam around the body, to provide greater movement to the arms and head. An inflatable collar was added to aid buoyancy and head support (see Figure 4.21). The VEST prototype provides only 60 Newtons of buoyancy, which is below the minimum requirement of 100 Newtons buoyancy prescribed by the European and Indian life jackets specifications.

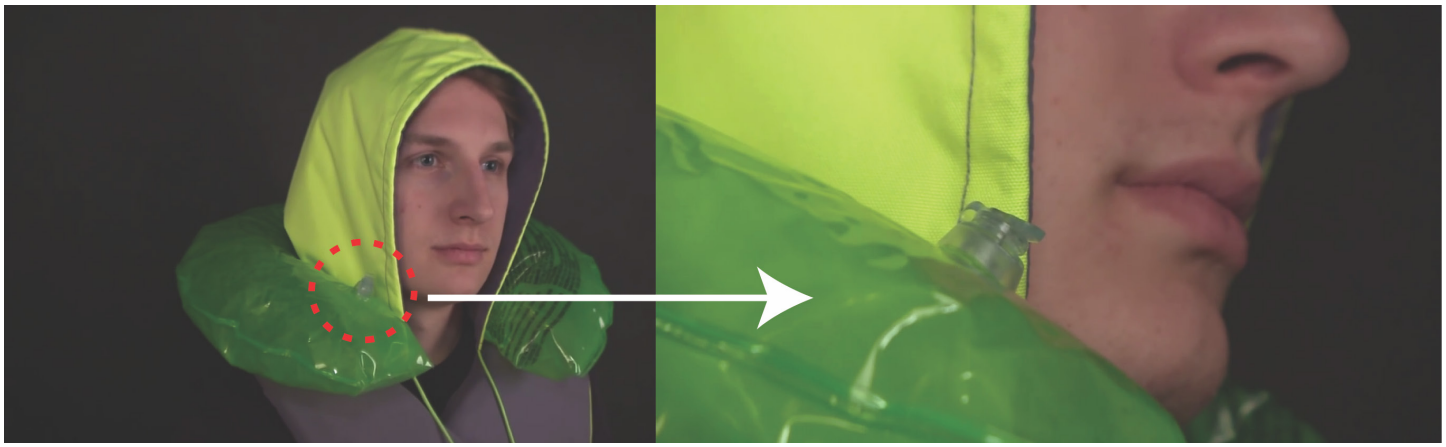


Figure 4.21: Inflatable collar in VEST concept (Source: Kinga Krężel, 2015).

The Vest concept is a precedent in buoyancy aid design, as it appears to be the first design using a crossover front panel fixed by a fastening, like some traditional Indian clothing archetypes.

4.6 Preliminary Design Criteria

From the insights gained from the above examples of secondary research, preliminary (rudimentary) design criteria provided a basis for early concept generation and concluded that;

1. The life jacket will be light and compact and shall be designed for wearing over clothing.
2. The life jacket will be safe and reliable (provides protection from flood water exposure, injuries from sharp jagged debris).
3. The life jacket will not restrict the field of vision or hearing of the wearer, nor impede breathing or the movement of limbs and hands.
4. The life jacket will be adaptable, with functional features of the design complying with the context and cultural clothing of the end-users.
5. The life jacket will be appropriate for people of all sizes, pregnant women, differently abled people and children.

4.7 Preliminary Concepts and Critical Reflection

Ideation in the earlier stages of research was influenced by fashion and industrial designers' approaches to product and apparel innovation. These included concepts that can be transformed into tents, multi-purpose clothing for the flood affected, and life jacket products with multiple add-on accessories like first-aid kit, GPS tracker and water purifier to add functionality. A range of life jacket concepts and rudimentary prototypes was generated (see Appendix D).

These early concepts, although novel, were less focused on improving the functionality and usability of life jackets design. This hybridisation approach sought to address multiple issues faced in a disaster event, however in doing so often complicated the solution by transforming for a related purpose, such as ladder or stretcher capability.

Chapter 5: Indian Field and Product Trial

Focus groups and questionnaires were conducted with emergency responders of the NDRF organization in India. The NDRF is a subdivision of the Indian armed forces, constituted "for the purpose of specialist response to threatening disaster situations" (NDRF, n.d.). NDRF personnel are equipped and trained to respond to natural as well as man-made disasters happening across India. At the time of this study, 13 NDRF battalions existed across multiple states of India. Locations of all battalions are plotted on a map of India (see Figure 5.1). 3 of the 15 NDRF teams were chosen to conduct focus groups interviews and questionnaires. The 3 teams that were chosen for this research (highlighted in red in Figure 5.1) were located in different states of India. The 3 locations were chosen from varied geographical locations, population densities, climatic zones, and experience with major flood events in the past. These locations included Ghaziabad in the North, Vijayawada in the Central, and Arakkonam in the South of India.

Emergency responders (expert and lead users), and flood affected and sometimes disaster victims (end users) are highly valued sources for obtaining information about the functionality and usability of current life jackets designs. However, flood affected respondents can experience psychological and emotional trauma (Green & Solomon, 1995) when subjected to retelling and remembering their lived experiences in disaster events (Freedy et al., 1992).

In consideration of the requirements to undertake a field research study with potentially traumatised end user respondents, the decision was made not to include this group in the data collection. Although subject to experiencing trauma emergency responders are professionally trained to manage risks and challenges in disaster scenarios. Emergency responders with expertise in flood rescue were highly valued in field work data collection.

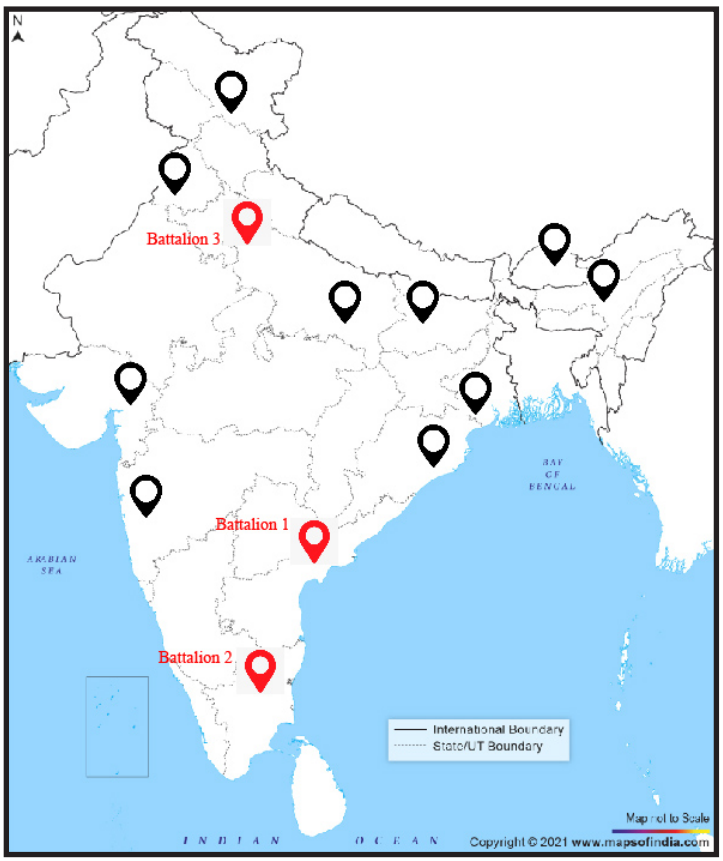


Figure 5.1: All NDRF battalions marked in black color on the India map. Battalions participated in this study are highlighted in red color (Source: Maps of India, n.d.).

5.1 Focus Groups with Emergency Responders

One focus group questionnaire with each of the selected teams was conducted separately at their respective locations. Focus groups comprised of 4 to 6 participants from each team. Information sheets in both English and Hindi languages were handed out to the participants at the beginning of the focus group. The information sheets explained the details of the researcher, the purpose of the study, focus group procedure, participant's rights and data management. Additionally, all participants signed a consent form that stated they agreed to participate in the study. The sessions were recorded on video, to which the participants agreed upon in the consent form. Each focus group was conducted in two sessions: a) journey mapping activity and b) discussion.

In the journey mapping activity participants were given 30 photographs of various Indian flood events (see Figure 5.2). The 30 photographs displayed a range of search-and-rescue activities performed by emergency responders such as transport to a flood location, preparing for flood rescue, evacuating people from their houses, rescuing people from swift-water, rowing boats, and other activities performed in a flood scenario. The photographs chosen for the journey mapping activity were obtained by the researcher from official websites of the National Disaster Management Authority of India (NDMA), National Disaster Response Force (NDRF), the Press Trust of India (PTI), and PTI's associates. The participants were asked to arrange the photographs on a board in the order of their occurrence as in a real-life flood event. Further, the participants were asked to define the activity performed in each of the photographs while also specifying the most dangerous and the most difficult activities. Using the journey mapping activity, I was able to initiate meaningful conversations with the participants which in turn allowed them to share their thoughts and experiences related to flood rescue. The journey mapping activity sequenced an overview of the activities performed by emergency responders during floods in the order of their occurrence.

Figure 5.2: Journey Mapping Activity with team 1

In the journey mapping activity, participants listed the activities generally performed by them during any given flood event. These were categorized into three categories: a) Preparation, b) Rescue and c) Relief. A detailed list of the activities is presented as a flow-chart (see Figure 5.3).

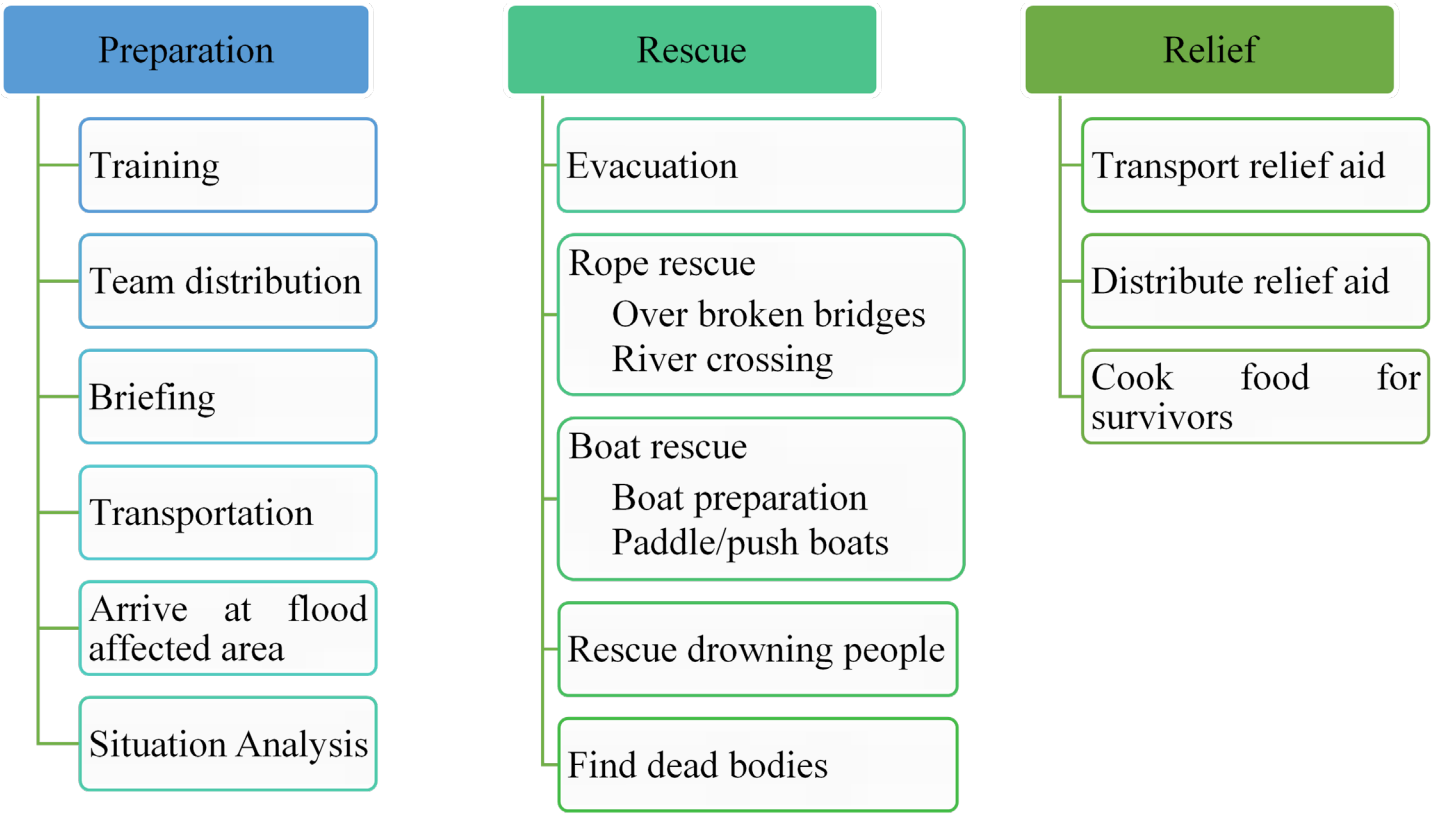


Figure 5.3: List of rescue activities performed by emergency responders

In the discussion phase (see Figure 5.4), in-depth conversation among the participants largely focused on three topics:

- The challenges and issues faced by emergency responders in flood scenarios,
- The emergency responders' opinions on the functioning of current Life jackets designs,
- The emergency responders' ideas towards the optimal functional, usability and aesthetic properties for a future life jackets design.

Figure 5.4: Discussion with team 2

The research process followed a semi-structured script that contained a set of 15 questions (see Appendix E). The questions were formulated so that it was possible to have a general idea about several issues (e.g., protection, fit, comfort, volume and, feel and texture of materials) and potential challenges that exist related to the activities performed by the emergency responders during floods. Additionally, the emergency responders were also asked to give some suggestions regarding the issues they would like to see changed.

All proceedings were undertaken in Hindi. The number of participants for each focus group was set as 4 to 6. The three focus groups had 6, 5 and 4 participants respectively. The participants were encouraged to speak freely, and each participant was encouraged to provide at least one comment for each question. Each of the sessions lasted approximately 1 hour and 30 min. The focus groups were transcribed directly into the English language by the researcher. There is a slight chance of information being lost while translating conversation from Hindi to English. However key technical terms and design attributes (e.g., protection, safety, flotation, comfort, Nylon fabric) are communicated in English by all the participants. After the transcription, the focus group contents were coded and analysed using the qualitative data analysis software NVivo (version 12.0), allowing a prompt extraction of the relevant results and insights (see Appendix E).

5.1.1 Findings from Focus Group Discussions

Data generated from the focus group discussions with emergency responders was broadly coded under three research questions:

1. What are the issues and challenges faced by emergency responders in flood scenarios?
2. What problems do they face while using the current jacket designs?
3. What are their suggestions for a future ideal rescue-wear design?

Data coded under each of the three research questions was interpreted into sub-themes. The sub-themes were named as one-line descriptions of the issues, challenges, problems and/or suggestions mentioned by the participants. Some examples of these sub-themes included challenges in flood scenarios like dangerous animals in the water and boat punctures, problems with current life jackets designs like restriction of body movements and bulky volume, and suggestions for an ideal life jackets that enhanced durability and comfort. Sub-themes were arranged in the descending order of the number of times each sub-theme was expressed by the participants during the focus group discussion. A detailed list of the sub-themes identified under each of the research questions along with their frequency are represented in Appendix F.

Issues and challenges faced by emergency responders

The participants mentioned that if the people to be evacuated are far away from the dryland (500m or more) and evacuation can't be done by river crossing or by individual assistance, then boats are used to evacuate people. Sometimes emergency responders must evacuate pet animals and cattle. This is because the owners of the animals don't wish to leave their cattle or pet animals behind.
When asked about the most dangerous activities of all, one participant from the first team replied, "All of these activities are dangerous. Also, it isn't like any one activity is less dangerous than the others." Flood water may contain animals like snakes, crocodiles, scorpions or other animals making it hazardous for the emergency responders to work in. One participant recalled a situation about his fellow participant, "This person has almost died twice. He has lots of experience. He is dead twice and alive for the third time." Moreover, the participants said that the flood rescue activities are difficult and strenuous too. A participant specifically highlighted, "Evacuating animals is very difficult. Animals do not have a brain like us. Making them understand our rescue plan is challenging."

Problems with current Life jackets designs

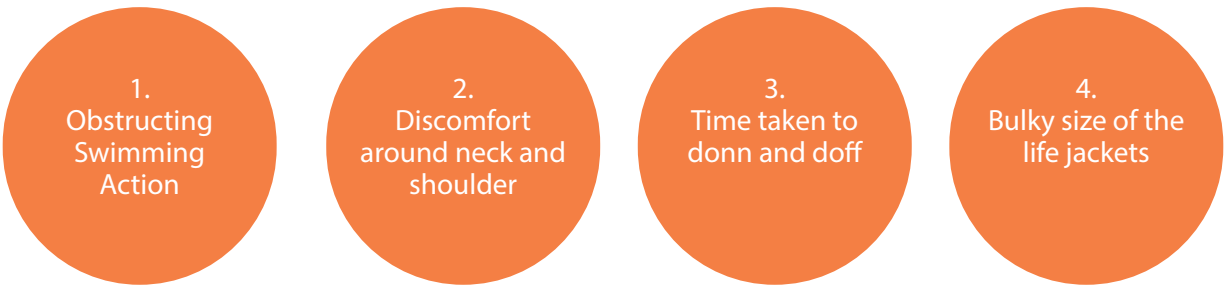
The life jackets used by the NDRF teams and military personnel in India are 'inherently buoyant' types with closed cell polyvinyl chloride or polyethylene foam. Inflatable type Life jackets are available with the NDRF teams but are seldom used for specialist operations only. The price of an inflatable life jacket in India is approximately INR 5,500 (NZD 105) whereas the price of a foam life jacket is around INR 1,000 (NZD 19). The price per life jacket of both types can alter based on the order size, manufacturer location, materials used and additional features in the life jackets. In general inflatable life jackets are five times more expensive than foam life jackets. Inflatable life jackets also require regular maintenance in terms of changing CO2 cylinders which generate gas for inflation. Other downsides of inflatable life jackets in flood scenarios include puncture by debris, malfunctioning of inflation mechanism and non-availability of additional CO2 cylinders to re-use deflated life jackets. All these conditions leave the emergency responders with no option but to prefer foam life jackets.

Corroborating my findings in visual research (Chapter 4), it is observed in the focus groups that the NDRF emergency responders use two models of foam life jackets. The first model is Markwel life jacket (with collar) and the second model is Galvaniser vest-type life jacket (without collar). These two models are like the life jackets worn by emergency responders in Figures 3.6 and 3.8 respectively. Under the life jacket, emergency responders wear T-shirts (half/full sleeves) and shorts made from 100% Nylon Bird-eye mesh fabric. This fabric is lightweight yet durable, breathable and quick to dry making them apt for working in wet and sometimes humid conditions. Orange coloured fabric is preferred due to its high visibility.

When asked about their preferred life jacket model, the participants unanimously voted for the Galvaniser life jacket without a collar. They further explained that the life jacket without collar has wider arm holes allowing for a wider range of movement to the arms while performing rescue activities, comfortable around the neck with no irritation, and it accommodates swimming.

As mentioned by the NDRF rescuers who participated in focus group discussions with the researcher, the NDRF authorities mandated life jacket wear compulsory for those rescuing or being always rescued while in and around flood water surroundings. When questioned about peoples' behaviour to donning life jackets in real life, the participants replied that the rescuers make sure that each member involved in a search-and-rescue activity wears a life jacket. However, from extensive visual research conducted on hundreds of photographs of flood rescue from news media, it is found that not all people being evacuated in boats, and some emergency responders did not wear a life jacket.

During the focus groups a lot of discussion was given issues of the currently deployed life jackets, and these grouped around four main areas:



Ease of swimming while wearing life jackets is regarded as a key issue, because an important duty of the emergency responders is to save drowning or trapped people in flood water. When the wearer's head and

"We find it difficult to swim wearing life jackets. The wearer can float but not swim. We need life jackets which can make us float and allow us to swim."

When free-style swimming, the foam on either side of the life jacket blocks (interrupts) the movement of arms. The wearer has to stroke the water on the outside of life jacket foam. Due to this the swimming efficiency is lost (reduced). The closer we stroke the arms from the body, the faster we can move (swim) forward. If we bring the arms close to our body, the foam is blocking it. We feel uncomfortable because of this. – Participant 5 of NDRF team 1.

Suggestions for an ideal rescue-wear design

All the participants of the focus groups demonstrated interest in having life jackets specialised for use in floods. They believe that there is a lot of scope for innovation in this area, while also mentioning that life jackets are the most critical piece of equipment, they use for flood rescue activities.

All participants requested compact and slimmer life jackets. because the bulkiness of life jackets interrupts rescue works by impeding the movement of neck, shoulder and arms. The participants emphasised that having freedom of movement around the neck and shoulders is important and, as the current design of life jackets with collar fails to do so. Hence, they suggested that re-designing the collar shape would be favourable. Additionally, bulky life jackets require enormous space for stowage in boats and trucks while being transported.

In turn, not a lot has been said about the fabric and aesthetics of the rescue-wear. They believe that the Nylon fabric used in their life jackets is durable and dries quickly. "We work in flood areas where we meet a lot of dirt and debris. So, any kind of fabric is meant to get dirty in these situations. The work we do is like this." Also, the participants understand that the fluorescent Orange color of life jackets is to make them visible at night and a recommendation by the SOLAS (Safety of Life At Sea) and ISO (International Standards Organization) standards.

5.2 Questionnaire with Emergency Responders

A questionnaire or survey was used as a quantitative tool used to generate information from the respondents about their experiences in flood rescue scenarios. Resulting data from the respondents was used for statistical analysis of the specific research questions in the questionnaire. The questionnaire followed the focus group interviews with 60 questionnaires collected in total, 20 from each team. The questionnaire was specifically designed for the purpose of this project – the questions were developed based on the findings from literature and visual research.

The questionnaire was divided into 3 sections. The questions in the first section aimed to get a quantitative representation of what the participants think are the most dangerous and most difficult activities during flood rescue in India. In the second section, questions were dedicated to participants' opinions on current life jacket designs, what aspects they like and don't like about life jackets and rate various aspects in the current life jackets. The third section was dedicated to knowing about the participants' perspectives about new life jacket designs. What are the ideal features they are looking for? What kind of functional features are most favoured? All questions are designed to help make a graphical/numerical decision to which aspects of life jacket designs are poor and which aspects are looked for by the emergency responders. Some questions were also asked regarding the suitability of current life jackets for children and women.

The questionnaires were printed and given to the team commandant at each of the battalions. The commandant then distributed them to random emergency responders who have had experience in flood rescue to fill in the questionnaire. The completed forms were uploaded to the Google Forms online tool to generate quantitative data. The analysis of the questionnaire used descriptive statistics, as the main purpose of the questionnaire was to have a clear idea of the current situation of the types of life jackets used by emergency responders.

The sixty emergency responders that participated in the questionnaire had been deployed in a minimum of five distinct flood events across multiple flood affected locations in India. The participants ranged from the age of 18 to 55. All participants were male.

The questionnaire included multiple choice questions drafted in two languages adjacently – English and Hindi. One open-ended question was also added at the end of the questionnaire to provide suggestions and feedback. The questionnaire was composed of 16 questions that were structured in six different sections (see Appendix G). Many questions used subjective rating scales (e.g., very convenient; convenient; normal; slightly inconvenient; very inconvenient) so that the emergency responders could indicate their satisfaction/dissatisfaction with the rescue-wear. Responses of the 60 participants to the questionnaire are presented in the form of graphical charts in Appendix H.

5.2.1 User Satisfaction of Rescue - wear

Most emergency responders indicated they are acceptably happy (inferred as so-so) with the life jackets they are currently using (see Figure 5.5). 13% of them indicated they were unhappy with the rescue-wear (not that happy = 10%; very unhappy = 3%), implying that most of the participants (63%) are anticipating better rescue-wear. Nonetheless, for 37% of the participants the satisfaction was high (23% very happy; 14% happy).

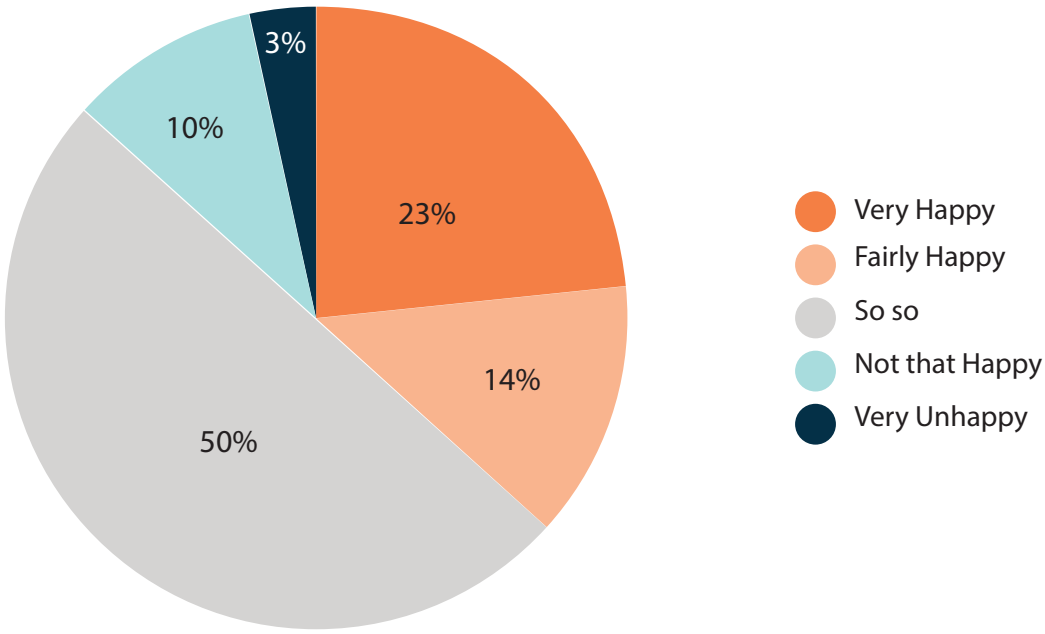


Figure 5.5: Pie-chart showing the percentages of emergency responders' satisfaction to current life jackets

When questioned about the causes of the dissatisfaction, most participants identified restriction of body movements, improper flotation, and volume of the life jackets as the main reasons (see Figure 5.6).

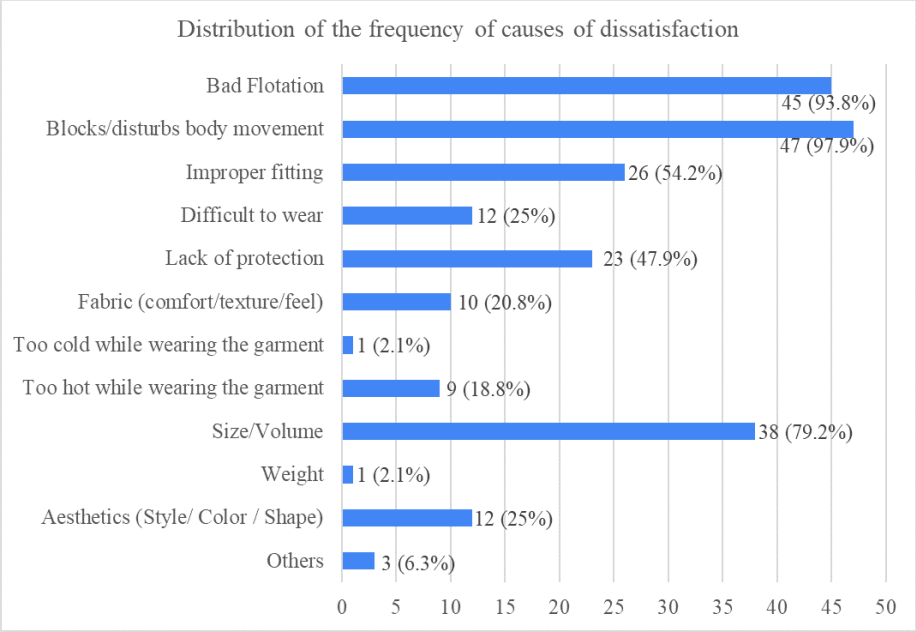


Figure 5.6: Distribution of the frequency of causes of dissatisfaction to current life jackets

5.3 Existing Product Dryland Trial

The existing life jacket (E1) used for this trial is without a collar and sourced from India. This life jacket is the most preferred option by Indian emergency responders who participated in focus groups and questionnaires and hence chosen for this study. The life jacket sample (see Figure 5.7) was purchased from 'Galvanisers India', a marine safety and rescue equipment based in Pune, during my field study in India. Galvanisers India is also a major supplier of life jackets for NDRF emergency responders.

Figure 5.7: Existing life jacket without a collar (E1)

The life jacket is manufactured in orange polyester fabric as the outer layer and expanded polyethylene (EPE) foam inside to provide buoyancy. It has a plastic zipper at the centre front and three polyester webbing straps with plastic buckles to secure the life jacket to the body.

5.3.1 Trialling Method of E1

The E1 was trialled on dryland conditions by three participants: 2 males and 1 female. The participants were chosen to match a broad range of Indian anthropometric chest measurements. The details of the three participants are listed in Table 5.1 along with the corresponding Indian anthropometric chest measurement category they matched. Chest measurements range across participants was 44cm.

Participant Number	Gender	Chest	Height
P1	Female	84cm	160cm
		50th Mixed	50th Mixed
P2	Male	106cm	182cm
		95th Male	95th Male
P3	Male	128cm	195cm
		95th Female	95th Female

Table 5.1: Details of the participants trialling E1

Participants 1 and 2 wore traditional Indian clothing, a sari and lungi underneath the life jacket. Participant 3 wore a t-shirt and a pair of trousers. All three participants donned the life jackets and performed simple tasks like walking, sitting on a chair, bending and picking up an object and a rowing action.

Standing position analysis

It can be observed from the standing photographs (see Figure 5.8, 5.9 and 5.10) that the life jacket fits well over the three participants. The male participants was the only participant who felt that the life jacket fitted closely to his body. For the female participant (who corresponds to 50%ile mixed anthropometry of India), the life jacket extended up to the hip level and felt loose on the body and this infers that the design does not accommodate smaller female

Figure 5.8 - Participant 1 in a standing position while donning the E1

Figure 5.9 - Participant 2 in a standing position while donning the E1

Figure 5.11: Participant 3 in a standing position while donning the E1

Figure 5.11: Life jacket fits loosely on the Participant 1 (female)

Sitting position analysis

It can be observed from the sitting photographs (see Figure 5.12, 5.13 and 5.14) that the life jacket rises at the shoulder point. The rise in shoulder point is highest for participant 1 (female) followed by participant 2 (male) and the least rise for participant 3 (male). The life jacket also folds along the waist of all the participants and the bulk created by the foam panels can cause discomfort while bending or reaching forward.

Figures 5.12 and 5.13: Participants 1 and 2 in a sitting position while donning E1

Figure 5.14: Participant 3 in a sitting position while donning E1

Bending forward position (Waist flexion at 90o) analysis

The life jacket rides up on all 3 three participants when bending forward when in a sitting position. The rise in shoulder point is highest for participant 1 (female) followed by participant 2 (male) (see Figures 5.15 and 5.16). Participant 3 (male) felt quite uncomfortable to bend 90° forward and was only able to partially bend. The folding line of the life jackets at the third participant's (male) waistline is restricted to bend forward comfortably (see Figure 5.17).

Figure 5.15: Participant 1 bending forward at 90° while donning E1

Figure 5.16: Participant 2 bending forward at 90° while donning E1

Figure 5.17: Participant 3 unable to bend forward at 90° while donning E1

It was observed that when bending forward the shoulder line raised up and touched the face, neck and ears of the participants. The rise in the shoulder line depended on the height of the participant and the fit around the body. Participant 1 being the shortest of the three participants and has a smaller chest girth at the highest rise in shoulder line (see Figure 5.18). On the other hand, participant 3, who is the tallest of the three and had a wider chest girth felt least rise in the shoulder line while bending forward. The rise in shoulder line for participant 2 was moderate in comparison with the others (see Figure 5.19).

Figure 5.18 and 5.19: Participants 1 and 2 bending forward to lift an object while donning E1. The life jacket shoulder line rises and touches the face and ears

All three participants mentioned that the life jacket touching the face and ears caused discomfort. Through trialling the existing life jacket product (E1) with participants of a large size difference, it is observed that the E1 provides a snug fit only to medium and larger male participants whereas it fits loosely on smaller female participants. This product is intended to fit a large range of sizes, but it is not fit for the purpose of flood events.

5.4 Modified Design Criteria

Creative design practice was informed by the primary research conducted with emergency responders in India. Based on the answers gathered from primary research focus groups and questionnaires, and secondary research from literature and visual research, it was possible to define a comprehensive set of design criteria supporting life jacket design that was specific to the context and conditions in India.

The design criteria are grouped under six attributes (comfort; fitting; ease of don on and off; safety; handling and storage; and performance). The six design attributes were prioritized over the distinct types of themes that emerged during this study. Each of the design criteria are further divided into subcategories and presented in Table 5.2.

Table 5.2: Design Criteria

Design Criteria	Sub-criteria	Interpreted Need
Comfort	Range of Movement	The life jacket allows free range of movement to the wearer's arms, limbs, head and neck.
	Irritation	The fabric and other materials of the life jacket are skin friendly in all climatic conditions.
	Interruption	The life jacket allows the wearer to perform rescue activities with full efficiency.
Fit	Misfit/Slip	The life jacket fits snug to the wearer's body and doesn't ride over the wearer's face in water.
	Appropriate to Indian Anthropology	The life jacket accommodates a broad range of Indian anthropometry from 5%ile females to 95%ile males.
Ease of Donn & Doff	Time	The life jacket can be worn and removed with ease. Life jackets have simpler and quick fastening mechanisms.
	Culturally Appropriate	The life jacket requires little or no user instruction or learning.
Safety	Reliability	The life jacket is reliable to float with zero/minimal failing chances.
	Protection	The life jacket keeps the wearer safe from all sorts of dangers in flood water. *Full protection can't be ensured by covering the entire body of the wearer with protective materials. Doing so will interrupt rescuers' performance and mobility. At least, protection to the core body can be made essential.*
Handling & Storage	Volume	The life jacket is light and compact.
	Carrying	The life jacket is easy to carry around.
Performance	Swimming	The life jacket facilitates the wearer to move in water.
	Vision	The wearer's line of vision in front and sides is clear at all times.
	Attachments	All functional and aesthetic attachments on the life jacket stays in place and are of required dimensions only.

Chapter 6: Design and Development

6.1 Concept Generation in Response to Design Criteria

Concepts were generated in response to individual design attributes listed in the design criteria. Selected examples of the concepts generated during this stage include:

1.The Dissected Foam Life Jacket

This concept (Figure 6.1) incorporates patches of aramid fabric (Orange coloured) with soft, lightweight flotation foam inside. The foam pads protect major parts of the core and reduce heat loss while the raglan sleeve provides greater range of movement to do rescue activities. The neck band of the T-shirt comes with a hidden inflatable cell for extra buoyancy. The base layer is neoprene mesh fabric with stretch to provide increased movement and ventilation in dry weather.

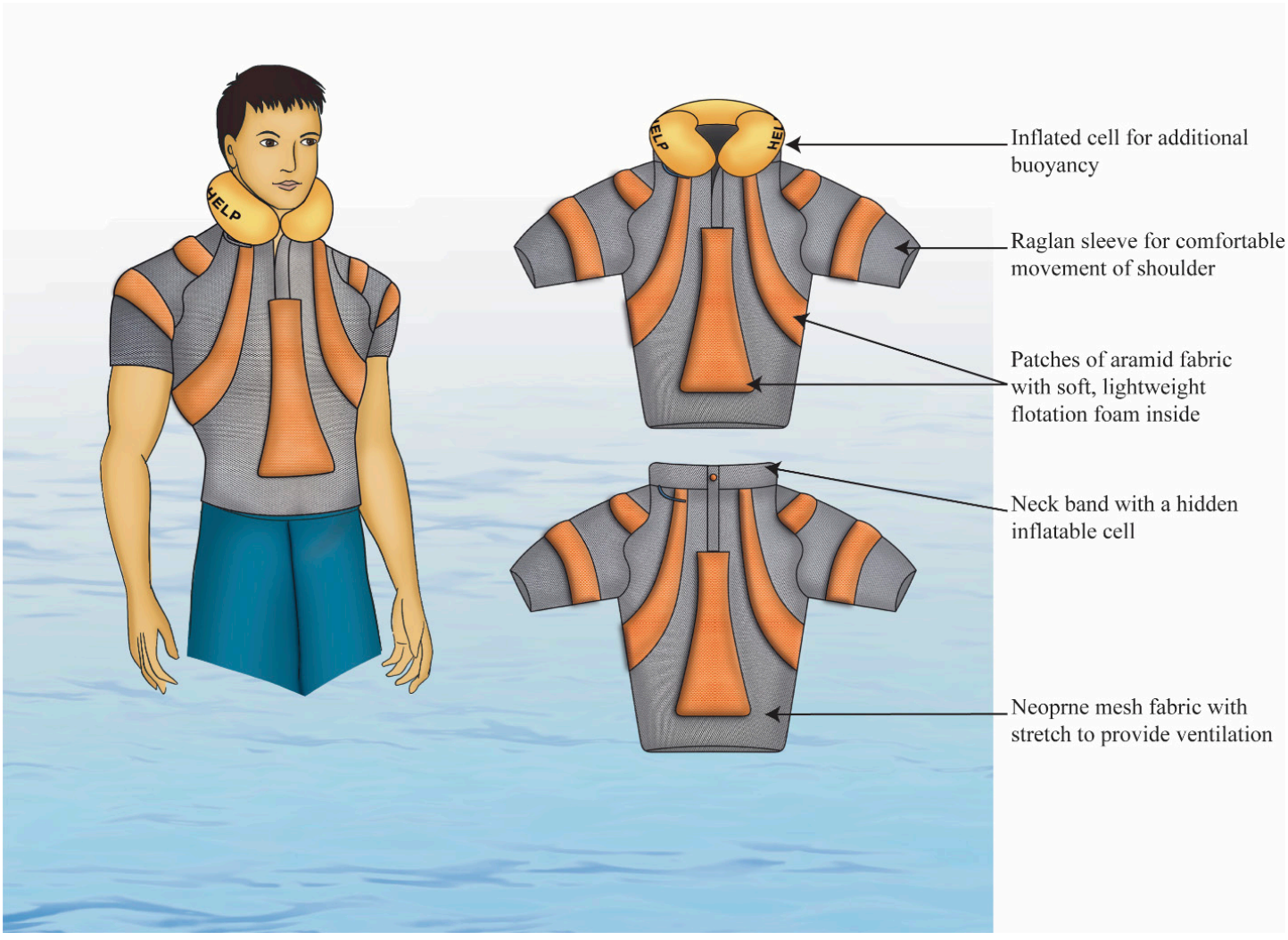


Figure 6.1: Dissected Foam Life Jacket

2.The Modular life jacket

This concept (Figure 6.2) references the 'Connect' concept from Chapter 4 (Figure 4.18), however it focuses on adaptability to user's anthropometry by adding or subtracting foam volume. This concept comprises foam sections that can be added to the upper life jacket segment using 3D printed peg and hole joints. The length of the life jacket can be increased by adding a new foam section which in turn increases buoyancy. Additionally, the collar can be detached using buckles if not required by the wearer.

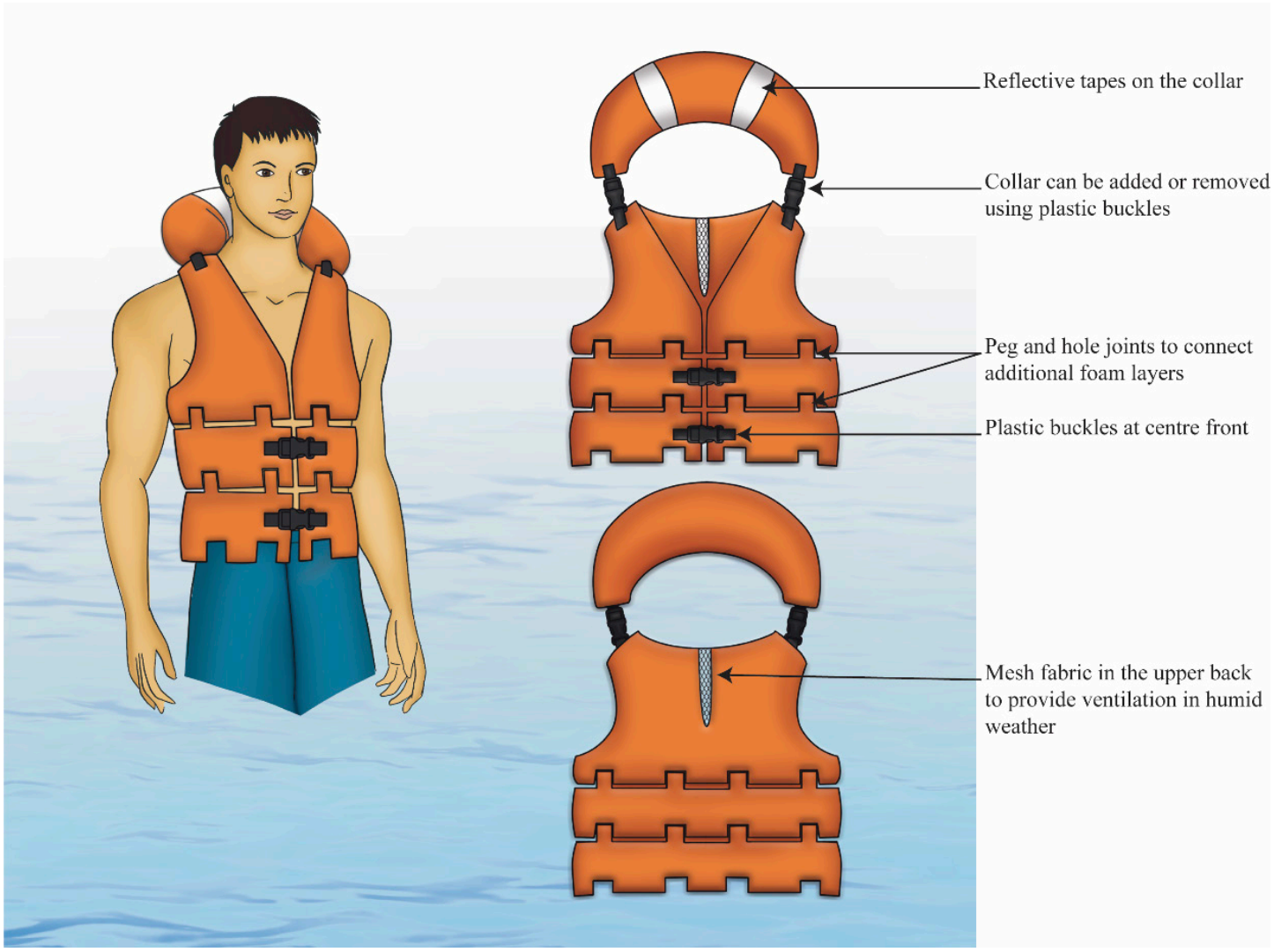


Figure 6.2: Modular life jacket

3.The Reversible life jacket

This concept (Figure 6.3) responds to the observed situation during a flood rescue when people are in a hurry to put on the life jacket and mistake the front side for back or vice versa. This reversible life jacket has no defined front or back. This life jacket concept can on be worn over the head facing either side. It references traditional Indian dress as well as western dress conventions. The webbing straps with a tri-glider can be used to adjust to the wearer's anthropometry. The cross over panel references the VEST concept seen in chapter 4 (Figure 4.20) and Sari and salwar kameez dress conventions.

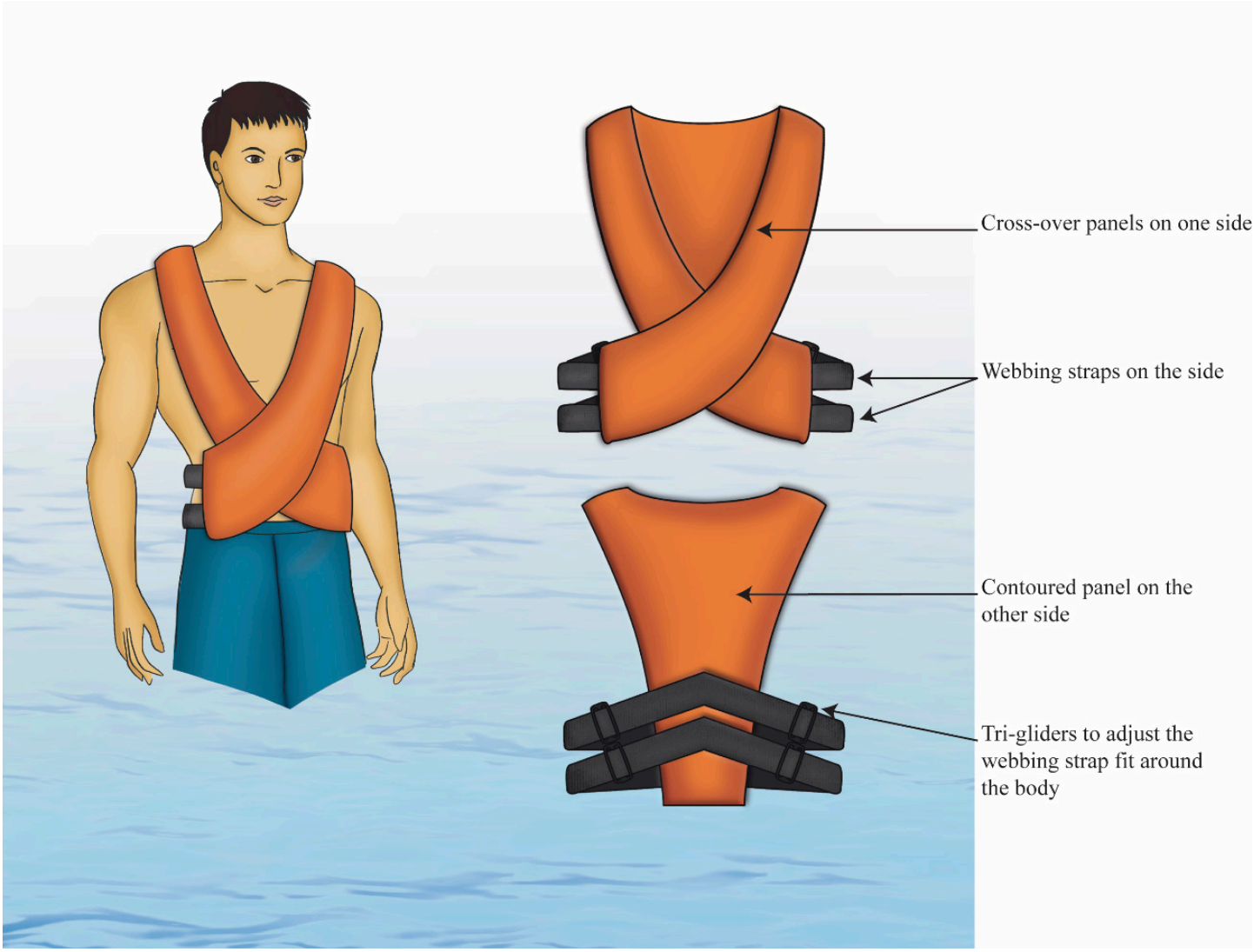


Figure 6.3: Reversible life jacket

4.The Ventilated life jacket

The main objective of this concept (Figure 6.4) is to reduce the pressure exerted by the foam panels on the wearer's body which impedes breathing and restricts the bending movements of the wearer. This life jacket concept incorporates a zipper at the centre front, polyester webbing around the waist secured with a plastic buckle and small tessellated holes in the foam panels. Tessellated holes in the foam and a slit in the centre back provide flexibility to the wearer while bending, lifting weight and rowing boats.

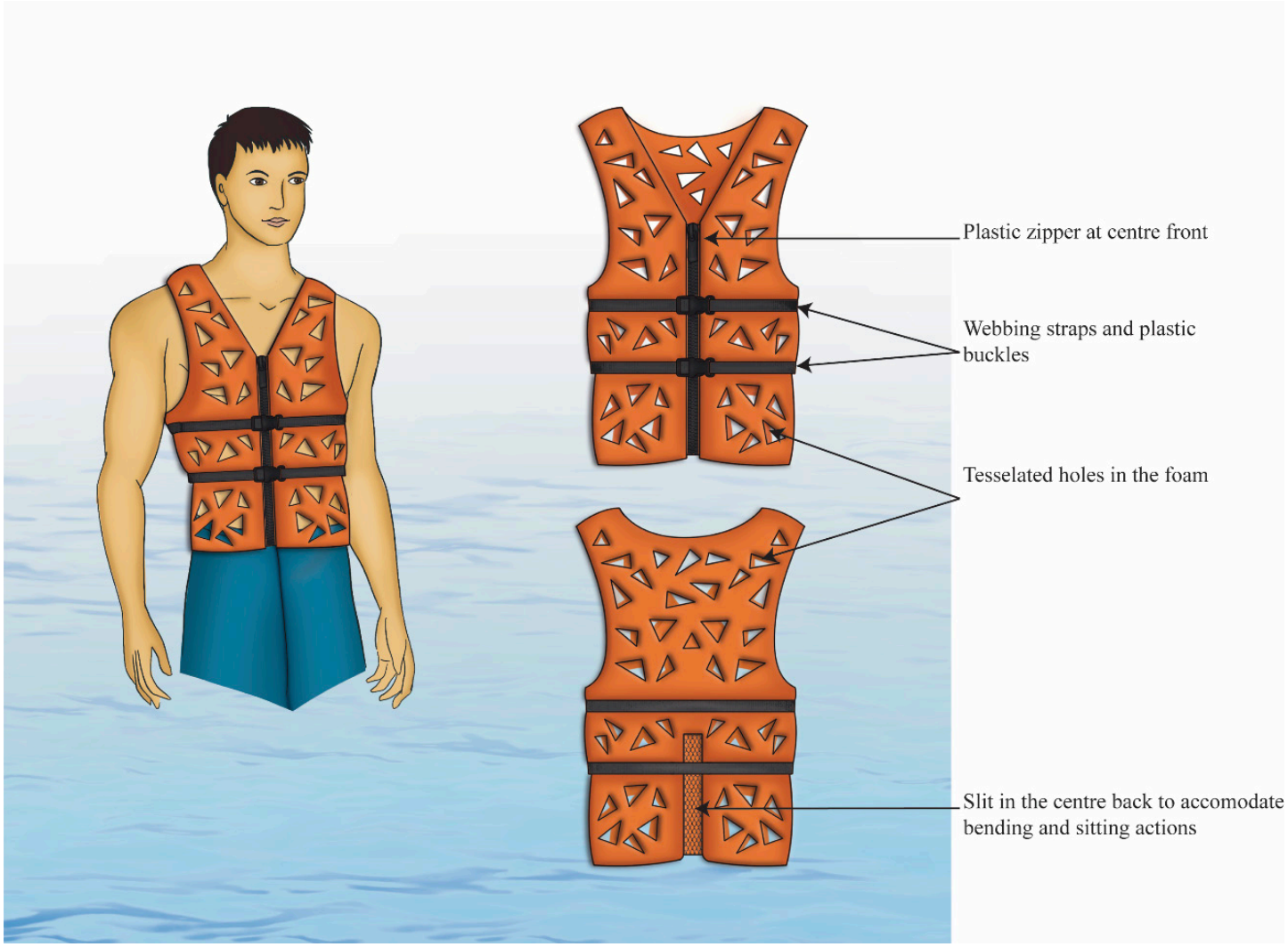


Figure 6.4: Ventilated life jacket

5.The Crossover panel life jacket

This life jacket concept (Figure 6.5) has 2 front panels that overlapped on each other referencing VEST Chapter 3 (Figure 4.20). However, in this instance the front panels are free to slide across each other to adjust the circumference of the wearer and to provide greater size adjustment for the wearer. There is no centre front access for this life jacket as in a traditional life jacket design.

This concept is inspired from the traditional wrap-around clothing in India like sari and lungi which are not worn like a shirt or jacket by putting the hands through sleeves. This broadly adjustable aspect is in keeping with traditional Indian clothing identified in Chapter 4; Section 4.4 Clothing Archetypes of India. Fasteners like zippers, hook n' loops, buttons and buckles are not commonly used in traditional Indian clothing.

Features: Two pieces of triangle shaped panels are joined at the back neck and worn around the head and placed on the front body. The balance of the pattern pieces originates from the centre back neck point to wrap the body with adjoining strap system to fit multiple sizes.

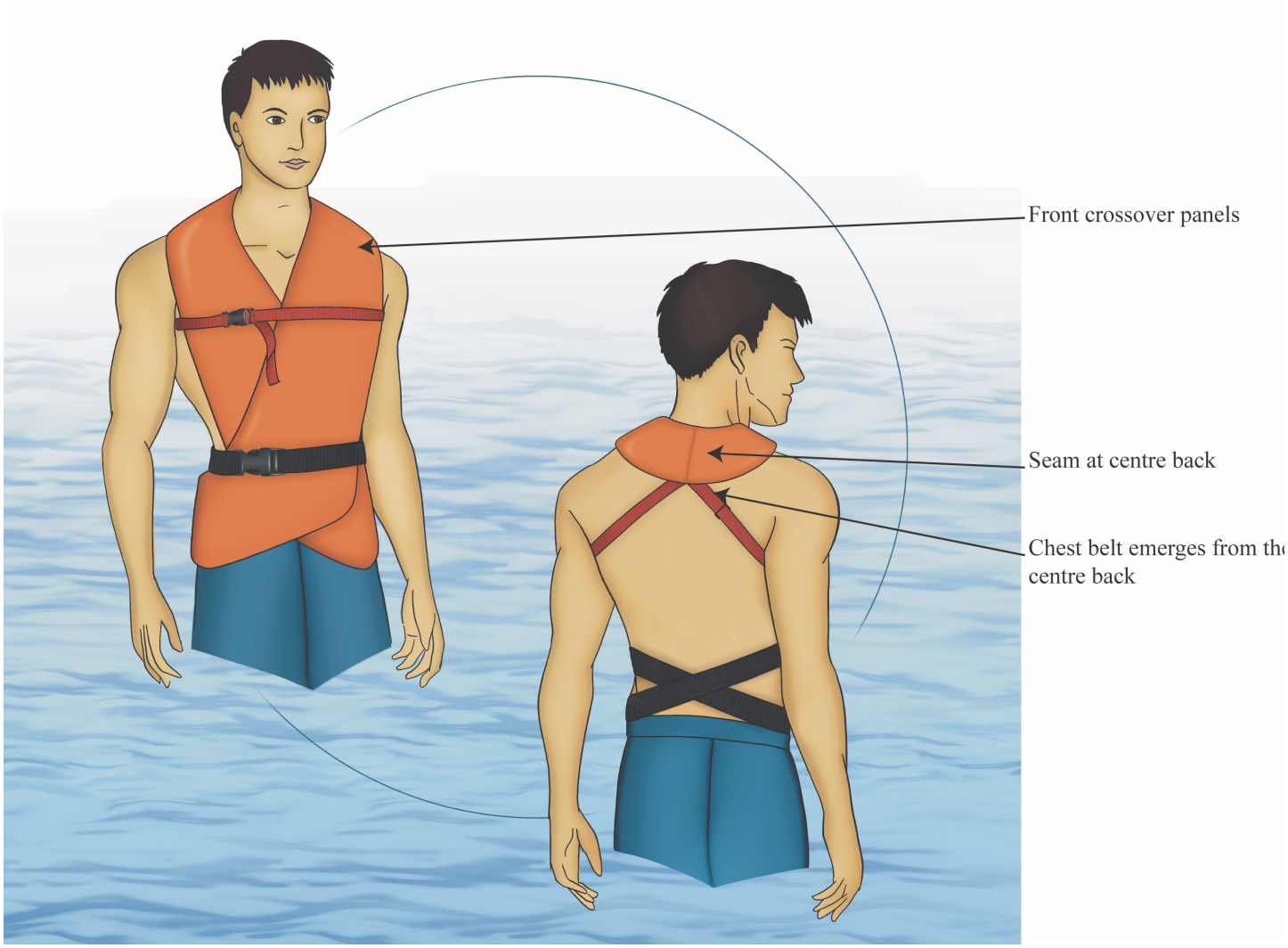


Figure 6.5: Crossover panel life jacket

6.2 Concept Screening and Reflection: The Cross Over Panel Life Jacket

Each of the concepts generated above are marked out of 5 points for each of the six design criteria established. The total score for each of the concepts out of 30 points is calculated (Appendix I). The reversible life jacket and crossover life jacket concepts scored 22 and 26 points each.

The concept with higher potential, to address the design criteria set-up prior to concept generation, was the crossover style concept inspired from the Indian traditional clothing sari and dhoti. This allowed for size adjustment of the life jacket by the movement of the panels. Generally, life jackets have size adjustment done by belts, zipper or hook n' loop. This life jacket concept can be adjusted to a wide range of non-gendered body anthropometry by crossover panels, sliding over each other to adjust the fit of the life jacket. This concept potentially addresses the major challenge in my research to make a life jacket that fits a wide size range of people as the size of the flood affected people can't be determined prior to search-and-rescue activity.

This crossover style concept aims to offer a wider range of movement to the wearer's arms without intercepting the rescue activities. A single buckle fastening mechanism is expected to reduce the donning and doffing time, and number of components compared to the current life jackets with three buckles. This concept, the crossover style, sliding panel life jacket was selected for further product development through physical prototyping or in fashion terminology sampling. The concept's initial objective was to shape the life jacket around the body in such a way that it fits all size ranges. Seven iterations of the crossover style life jacket concept were developed. Each of the developments will be discussed in the following section.

6.3 Prototyping Method

Patternmaking and construction are the primary techniques used to prototype apparel concepts. After developing a prototype, it is tested on a mannequin or a volunteer participant to check for issues like fit, comfort, range of motion possible to the wearer's limbs and shaping of the prototype to the wearer's body. This approach is like the iterative development of focused physical prototypes used in industrial design contexts (Ulrich and Eppinger 2012), and brings together learning and communication to develop design integration in a creative practice. I would like to mention here that my educational background is in Apparel Manufacturing and Fashion Innovation with no/little teaching of drawing/sketching. But, I use methods of descriptive writing, basic line drawings and convert them to garment patterns to visualise 3D form.

Digital methods of design and pattern development are increasingly used in 3D analysis on avatars (CLO software). Possible changes or refinements that will improve the usability of the prototype are noted and reflected upon.

Prototyping a life jacket requires several materials and components. These include a durable fabric as the outer layer, non-absorbent foam to provide buoyancy, fasteners like zippers, plastic buckles and hook n' loop, additional components include webbing straps, reflective tapes, metal harness, and tri-glides. An extensive range of fabrics, foams and other materials were sourced from New Zealand, India and China to understand the properties of materials available on the market and then selected appropriate materials for life jacket prototyping. The sourced materials include more than 100 fabric swatches, 40 foam samples, 3 zippers, 2 hook n' loop samples, 5 webbing straps and 3 reflective tape samples.

Among all the fabric swatches sourced, the Nylon oxford fabric was chosen for its high durability, tensile strength and high abrasion resistance. This fabric was described by the supplier as shower-proof (water-repellent but not waterproof) and is available in Citrus Yellow and Fluorescent Orange fabrics (suitable for life jackets for their high-visibility). The Nylon Oxford fabric has similar but better properties to the polyester fabric used to manufacture existing life jackets in India. The affordable price of the fabric and the supplier's close location to receive delivery also contributed to the reason for selecting this fabric to develop the life jacket prototypes of my research.

Of all the foam samples sourced, the Expanded polyethylene (EPE) from a New Zealand based supplier was chosen for its non-absorbent and light-weight properties. The EPE foam, three times less expensive than Ethylene-vinyl acetate (EVA) foam, is also used in the manufacture of existing Indian life jacket products. Other materials including hook n' loop, plastic buckles, webbing straps, elastic were sourced from local suppliers in New Zealand and online suppliers in China through the Ali Express website.

The materials used to prototype the seven iterations of the crossover style concept are listed in Appendix J (see Table J1).

6.4 Design Development Cross-over Panel Life Jacket

Design developments of the cross over panel design initially focused on: developing an effective donning and doffing process, achieving a snug fit for a broad range of sizes, pattern shape for comfort and movement, flotation head support, and integration with Indian dress conventions.

The first variation of the crossover style life jacket is placed over the head. The left panel is adjusted for fit in relation to the right panel and pressed down to engage hook and loop fastenings, the waist-belt is wrapped around and fastened at the front with ladder lock buckle (see Fig 6.6).

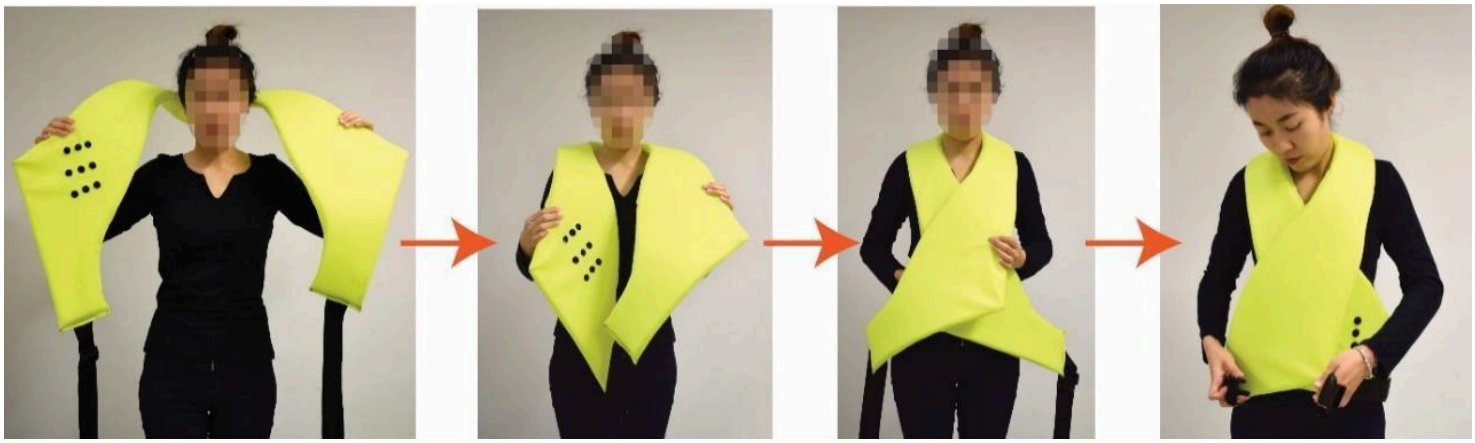


Figure 6.6: Donning method of crossover style life jacket iteration 1

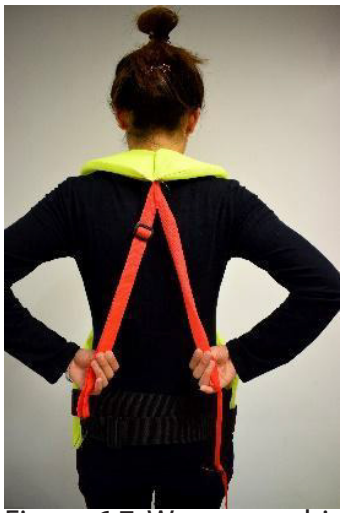


Figure 6.7: Wearer reaching for the chest belt.

The above donning method requires passing the belts around the back and fastening them at the front, which was reported as feeling awkward by the wearer. This was followed by reaching behind to locate the unseen chest belt providing a second awkward process (see Figure 6.7).

The donning approach was then modified to be worn over the head like a t-shirt (Figure 6.8) with adjustable webbing belts on either side that slide the panels over each other when tightening the life jacket to the wearer's body.

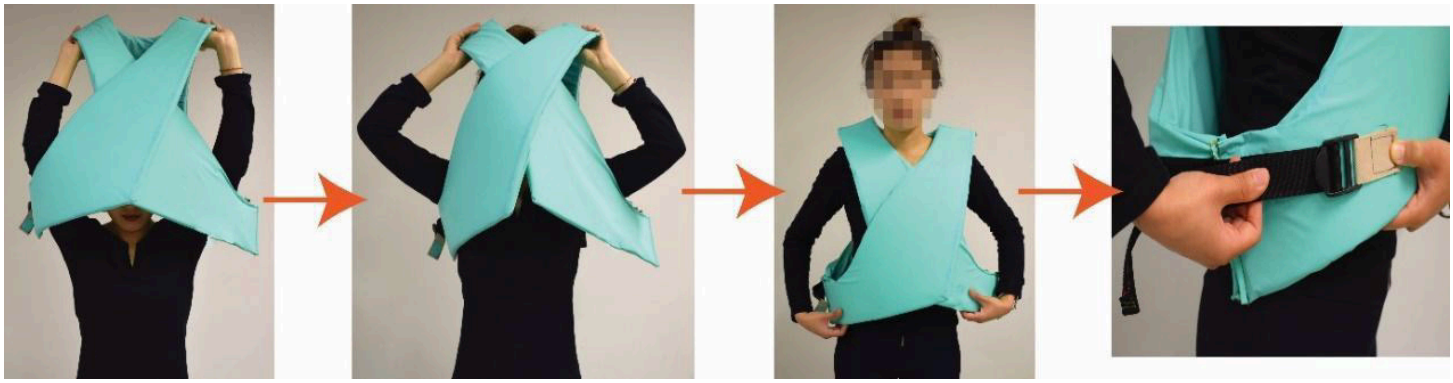


Figure 6.8: Donning method of crossover style life jacket over the head

Development of pattern shape and seam location provided comfort and ease of panel movement. The first crossover style life jacket iteration is modified into a single length pattern with no joining seam at the back (see Figure 6.9). This was done to give a consistent flexibility in the wrapping motion around the body, provide strength at centre back, comfort and efficient manufacture, and was used for all subsequent iterations.

Figure 6.9: Comparison of seamed joint at neck and continuous pattern providing flexibility, easier movement and comfort.

The length of the initial cross over panel life jacket is down to the hip level. Shortening the length to waist level enabled easier body waist bend, an advantage for active emergency responders. Fig 6.10 shows the reduction in the height of the life jacket through subsequent variations.

Figure 6.10: Reduction of life jacket height in subsequent iterations.

Hook and loop fasteners were trialled to provide panel adjustment for a range of sizes and to keep the customised foam panel relationship intact (see Figure 6.11). The hook and loop fasteners allow for the crossover panels to be adjusted in relation to each other, and the requirements of fit but once connected are locked in place. This became an issue later in the development stage when sliding panels were integral to fit and adjustment.

Figure 6.11: Hook and Loop fasteners stitched between the crossover panels

Developing the pattern shape needed additional buoyancy (IS-6685 recommends minimum buoyancy of 100 Newton for an adult life jacket) and supportive head flotation features. Initially, the neckline was extended into a head support, to which side straps filled with foam are attached, and finally modified into a full back panel to provide sufficient levels of buoyancy (Fig 6.12).

Figure 6.12: Modification of back panel across variations

Additional features such as rescue handles were sewn on the upper chest level to aid with pulling the wearer out of water (Figure 6.13).

Figure 6.13: Lifting handles to aid with pulling the wearer out of water

Traditionally crotch straps are used to stop life jackets from riding up and slipping off when immersed. Traditional Indian clothing such as the sari and the dhoti are difficult at best to fasten a crotch strap, and its adjustment is problematic. In response a safety harness was incorporated into one of the variations to stop the life jacket from riding up in water. The safety harness is attached to the centre back under the head support, webbing goes under the armpit to hold the life jacket down in water (see Figure 6.14).

Figure 6.14: Back-view of the life jacket variation showing the safety harness under the head support.

The seven variations of the crossover panel concept discussed are presented in Table 6.1 along with design details and features and front and back photographs of the life jacket prototypes.

Table 6.1: Seven life jacket variations

Life Jacket Variations	Design Details & Features
Variation 1:	
	• Height of the life jacket is shoulder to hip. • Seam at the centre back of the collar. • Chest belt from the centre back to under armpit. • Adjustment belt requires wrapping around the body.
Variation 2:	
	• One piece panel pattern. • Foam thickness is reduced by half around the neck for comfort. • Hook and Loop fasteners between panels to keep the foam panel intact.
Variation 3:	
	• One piece panel pattern. • Height of the life jacket is shoulder to waist. • Rescue handles on the upper chest level for pulling the wearer out of water. • Pull strap at the end of floating head support.
Variation 4:	
	• One piece panel pattern. • Height of the life jacket is shoulder to waist. • Integral safety harness under armpit over shoulder. • Pull strap at the end of floating head support. • Adjustment buckles are placed on the centre of left panels to improve location position, leverage and adjustment range.

Variation 5:

- Height of the life jacket is shoulder to waist.
- Crossover panels without collar or head support.
- Adjustment buckles attached to both front panel sides.
- Full length foam back panel.
- Hook n Loop fastener on the back panel to secure webbing straps.

Variation 6:

- Height of the life jacket is shoulder to waist.
- Foam widened at the chest level to increase buoyancy.
- Side straps extend from the back neck and fasten at the centre front using a plastic buckle.

Variation 7:

- Height of the life jacket is shoulder to waist.
- Adjustable straps on the shoulder and around the waist.
- Minimal foam to increase adjustability to a large size range, and provide greater range of movement to the wearer's arms.

6.5 Usability Testing - Dryland Trial 1

The crossover style sliding panel life jacket prototypes, along with a selection of existing production life jackets were evaluated through wear-trials by three participants in a dryland (non-aquatic) environment. The purpose was to evaluate the selected production life jackets against the developed variations. The participants were asked to evaluate each of the trialled life jackets in terms of overall comfort, ease of donning and doffing the life jackets, fit in the chest area and waist area, freedom of movement to arms and bulkiness of the life jacket.

Three female participants within the age range of 21 to 41 years volunteered for the wear-trial. The participants usefully represented a broad anthropometric range in terms of chest girth and height (see Table 6.2). The request for volunteers did not attract male participation for this trial.

Table 6.2: Dryland trial 1 participants chest and height measurements

Adult Female	Chest Girth	Height
Participant 1	85.09 cm	160 cm
Participant 2	96.52 cm	168 cm
Participant 3	111.76 cm	152 cm

A total of ten life jackets were evaluated in this wear-trial study. Three life jackets are currently existing models in the market, two of which are deployed by the NDRF personnel for flood rescue while the third model is an aquatic sports life jacket, added to gain the perspective of life jackets made for leisure activities. These three life jackets are labelled as E1, E2 and E3 respectively. Seven life jackets are the crossover style variations previously discussed which are labelled as V1, V2, V3, V4, V5, V6, and V7 respectively. Reference images of the ten life jackets are shown in Figures 6.15 and 6.16. The images of all trialled life jackets by the three participants from all sides are presented in Appendix K.

Figure 6.15: Existing life jackets models trialled in Dryland Trial 1

Figure 6.16: Crossover life jacket prototypes trialled in Dryland Trial 1

6.5.1 Evaluation Process

Each of the ten life jackets were trialled by all three participants with exception of V5 and V6 life jackets which were trialled by two participants. Participants were asked to donn the life jackets in a designated space without any hindrances, tighten all straps by themselves and the following aspects were checked by the researcher: sufficient strap length, tension and fit.

Each subject was asked to perform several types of body movements in the standing position. The movements include;

- Shoulder joint flexion, extension, hyperextension, adduction, abduction, and circumduction
- Waist flexion and extension

Each subject is asked to do the following tasks:

- Sit on a chair
- Imitate a rowing motion with a stick
- Stand and walk 10m

After performing the tasks, the participants were asked to rate the life jackets based on six factors – intuitiveness, ease of donning, comfort, fit, adjustability, bulkiness. Rating is given on a scale of 1 to 3 (1 for Bad/Difficult/Bulky; 2 for Good/Easy/Moderate; 3 for Very good/Quick/Not bulky). Participants were encouraged to describe the reasons for unfavourable aspects in the life jackets.

List of questions for the participants:

EASE OF DONN & DOFF

- How intuitive/easy was it to Figure out how to wear the life jacket?
- How quick are you able to donn and doff the life jacket?
- If it takes time, which part do you have problems fastening or donning the life jacket?

COMFORT

- How comfortable are you to rotate your head to the sides?
- How comfortable are you to rotate your arms in circular and horizontal motions?
- Do you feel the life jacket cuts under arm-pits or rubs against the skin?
- How much pressure/strain does the life jacket exert on your chest area?

FIT

- How well does the life jacket fit you? If not, where does it not fit well?
- Is the life jacket adjustable to your size?
- How easy is it to adjust the life jacket to your size?

VOLUME

- How bulky do you feel the life jacket is?

6.5.2 Wear-Trial Responses of Participants

The responses to the survey questions by each of the participants are presented in Appendix K. Overall satisfaction rating of the participants for each life jacket is derived from the average of six factors. The overall satisfaction ratings for the existing and crossover style life jacket prototypes are presented in Table 6.4. The life jacket prototypes with "overall satisfaction = 3" are considered as the most popular models. V3 life jacket (highlighted in yellow in table 10) is the only prototype to receive "overall satisfaction = 3" from all trialling participants.

Table 6.3: Overall satisfaction rating of the participants

	E1	E2	E3	V1	V2	V3	V4	V5	V6	V7
Participant 1	1	1	3	3	3	3	1	3	3	2
Participant 2	2	1	3	2	2	3	2	3	-	2
Participant 3	2	1	1	3	2	3	1	-	3	2
Average Rating	1.7	1	2.3	2.7	2.3	3	1.3	3	3	2

Among the existing life jackets, Participant 1 and 2 favoured the E3 (aquatic sports life jacket) to the other two designs. E3 model is described to be comfortable, fitting well, easily adjustable, and less bulky. Participant 3 didn't favour any of the existing life jacket models to full satisfaction. The E1 model was moderately favoured due to its comfort and fit. E2 is described as uncomfortable, causing irritation around the neck, whereas E3 was too small for the participant's size (see Figure 6.17). However, E3 (aquatic sports) had observable benefits in the manner it was donned. The side access provided an easy orientation, access directly to an arm hole and head opening. The wearers essentially 'slot' into the product, have quick arm and head location and closing the open side forms the second arm aperture.

Figure 6.17: E3 (aquatic sports) life jacket is too small for participant 3 to properly donn

The most popular life jacket prototypes in the dryland trial 1 are presented in Table 6.4 followed by a discussion on the outcomes of the dryland trial 1 in Table 6.5.

Table 6.4: Most popular life jacket prototypes in the Dryland Trial 1

Variation	Image	Favoured Features
V3		Only the V3 life jacket was unanimously favoured by all three participants. All participants described this prototype as easy to put on once they understand how the crossover style works, fits snug to their body while making them feel secure, easily adjustable by pulling the straps sideways and less bulky than other life jackets.
V5		V5 life jacket was trialled and scored highly by two participants only. The V5 life jacket scored high on all factors by the two participants who tried it. They described it to be a very intuitive design, comfortable around the neck and arms, fits well, easily adjustable, and not bulky at all.
V6		V6 life jacket scored high on 4 factors by the two participants who tried it. They described it to be very intuitive, comfortable around the neck and arms, secure on the back, quick to donn, and less bulky. The participants mentioned that the 'ladder lock buckles' connecting the front and back panels makes it easy and quick to donn the life jacket.

Table 6.5: Discussing dryland trial 1 outcomes in relation to design criteria

Design Criteria	Outcomes from Dryland Trial 1
Comfort	The participants felt comfortable to perform hand movements in all crossover style iterations. The bending, sitting and rowing actions are comfortable to perform in the life jackets with shortened height. Participant 2 commented on V2 (in which the life jacket height is down to the hip-level): “Very comfortable. No irritation. Can sit and bend but life jacket rides up when bending or sitting.” The participants also favoured the life jacket iterations with a back panel. Participant 1: “I like the back design of this life jacket. It feels supportive on my back.”
Fit	The single buckle locking by pulling the straps sideways is highly favoured for its quick donning time. Participant 1 commented: “The V3 life jacket is well adjustable by pulling the open-ended straps to side-ways. But the two buckles on the front are confusing. The positioning of the buckles on the front is better than on the sides. It keeps the foam panels adhered to the body.”
Ease of Donn & Doff	All participants described the crossover style as easy to put on once they understand how the crossover style works. Participant 2 commented: “I could easily figure that I must wear it over the top. It looks like a hand-bag style. I like the foam panels on the back. They make me feel secure.”

6.6 Refinement 1

The participants of the Dryland Trial 1 rated the V3, V5 and V6 higher than the other life jacket designs. Favoured design features from these three life jacket prototypes including a single buckle for quick and easy adjustment, wider back panel, and the crossover panel style are incorporated into the design aims for the next stage of prototyping. In addition, the ‘slot’ side access feature from E3 was included. This new prototype is termed ‘Refinement 1’ and is trialled and refined through usability and wear-trial testing. This section presents the further design developments to the crossover style sliding panel concept, showcasing how ‘Refinement 1’ is modified and developed into an integrated prototype, ‘slot n slide’ panel life jacket, for the subsequent dryland trial.

6.6.1 Prototyping Method

Like the variations developed in the previous section, patternmaking and construction techniques are used to prototype the refinements. Laser cutting and 3D printing methods are also employed to assist with the prototyping process in this stage. Each of the refinements is trialled by a female participant who was available to volunteer all through the design process. Each refinement is checked for issues with ease of donning and doffing, fit, adjustability, comfort, and range of motion to the wearer's limbs. Modifications are made into the refinements based on the participant's feedback, and reflection on usability aspects of the prototype.

6.6.2 Design Development Refinement 1

A range of design development was trialled across Refinement 1, initially validating the 'slot' entry feature compared to an alternative simple 'pull-over' approach. Refinement 1 moved to develop comfort, the capacity to achieve one-size-fits-all, sufficient flotation in line with standards, and single buckle adjustment enhancing usability.

Effective donning to provide fit, and stability of cross over panels prior to adjustment.

The participants in the dryland trial 1 favoured two life jacket concepts that are worn over the head without an opening and then fastened by pulling the straps sideways and then buckled at the centre front. The life jacket prototype didn't have an opening on any side and is pulled over the head like a T-shirt (see Figure 6.18). However, this donning method can be inconvenient for a person with a larger anthropometry to pull down the life jacket over the head without support from another person.

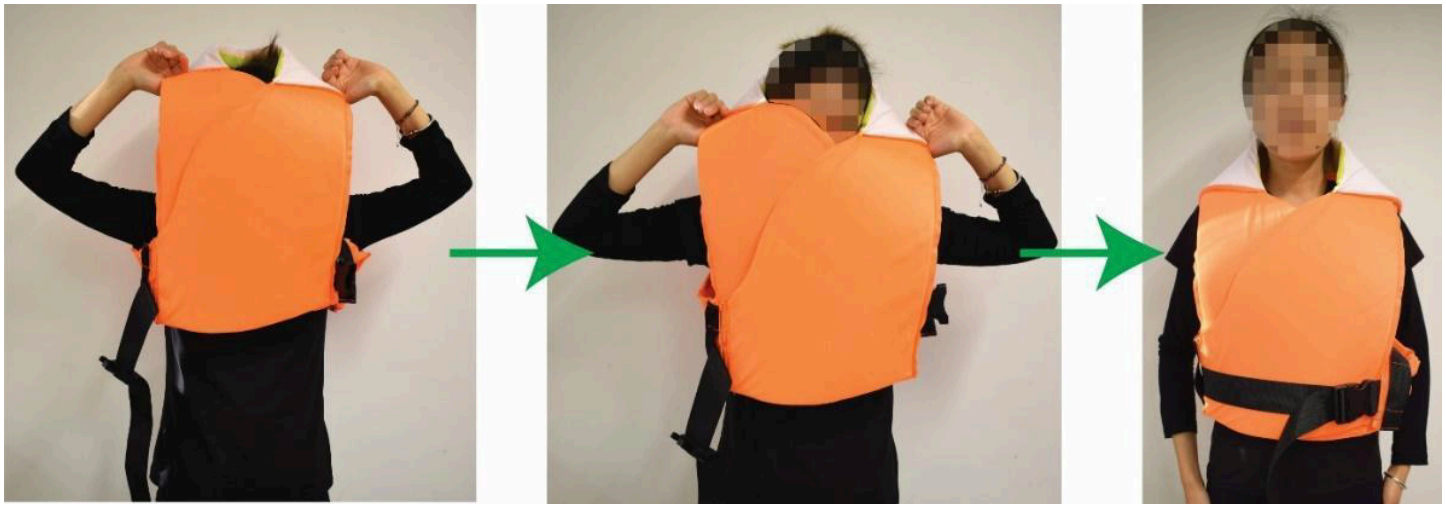


Figure 6.18: Donning life jacket over the head

This donning method is modified to be worn by sliding the right hand first and worn over the head. The right-hand side entry into the life jacket was found to be preferred by the participant in comparison to wearing it over the head (see Figure 6.19).

Figure 6.19: Donning life jacket using 'slot' side entry

Considerations of pattern shape in respect to comfort for movement.

All 3 participants in the Dryland Trial 1 mentioned that the addition of a back panel made them feel more secure in the coverage provided by the life jacket around their body. The back-panel design with side straps is modified initially by increasing the width of the side straps and then enlarged into a full back panel. Figure 6.20 shows the modifications in the back panel.

Figure 6.20: Modifications to back panel

The width of the back panel is enlarged to cover a larger area of the body while also not obstructing head and arms movement. The life jacket refinement with fuller back panel provided a contoured fit around the body and felt secure with increased foam area covering the body.

Adjustable features for a one-size fits all solution

Initially side straps are joined with elastic panels to accommodate a more extensive size range around the waist (see Figure 6.21). A trialling participant (female with a chest girth measurement of 83cm), found that the length of the side panel and elastic were much more than required resulting in a loose fit.

Figure 6.21: Elastic panel joined to side straps

In response, shaped fabric panels are placed on either side of the life jacket (see Figure 6.22) to accommodate wearers with a larger chest and waist girth. When trialled on a participant with smaller chest girth, fabric panels created less bulk in comparison to elastic, when adjusted.

Figure 6.22: Fabric panel on the right-side

Hook n' loop fasteners are placed on the left side as a preliminary locking mechanism between the left-side fabric panel and front crossover panel (Figure 6.23). This locates the elements of the life jacket in relation to one another prior to final belt adjustment.

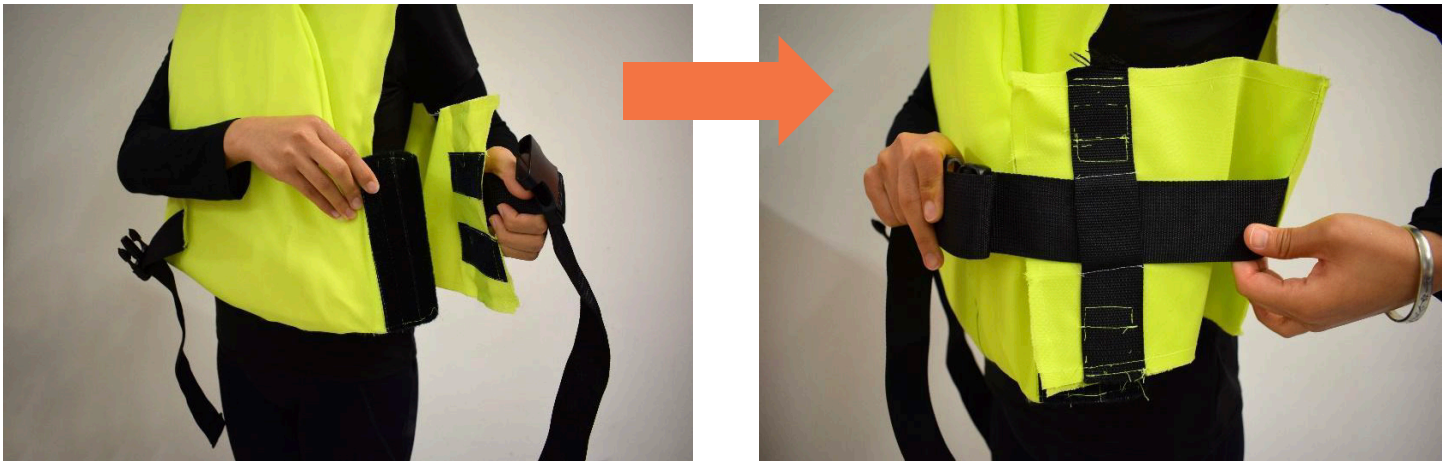


Figure 6.23: Hook n Loop between left-side fabric panels and front crossover panel

Pattern shape development to provide sufficient flotation and head support.

In place of the head support, a collar is added into the refinements to provide additional buoyancy to the wearer's head. The size and shape of the collars in the initial refinements felt too wide in a raised position at the shoulder. In the subsequent refinements it is shortened and contoured to stay upright around the wearer's neck. Figure 6.24 presents the modification of the collar shapes from flat and wide to short and contoured.

Figure 6.24: Collar modifications in refinements

Single-buckle fastening for quick donning and fit adjustment.

The life jacket is fastened around the body by pulling the webbing straps on either side and locked at the front using a plastic buckle (see Figure 6.25). During this action, the webbing straps pull the back panel closer to the front panels. The trialling participant mentioned that pulling the webbing straps improved the fit of the life jacket in the back but had no impact in sliding the crossover panels. This was a significant insight from prototyping trials, as the benefit of a crossover and sliding panel was key to achieving a one-size-fits-all objective.

Figure 6.25: Initial waist-belt fastening method

By trimming foam sections in the crossover panels and passing the webbing straps through the sections. The webbing strap on the right-side is passed through the crossover panels and then fastened with the left-side strap using a plastic buckle (see Figure 6.26).

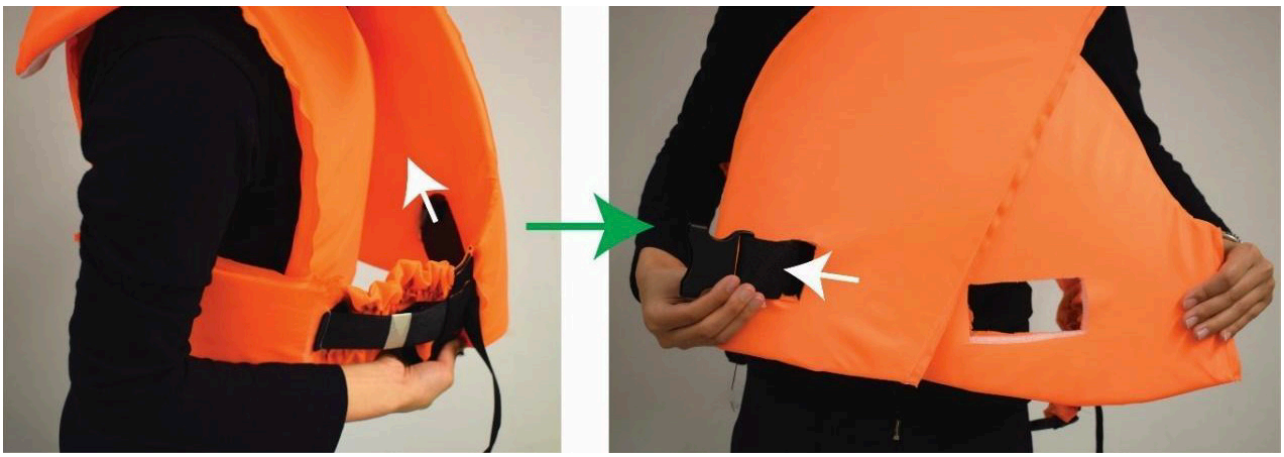


Figure 6.26: Foam sections are cut in the crossover panels to guide the webbing straps

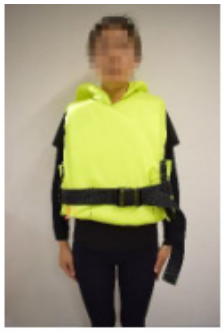
The desired slide effect was not sufficiently achieved, and to assist the webbing straps to slide through the crossover foam panels, a two-piece guide was printed on a 3D printer in Fablab, a digital fabrication lab at the Massey University campus in Wellington.

The material used to print the guide is polylactic acid (PLA), a biodegradable thermoplastic with a higher strength and stiffness and suitable for this prototyping process. The blue colour filament is chosen for its contrast to the Fluro Yellow Nylon outer fabric of the life jacket. Two sets of guides are inserted, one into each of the crossover foam panels, and the webbing strap is then passed through the guides (see Figure 6.27). The plastic guides effectively operate as pulley blocks, moving closer to each other as the webbing belt adjustment is pulled in, until they are directly on top of each other (block-to-block) at their tightest adjustment. Conversely, for larger size the belt adjustment releases, and the guides slide away from each other. This improves the slide performance as the plastic inserts locate the webbing belt in relation to the top and bottom panels, sliding the upper panel across and pulling down onto of the bottom panel in adjustment.

Figure 6.27: 3D printed guides inserted into the crossover front panels; Webbing strap is passed through the guides in the under and upper crossover panels

The developments discussed in the above section are presented in Table 6.6 along with key design features and front and back photographs of the life jacket prototypes.

Table 6.6: Refinement 1: Developments

Design Features	Front & Back View
R1: Front Cross Over Panels	
• Side straps with elasticated panels. • Wide collar. • Enlarged back panel. • Donned over the head like a T-shirt.	 
R2: Front Cross Over Panels	
• Enlarged back panel. • Wide collar. • Donned through right-hand entry and over the head.	 
R3: Front Crossover Panels	
• Side straps from the back are extended with elastic panels and fastened at the centre front using a plastic buckle. • Hook n Loop fastener between front crossover panels.	 
R4: Front Cross Over Panels	
• Enlarged back panel and right panels on front side. • Fabric panel with Hook n Loop fastener on left side. • Webbing straps pass through a slot in the foam panel. • Shortened collar	 
R5: Front Cross Over Panels	
• Enlarged back panel • Fabric panels on the right side. • Fabric panel with Hook n Loop fastener on left side. • Webbing straps pass through 3D printed guides. • Contoured collar	 

6.6.3 Summary: Design Development Refinement 1 'Slot n Slide' Panel Life Jacket

The final iteration of Refinement 1, incorporating plastic guides to enhance the sliding panel aspect, and panel alignment as it pulls down in adjustment, provided a range of potential benefits. These included: accommodation of a broad range of sizes, 'slot' access usability, single belt adjustment, alignment with cultural dress conventions.

The final iteration in this development was consequently selected for evaluation through user trials with multiple participants (see Figure 6.28). This life jacket prototype is made using a single-cut foam pattern that includes both the front crossover panels and back panel. Thickness of foam is kept at 3cm across the life jacket (approximating to the thickness in existing life jacket designs) to provide sufficient buoyancy. Foam thickness is reduced to 1cm around the neck and shoulder in response to the discomfort experienced by participants in dryland trial 1 while donning E2 (existing life jacket with bulky collar).

Figure 6.28: 'Slot n Slide' panel life jacket

6.7 Usability Testing - Dryland Trial 2

The purpose of conducting the dryland wear-trial was to evaluate the final iteration of Refinement 1: 'Slot n Slide' panel life jacket gaining understanding of usability and functional features and the ability to respond through design, prior to moving to a wet environment. The participants of this study were asked to trial an existing life jacket (E1), and Refinement 1: 'Slot n Slide' panel life jacket (R5) and evaluate the prototype in terms of; ease of donning and doffing the life jacket, comfort, fitting and adjustability, and bulkiness.

Ten participants (Male = 5 and Female = 5) within the age range of 20 to 55 years volunteered to participate in this trial. Each of the ten participants in the Dryland Trial 2 were coded as Participant 1 (P1), Participant (P2) and so on up to Participant (P10), in the order in which they were trialled. The participants' details including their gender, age, chest and height measurements are detailed in Appendix L.

The 10 participants who trialled for this study corresponded to a broader size range in terms of their chest girth and height. The lowest and highest measurements of the participants' chest girth (measured over the bust) are 77cm and 118cm respectively, while that of the lowest and highest measurements of the participants' height (measured from the bottom of the footwear to the top of the head) are 157cm and 189cm respectively. The participants' chest and height measurements are plotted on a graph to visualise the multiple combinations of chest and height measurements selected for this trial. It can be inferred from the graph (see Figure 6.29) that the difference between the lowest and highest measurements of the chest is 41cm, and the difference between the lowest and highest values of height is 32cm. An objective of this trial is to experience end user fitment across a broad range of sizes (chest girth) with Refinement 5 to validate the potential of a one-size-fits-all approach.

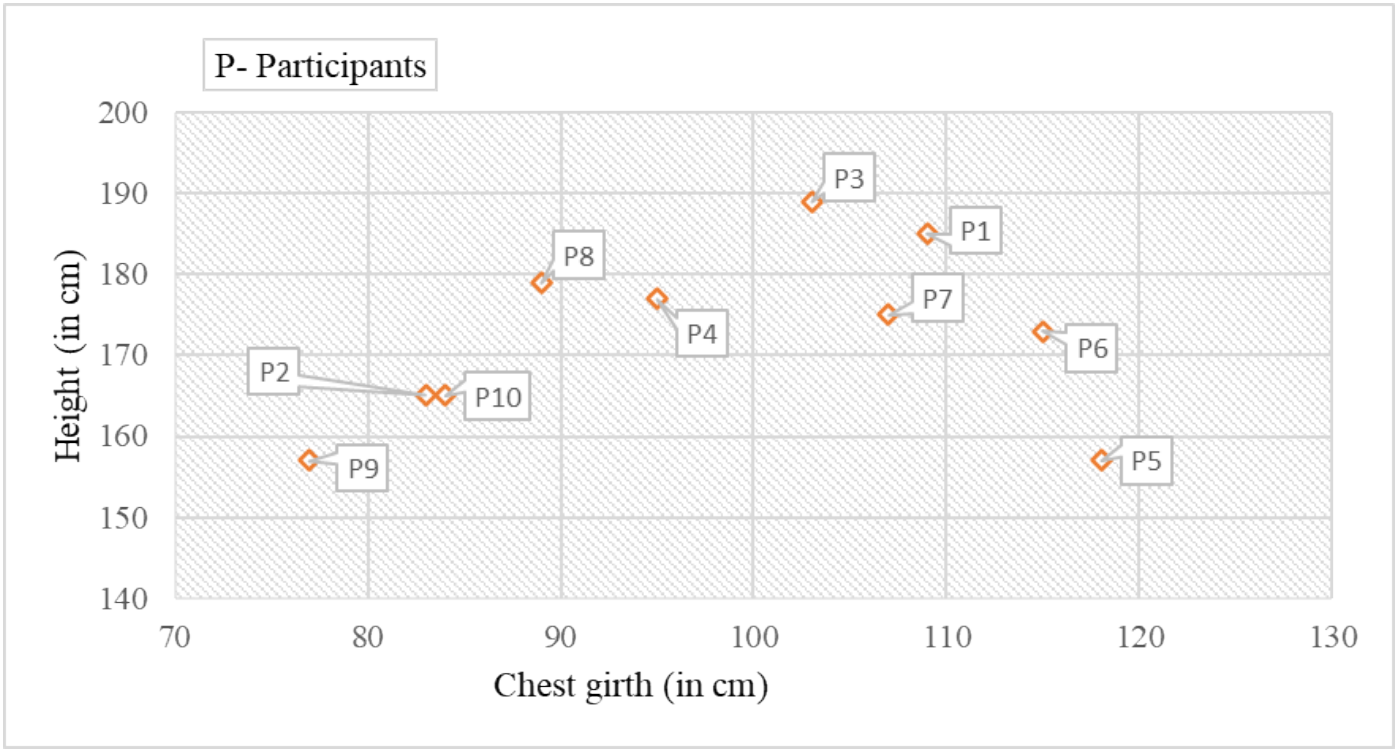


Figure 6.29: Dryland trial 2 (D2) - Participant Anthropometry Variation

One existing life jacket (E1) and Refinement 5 (R5) life jacket prototype were trialled by each of the participants (see Figure 6.30), and the participants were asked to fill a questionnaire to evaluate R5 life jacket with a comparative assessment made against E1. The existing life jacket used for this trial is the life jacket without a collar. This life jacket is the most preferred option by Indian emergency responders who participated in focus groups and questionnaires and hence chosen as a comparative baseline for the participants to evaluate the features of the R5 life jacket prototype.

Figure 6.30: Life jackets trialled in dryland trial 2

The photographs (front, back, left-side and right-side view) of all participants donning the R5 life jacket are presented in Appendix L.

6.7.1 Evaluation Process

The trial was carried out in a studio. The participants wore everyday clothing: shirts, t-shirts, pants, dresses, jumpers and jackets. First participants were asked to donn the existing life jacket (E1) in a designated space without any hindrances, tighten all straps by themselves and the following aspects were checked by the researcher; sufficient strap length, pressure exerted by the life jacket on the participant's body and fit.

While the participants donned the life jackets, the researcher measured the time taken by each participant to donn both life jackets and time taken to remove or doff the life jackets. The donning time measured starts from the moment the participant touches a given life jacket and measures the time taken to unlock fasteners, put the life jacket on, secure all fasteners and signal the researcher with a thumbs up that they are satisfied with the fit of the life jacket. On the other hand, doffing time is the time taken by the participant to unlock all fasteners of the worn life jacket, remove the life jacket and place it on a table in front of them.

After donning the existing life jacket E1, each subject was asked to perform several types of body movements in the standing position. The movements include;

- Swing the arms at shoulder level from side to side.
- Rotate the arms forward and backward in circular motion for five times each way.
- Rotate the head squarely over the shoulders in clockwise and anticlockwise direction 3 times.
- Bend and lift a 3Kg object from the floor to a standing position and place it back on the floor.

Secondly each participant is asked to do the following tasks:

- Stand and walk 10m forward.
- Sit on a chair upright. Lean back to a relaxed position.
- Imitate a rowing motion with a stick.
- Stand up and remove the life jacket.

After performing the above tasks, the participants were asked to remove the E1. Then the participants were asked to perform the same set of tasks mentioned above while the researcher noted the time taken to donn and doff R5.

Based on their experience with trialling the two life jackets, the participants were asked to fill-in a questionnaire containing Likert scale questions to rate various parameters of the R5. The questionnaire included four major sections: Intuitiveness, Comfort, Fit & Adjustability, and Volume. Each section had multiple questions asking the participants to rate a given parameter on a scale of 1 to 5 (1 for lowest rating; and 5 for highest rating). Furthermore, participants were encouraged to subjectively describe the reasons for unfavourable parameters in the life jacket.

List of questions for the participants:

INTUITIVENESS

- How intuitive/easy was it to Figure out how to wear the life jacket?
- How intuitive/easy was it to remove the life jacket?
- If it takes time, which part do you have a problem wearing or removing the life jacket?

COMFORT

- How comfortable is your torso while wearing the life jacket?
- How comfortable are you to rotate your head?
- How comfortable are you to rotate your arms in circular and horizontal motions?
- How comfortable are you to sit and stand while wearing the life jacket?
- How comfortable are you to bend forward and pick up an object while wearing the life jacket?
- How comfortable are you while performing a rowing action with the life jacket on?
- Do you feel the life jacket cuts under arm-pits or rubs against the skin?

FIT

- How well does the life jacket fits you? If not, where does it not fit well?
- How easy is it to adjust the life jacket to your size?

VOLUME

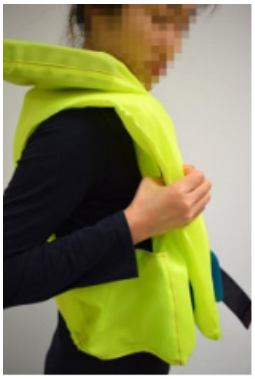
- How bulky do you feel the life jacket is?

6.7.2 Wear - trial Responses: R5 Assessment

The participants' responses to the Likert-scale questions (ranked 1-5, 1 indicates lowest rating and 5 indicates highest) are presented in the form of tables. Inferences are made on the rating for each parameter and the qualitative responses by the participants are explained alongside where necessary. Full responses of the questionnaire by each of the participants are presented in Appendix L.

The outcomes of the Dryland Trial 2 based on the feedback from the trialling participants is presented in Table 6.7 in relation to design criteria.

Table 6.7: Discussing Dryland Trial 2 outcomes in relation to Design Criteria and R5

Design Criteria	Discussion R5
Comfort	The overall rating by the participants for the parameters 'comfort to head and arms movement, sitting/standing and bending tasks' is above 4 (inferred as comfortable to very comfortable). 'Comfort around the torso and during rowing action' are rated 3.8 (inferred as so-so). Majority of the participants mentioned that the foam in the life jacket is hard and pressed on the chest when fastened tightly.  Additionally, Participant 3, Participant 8, and Participant 10 mentioned that the front crossover panels obstruct rowing action of arms at the shoulder. 
Ease of Donn & Doff	The overall rating by the participants for the parameter 'intuitiveness to wear' is 3.2 (inferred as so-so) and 'intuitiveness to doff' is 4.2 (inferred as good). Majority of the participants struggled to find the correct way to donn the life jacket. This is also reflected in the time taken to donn the life jacket. On average the participants took 43.9 seconds to donn 'Refinement 5' (four seconds more than the average time to donn E1) even though R5 has less fasteners compared to E1 which has a zipper and 3 buckles and straps. Almost all participants struggled to find the right way of donning the life jacket. Participant 2 commented: "I was a little bit confused about how to wear it. I only could figure out I needed to unlock the buckle. After unlocking the buckle, it took me some time to find out how to enter the life jacket."  The colour of all the panels being the same could be a major reason for the participants not figuring the right way to donn. Also, the participants mentioned that they had never seen a life jacket with crossover panels.

Fit	The overall rating for the fitting parameter is 3.6 (inferred as so-so fit), adjustability is 4.2 (inferred as easily adjustable) and bulkiness is 4 (inferred as slightly bulky). Participants mentioned that the hardness of foam panels make the life jacket stay flat on the body rather than contoured to the body shape. The 1cm deep perforated lines in the foam using laser cutting has failed to shape the foam panels to the wearer's body shape.  Participant 5 and Participant 6 (both have the largest chest girth among all participants) commented: "The left-side panel is hard to reach."

Overall experience of the participants with R5

In general, all participants preferred the R5 life jacket to E1 for the novel sliding panels design, range of movement for the arms to perform tasks, snug fit around the body and adjustability to a broader range of anthropometry.

"I felt that my back was very supported by the back shape of the life jacket. But my chest was pressed by the jacket. The jacket fits me well and is not bulky. I prefer the new jacket to the old one".

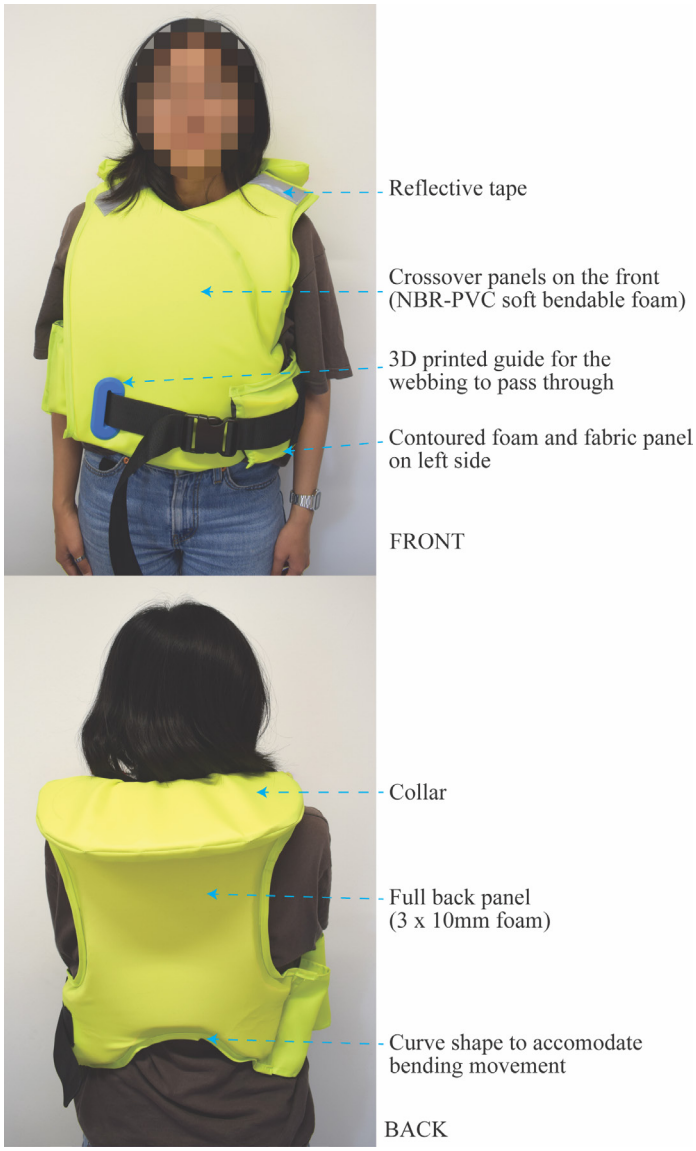
- Participant 2

"I felt very secure in the new life jacket, and it doesn't ride up easily when I'm sitting, bending or rowing".

- Participant 9

All participants desired changes in the life jacket to improve the intuitive donning mechanism, contoured fit around the sides, softer foam that can shape to the body, and increased mobility at the shoulder.

6.7.3 Refinement 6 (R6)



Feedback from the participants of Dryland Trial 2 was reflected upon and modifications were made accordingly. A new refinement 'R6' (see Figure 6.31) is made with PVC–NBR foam (Polyvinyl chloride – Nitrile-butadiene rubber), purchased from Texspec NZ Ltd, a New Zealand based supplier for foam and textile materials like Hook n Loop, sewing threads, webbing and elastic. The PVC–NBR foam (coded as WH-201S by Texspec NZ Ltd) is a lightweight, soft, and durable closed-cell (waterproof) foam. The price of the foam per sheet (210cm x 140cm x 1cm) is NZD $64 at the time of purchase, which is 3 times more expensive than the EPE foam. Nevertheless, this foam is preferable for a softer feel and ability to contour around the wearer's body. The WH-201S foam is also used by Hutchwilco, a New Zealand based popular life jacket brand and manufacturer, and hence the suitability of this foam for aquatic use is presumed.

Figure 6.31: Refinement 6 - Front and Back

The left-side panel is extended from the back and contoured around the body to overlap on the crossover panels at the front (see Figure 6.32). This is made in response to the participants' (with large chest girth) comment that the left-side panel is not in reach for easy fastening. Similar to Refinement 5, a plain fabric panel is placed on the right-side (see Figure 6.33) for wider adjustability and 3D printed grommets are inserted into the crossover panels for the waist-belt to pass through.

Figure 6.32: Left-side panel with foam

Figure 6.33: Right-side fabric panel (no foam)

6.8 Usability Testing - Dryland Trial 3

The purpose of doing this dryland wear-trial was to evaluate the final iteration of Refinement 1: 'Slot n Slide' panel life jacket gaining understanding of usability and functional features and the ability to respond through design, prior to moving to a wet environment.

Dryland Trial 3 was similar in process to Dryland Trial 2, however resolution of the design and the functional features has been developed and this trial provided an opportunity to check effects of changing foam types and eliminating hook n' loop fastening, that provided challenges for larger girth participants having to reach behind and locate the extension from the back panel on their left panel.

Five participants from the Dryland Trial 2 returned to participate in this trial. The returning participants were asked to trial only the R6, whereas new participants were asked to trial both E1 and R6 (see Figure 3.4). All participants were asked to evaluate the R6 prototype in terms of ease of donning and doffing, comfort, fitting and adjustability, and bulkiness of the life jacket.

E1 R6

Figure 6.34: Life jackets trialled in Dryland trial 3

Seventeen participants (Male = 9 and Female = 8) within the age range of 20 to 55 years volunteered to participate in this trial. Each of the seventeen participants were coded as P1, P2, and so on up to P17 respectively in the order in which they were trialled. The participants' details including their gender, age, chest and height measurements are detailed in Appendix M.

The 17 participants corresponded to a much broader size range in terms of their chest girth and height compared to the previous trial. The lowest and highest measurements of the participants' chest girth (measured over the bust) are 76cm and 128cm respectively, while that of the lowest and highest participants' height (measured from the bottom of the footwear to the top of the head) are 150cm and 195cm respectively. The participants' chest and height measurements are plotted on a graph to visualise the multiple combinations of chest and height measurements selected for this trial. It can be inferred from the graph (see Figure 6.35) that the difference between the lowest and highest measurements of the chest is 52cm, and the difference between the lowest and highest values of height is 45cm.

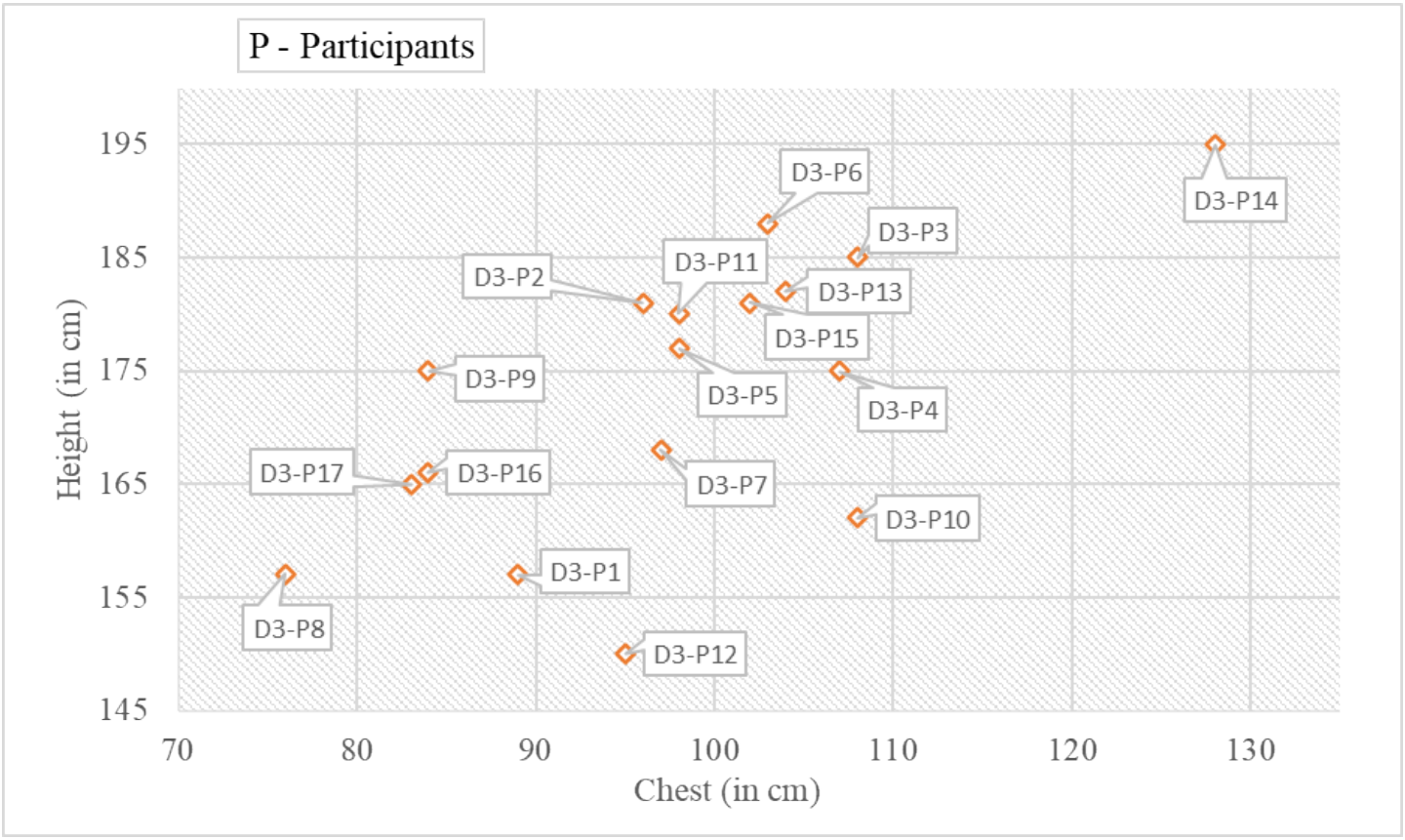


Figure 6.35: Dryland trial 3 (D3) - Participant Anthropometry Variation

The photographs (front, back, left-side and right-side view) of all participants donning the researcher's life jacket prototype are presented in Appendix M.

6.8.1 Evaluation Process

The evaluation process and questionnaire used for this trial are similar to the Dryland Trial 2. Participants were asked to donn the existing life jacket (E1), except for returning participants. While the participants donned the life jacket, the researcher measured the time taken by each participant to donn both life jackets and time taken to remove or doff the life jacket. For the recurring participants, the donning and doffing times were considered from the dryland trial 2.

After donning the existing life jacket E1, each subject was asked to perform several types of body movements (same as in dryland trial 2). After performing the tasks, the participants were asked to remove the E1 and wear the R6. Then the participants were asked to perform the same set of tasks while the researcher noted the time taken to donn and doff the R6.

Based on their experience with trialling the two life jackets, the participants were asked to fill-in a questionnaire containing Likert scale questions to rate various parameters of the R6. The questionnaire (same as in dryland trial 2) included four major sections: Intuitiveness, Comfort, Fit & Adjustability, and Volume.

6.8.2 Wear Trial Response of Participants: R6 Assessment

The participant's responses to the Likert-scale questions in each section of the questionnaire are presented in the form of tables. Inferences are made on the rating for each parameter and the qualitative responses by the participants where necessary are explained alongside. A full-length report on the full-responses of the questionnaire by each of the participants are presented in Appendix M.

The outcomes of the dryland trial 3 based on the feedback from the trialling participants is presented in Table 6.8 in relation to design criteria.

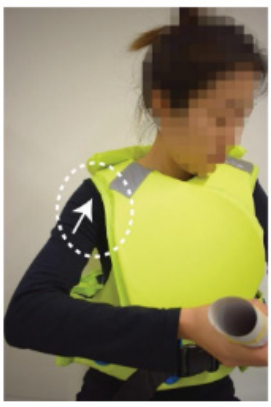
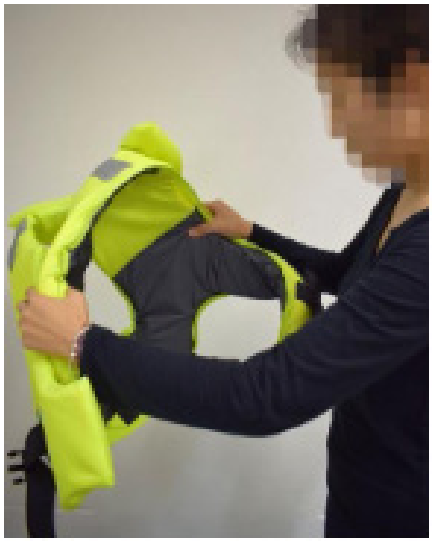
Design Criteria	Discussion R5
Comfort	The average for all the parameters of comfort is rated above 4 (inferred as comfortable to very comfortable). No participants mentioned any feeling of discomfort or irritation at any body parts while wearing the life jacket prototype. Recurring participants mentioned that the soft bendable foam improved the comfort level significantly in this refinement. The soft bendable foam also made the life jacket more contoured to the wearer's body shape making them feel secure. Unlike refinement 5, none of the participants mentioned any obstruction to the shoulder during rowing.  

Table 6.8: Discussing Dryland Trial 3 outcomes in relation to Design Criteria and R6

Design Criteria	Discussion R5
Ease of Donn & Doff	The overall rating by the participants for the parameter 'intuitiveness to wear' is 4.3 (inferred as intuitive and easy) and 'intuitiveness to doff' is 4.6 (inferred as very intuitive and easy). In comparison to the previous refinement, the participants found R6 to be highly intuitive to donn. This is also reflected in the time taken to donn the life jacket. On average the participants took 20.5 seconds to donn R6 (close to half the average time taken to donn E1) and 4.8 to doff R6 (again half the average time taken to doff E1). A returning participant, P6 commented: "The inside color of the life jacket helped me to figure out (how to donn) faster this time." All returning participants took less than 10 seconds to donn the life jacket because of their awareness of the crossover style life jacket. While the new participants were confused a bit when the crossover style life jacket was presented to them, the contrasting colours of the inner and outer sides of the life jacket helped signal the right way to donn. 
Fit	The average rating for the fit and adjustability parameters is 4.8 and 4.6 (inferred as fits very well and easily adjustable), and bulkiness is 4.3 (inferred as not bulky at all). Recurring participants with large chest girth who had trouble with holding the left side panel in the previous refinement found it very easy when the left side panel is contoured to the body shape and held in place for easy fastening of waist-belt.  However, three participants (P1, P4, P8) noted that they found it confusing to place the left-side panel above or under the crossover panels. A note was made to rectify this in the next prototype.

All participants, returning and new, were highly satisfied with the R6 'Slot n Slide' panel life jacket. The participants (irrespective of their chest and height measurements) liked the contoured fit of the front, back and side panels more than the loose non-contouring fit of the existing life jacket designs. Other favoured features in the R6 include, quick and easy donning with a single buckle and webbing fastener, range of movement to the arms to perform rowing and other tasks, minimal rise in shoulder line in a bending or sitting position, and soft foam inside the life jacket.

Participant 2 commented: "This (R6) life jacket is very comfortable to wear. It feels snug and secure while allowing me to perform any movement. Compared to the traditional life jacket this jacket is a lot more comfortable to sit down, bend down and perform rowing motion. As long as it performs the same function and it is safe, I'd prefer to use this life jacket. Especially if I need to sit or row for a long time, I need a wide range of movement."

Participant 5 commented: "This new life jacket is more adaptable to the human's body. It is well designed according to the height and chest measurement. The traditional one is way looser on my body compared to the new life jacket."

Participant 14 (with the largest chest and height measurements in dryland trial 3) commented: "Overall feeling of the life jacket is great. I prefer this a lot to the existing life jacket. Also, the new life jacket design doesn't hit my back when bending forward or in sitting position."

6.8.3 Minor Modifications R6

A modification required in the R6 life jacket was to move the placement of the webbing loop (that the adjustment webbing belt passes through) on the left-side foam panel, toward the outer edge in a forward position. This improved usability ensuring this panel was always placed on top enabling easy slide adjustment and alignment with the corresponding belt buckle (see Figure 6.36). Hence, when the wearer fastened the plastic buckle on top of the crossover panels, the left-side panel that is adhered to the webbing strap always sits on the top of the crossover panels.

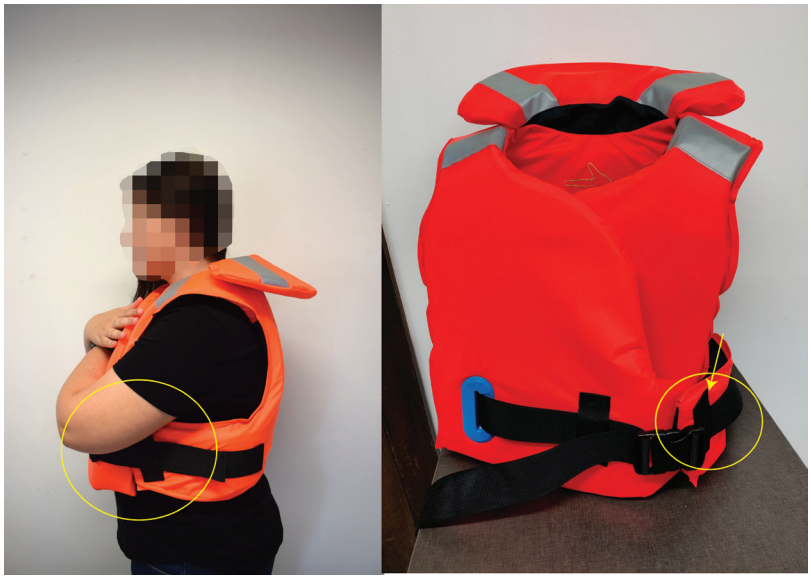


Figure 6.36: Loop on the left-side panel is moved forward and close to the outer edge

Additionally, a hand-sign is embroidered on the inner side of the back panel (see Figure 6.37). This feature is added to guide the wearer with the right-hand entry into the life jacket opening, accompanied with contrasting colours of the outer and lining fabrics.

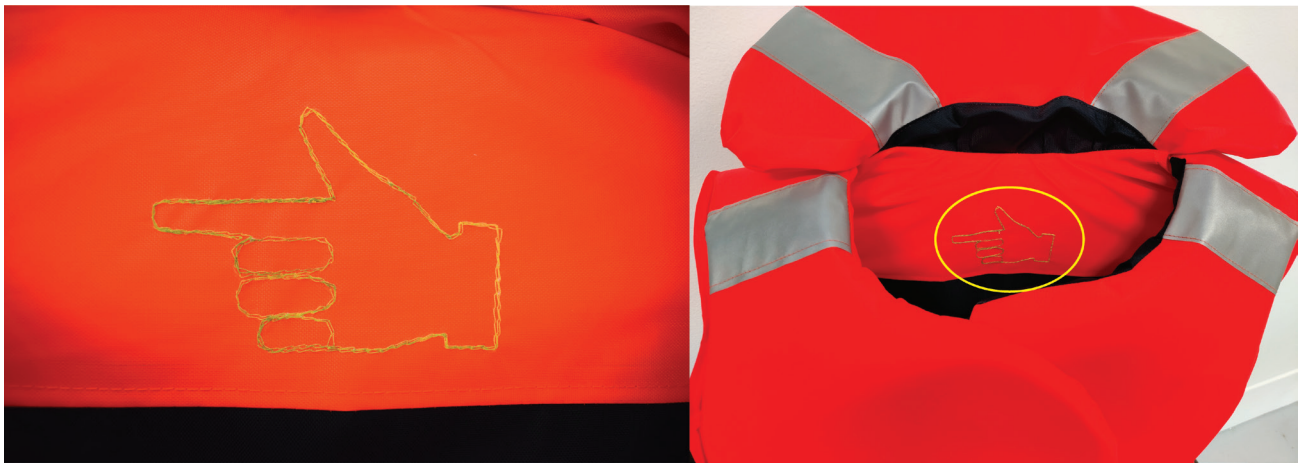


Figure 6.37: Hand-sign embroidered on the inner side of the back panel

6.9 Aquatic Trials

The aquatic trials (see Figure 6.38) study follows on from the series of Dryland Trail studies conducted with previous life jacket refinements. The R6 life jacket prototype with minor modifications, that was highly favoured by trialling participants, needed to be assessed for its flotation, self-righting ability, comfort to swim and perform simple rescue tasks in an aquatic environment. The water-based trials helped to inform the design process by evaluating the life jacket prototypes for their functionality and usability in a swimming pool.

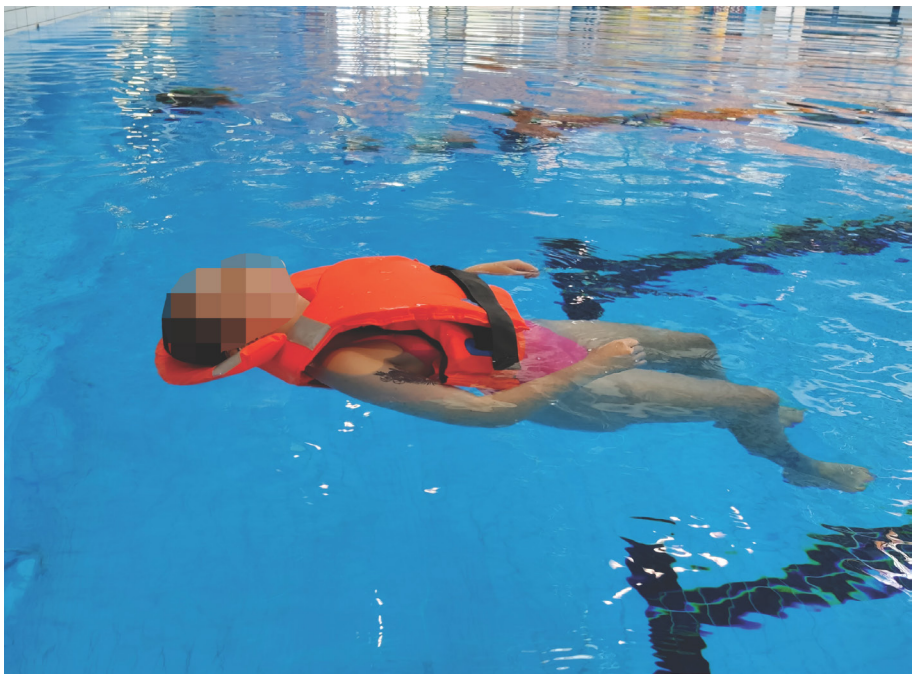


Figure 38: Aquatic trials conducted with the R6 life jacket prototype with minor modifications

The Wellington Regional Aquatic Centre (WRAC) was chosen as the test location to conduct the swimming pool trials for this study. The reasons for selecting WRAC for this study is its close proximity to Massey University Wellington campus, availability of multiple pools for hire and certified pool lifeguards working at WRAC as required by ethics approval. The pool lifeguards working at the WRAC swimming pool were identified as suitable participants for this research. All pool lifeguards working at the WRAC are certified in the New Zealand Qualifications Authority (NZQA) approved Pool lifeguard practicing certificate (PLPC). Pool lifeguards are skilled in water survival competence and experienced in rescuing drowning people. This study aims to keep any possible risks that can happen in a swimming pool to a minimum and hence, pool lifeguards as participants undergoing scheduled professional development were chosen.

The possible risks involved to the participants during the swimming pool trial process were discussed with the supervisors (and members/manager at WRAC). Possible measures to avoid risks were identified during the peer review process. Suitable documentation processes that address the safety and anonymity of the participants are drafted and a full ethics application has been submitted to the Massey University Human Ethics Committee, which was later approved (Application Number: SOA 21-39 – see Appendix A).

The study initially aimed to conduct the life jacket aquatic trials on a minimum of twenty participants to obtain reliable feedback from the participants on the safety and self-righting ability of the life jacket prototype being tested. Six adult participants (Male = 4; Female = 2) within the age range of 21 to 41 years participated in the first round of the study. The duty manager of WRAC allocated the six participants based on the availability of pool lifeguards on the day of visit. Lockdown restrictions in New Zealand due to the COVID pandemic set back my ability to conduct another round of aquatic trials. Pool lifeguards' absence due to illness from COVID variants made it difficult for the duty manager at WRAC to allocate pool lifeguards.

The six participants corresponded to a broad size range, in terms of their chest girth, height and also weight measurements. The lowest and highest measurements of the participants' chest girth are 87cm and 112cm respectively, while that of the lowest and highest participants' height are 169cm and 189cm respectively. The weight of the lightest and heaviest participants is 69Kg and 98Kg respectively. The difference between the lowest and highest measurements of the chest is 25cm, height is 20cm, and weight is 29Kg.

An existing life jacket design (E1) and R6 prototypes were trialled by the six participants (see Figure 6.39). As discussed in the previous section, R6 was slightly modified after the dryland trial 3 and new prototypes were made in 2 colours. The participants were allowed to choose from the two colours available for R6, Citrus Yellow and Fluoro Orange.

Figure 6.39: Life jackets trialled in aquatic trials

6.9.1 Evaluation Process - Aquatic Trials

Participants were given an information sheet prior to the swimming pool trial. The information sheet explained the objectives of the trial, the process to be undertaken and how information will be recorded. Only one participant was trialled at any given point of time for controlled management of the trial environment. For every participant being trialled, two other lifeguards were on watch to ensure safety of the participant being trialled in case the participant experiences any discomfort or loss of balance in water. Documentation of the swimming pool trials included video and photographic recording. In addition, feedback from the participants was gathered through a questionnaire.

The participants were asked to perform the following activities by donning E1 firstly, followed R6 life jacket:

Activity 1: Wear the life jacket prototype assigned to you by the researcher. Fasten the life jacket for a proper fitting. Notify the researcher once you think you wore the life jacket properly.

Activity 2: Enter the swimming pool in either of the following ways that they felt comfortable with: using the handrails or jump into the pool from floor level. After entering water, the participants are asked to make little body movement and float in the way the life jacket makes them float.

Activity 3: Swimming

- Swim a stride of 10m-20m using free-style swimming.
- Swim a stride of 10m-20m using back-stroke swimming.

Activity 4: Mock-rescue activity
The participants performed this activity in pairs. Each participant was asked to grab and pull their partner out of water, while themselves wearing another life jacket prototype and standing outside the pool. The participants standing outside the swimming pool were not given any indication on how and where to grab for pulling them out of water. The intuitive grab and pull action of the participants is being observed in this activity.

After performing the above tasks, the participants were asked to remove the life jacket worn. Based on their experience with trialling the two life jackets in the pool, the participants were asked to fill-in a questionnaire containing Likert scale questions to rate various parameters of both E1 and R6 life jackets. The questionnaire included five major sections: Ease of donning and doffing the life jacket, Comfort, Fit & Adjustability in water, Flotation and Rescue. Each section had multiple questions asking the participants to rate a given parameter on a scale of 1 to 5 (1 for lowest rating; and 5 for highest rating). Furthermore, participants were encouraged to subjectively describe the reasons for unfavourable parameters in the life jacket.

List of questions for the participants:

EASE OF DONN & DOFF

- How intuitive/easy was it to figure out how to wear the life jacket?
- How intuitive/easy was it to remove the life jacket?
- If it takes time, which part do you have a problem fastening or donning the life jacket?

COMFORT

- How comfortable is your torso in the water while wearing the life jacket?
- How comfortable are you to rotate your head?
- How comfortable are you while performing free-style swimming?
- How comfortable are you while performing back-stroke swimming?

FIT & ADJUSTABILITY

- How well does the life jacket fit you while being water? If not, where does it not fit well?
- How easy is it to adjust the life jacket in water?

FLOTATION

- How satisfied are you with the flotation of the life jacket?
- How satisfied are you with the self-righting ability of the life jacket in water?

RESCUE

- How accommodating was the life jacket to pull a person out of water?

6.9.2 Wear Trial Responses of Participants: R6 Aquatic

The participant's responses to the Likert-scale questions in each section of the questionnaire are presented in the form of tables. Inferences are made on the rating for each parameter and the qualitative responses by the participants are explained alongside where necessary. A full-length report on the full-responses of the questionnaire by each of the participants are presented in Appendix N.

Overall satisfaction rating for each parameter is derived from the average of six participants. A comparison between the overall satisfaction rating for each parameter of both life jackets is presented in Table 6.9. Inferences followed.

The R6 life jacket rated higher than the existing life jacket on seven parameters (highlighted in yellow in Table 6.9), lower in two parameters and equal in two.

Table 6.9: Overall satisfaction rating of E1 and R6 life jacket parameters

Parameter	Existing Life Jacket E1	Comparison	Refinement 6 (R6)
Intuitive/easy to wear	4.67	>	3.67
Intuitive/easy to remove	4.83	>	4.00
Comfort at Torso	3.00	<	3.33
Comfort at Head	4.17	<	4.33
Comfort for Freestyle Swimming	4.33	<	4.50
Comfort for Backstroke Swimming	3.17	<	4.00
Fitting and Adjustability	3.67	<	4.00
Ease of Adjustment	3.33	<	3.67
Flotation	4.50	=	4.50
Self-righting Ability	4.00	=	4.00
Pull a Person out of Water	3.83	<	4.33

The outcomes of the aquatic trial based on the feedback from the trialling participants is presented in Table 6.10 in relation to design criteria.

Table 6.10: Discussing aquatic trial outcomes in relation to design criteria

Design Criteria	Discussion R5
Ease of Donn & Doff	Two of the parameters for which R6 rated lower than the existing life jacket are intuitiveness to donn and doff the crossover style life jacket. Similar to the participants in dryland trials, aquatic trial participants took longer to interpret R6 and its process of use. Participants mentioned that the contrasting colours of the inner and outer layers of the R6 life jacket and the added graphic element (the hand sign) on the inside of the life jacket guided them in understanding use.
Safety	Flotation and Self-righting ability: Both life jackets rated equally for their flotation and self-righting abilities. The R6 life jacket provided enough buoyancy to all participants irrespective of their weight, while also keeping the wearer's head above water level.  P6 in a self-righting position in the R6 life jacket prototype  P1 floating in R6 life jacket prototype The E1 life jacket rose at the shoulder significantly more than R6. The female participants with smaller chest girth experience significantly higher rise at shoulder with E1. 

Performance	Swimming: The participants favoured both the life jackets equally for free-style swimming, but only favoured the R6 for back-stroke swimming. The participants preferred the R6 life jacket for its contoured fit during swimming and not obstructing the hand rotation in free-style and back-stroke swimming. The improperly fitted E1 life jacket obstructed the arm movement of the participants during back-stroke swimming.  
Comfort	Rescue: All participants pulled their partners out of water by grabbing at shoulder level of crossover front panels. The decision to reduce thickness of foam at the shoulder to provide comfort to the wearer's neck (made in refinement 5) provided an intuitive placement for the participants to hold the life jacket. No participants experienced any notable discomfort during the pulling action. 

Overall experience of the participants Aquatic Trial R6

Participants in the aquatic trial were highly satisfied with the R6 (modified 'slot n slide' panel life jacket) in comparison to the E1 production life jacket design. A significant difference the female participants experienced with the R6 life jacket was its minimal rising at shoulder in comparison. to E1. This was achieved without a crotch strap and would appear to provide benefits to dress form worn in India.

Functional performance tests of hauling participants from the water mimicking flood rescue were achieved satisfactorily. R6 provided satisfactory buoyancy and supported the participants in a self-righting position. Testing included participants up to 100 kg.

All participants used the same physical specification (size) of R6 all but one participant adjusted the life jacket for a snug fit prior to entering the water. Participants also managed to adjust the waist belt in the water, and this was successfully achieved.

Chapter 7: Discussion of the Flood Event Life Jacket

The final product (Figures 7.1 to 7.4) presented in this chapter is a conceptual design of a flood event life jacket, (the 'Slot n Slide' panel life jacket) developed, trialled, and tested in both dryland and aquatic environments. An iterative design process with reflective analysis at each stage supports the originality and reliability of the design features of the final product.

Figure 7.1: Front – Left view of the Slot n Slide' panel life jacket

Figure 7.2: Front – Right view of the Slot n Slide' panel life jacket

Figure 7.3: Back – Left view of the Slot n Slide' panel life jacket

Figure 7.4: Back – Right view of the Slot n Slide' panel life jacket

7.1 Features and Benefits of the Final Flood Event Life Jacket Design

(see Figures 7.5 & 7.6)

1. A design that is responsive to the dress conventions of India, that are not specific to a single size.
2. Crossover front panels that slide to adjust for fit, contributing to the ability to accommodate a large range of sizes (anthropometry).
3. Innovative inter-panel strapping system with integrated side adjustments, provides a floating connection between the front panel components, and achieves a single belt adjustment across a broad range of sizes.
4. 3D printed guides and webbing loops, that manage belt adjustment and slide interaction between panels.
5. Single belt adjustment, for quick and easy donning and doffing, reducing components and costs.
6. One-piece, contoured foam provides a snug fit, usability of arm movement to perform rescue activities, rowing and swimming is enhanced.
7. Concave shaped back panel allows sitting, bending, and lifting activities.
8. A non-obstructive comfortable collar that doesn't cause discomfort or hinder the wearer's vision.
9. Reflective tapes on either side of the collar and upper chest level, increase visibility in water and especially in low light situations.
10. Contrasting colours of outer and inner fabrics and a graphic feature guide operation and use.

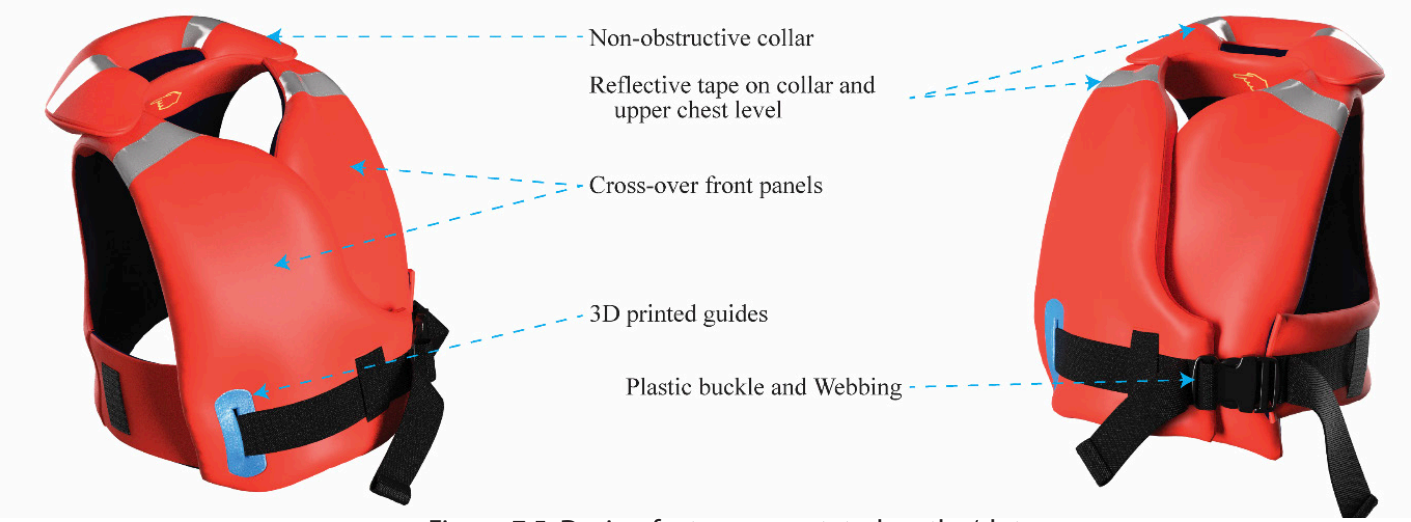


Figure 7.5: Design features annotated on the 'slot n slide' panel life jacket concept (front)

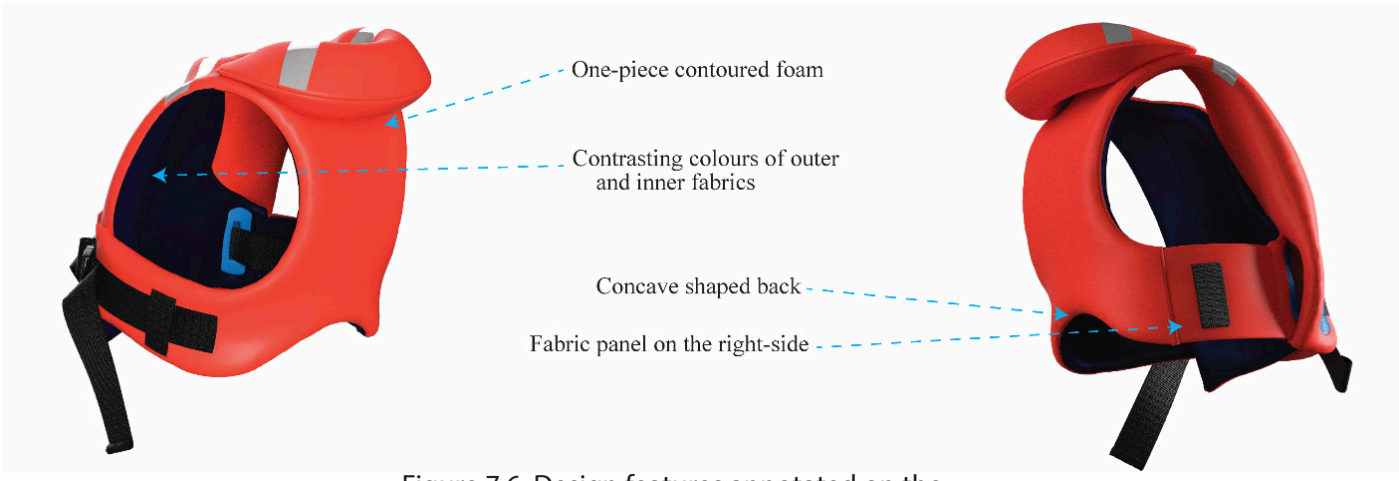


Figure 7.6: Design features annotated on the 'slot n slide' panel life jacket concept (back)

7.2 Discussing the Design Against Criteria

7.2.1 Comfort

Participants in the dryland trials and aquatic trials rated the 'slot n slide' panel life jacket high for its comfort when compared to existing life jacket designs. They described that the shape of the front and back panel along with contouring on the sides provided significant arm movement. No participants mentioned any feeling of discomfort or irritation at any body parts while wearing the life jacket prototype. The soft bendable foam in the life jacket contours to the body shape of the wearer and doesn't give a rigid feel. The seams of the life jacket around the neck are turned inwards to avoid causing irritation to the wearer. Additionally, the concave shaped back panel allows for body bending, lifting and sitting activities without contact of the life jacket to the wearer's hip.

The height of the life jacket is shorter than the waist flexion point in comparison to E1. Hence, when the wearer bends the life jacket doesn't create bulk at the waist. Contrary to the excessive size of armhole in existing life jackets, the armhole level is higher in the slot n slide panel life jacket which creates minimal rise at shoulder in water (see Figure 7.7).

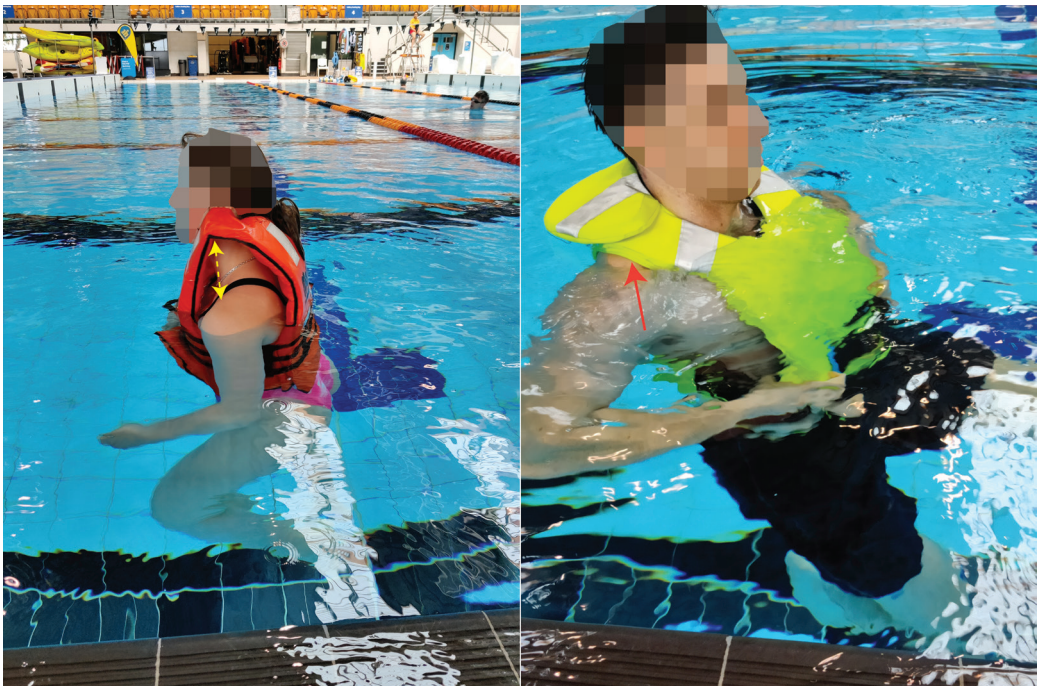


Figure 7.7: Comparison of shoulder rise between Existing life jacket and Slot n' Slide panel life jacket

7.2.2 Fit

The foam inside the life jacket is contoured over the shoulder, around the lower back and side-waist. When the webbing straps are fastened, the contoured shapes of the foam overlap with each other and slide closer to the wearer's body. The life jacket provides a snug fit with no or minimal gaping between the body and the life jacket on a wearer with smaller chest girth (see Figure 7.8) and larger chest girth alike.

Figure 7.8: Slot n' Slide panel life jacket fits snug on a female with chest girth 74cm

The knowledge of anthropometric dimensions of the end-users is necessary for the development of life jackets deployed in flood rescue operations (Zakaria & Gupta, 2014). The Indian population is diverse and non-homogeneous, the sizes and shapes of people vary from state to state. Chakrabarti (1997) presents anthropometric data for 961 Indians (male and female) from 6 geographical zones across India to guide the industrial design of equipment and workplaces.

Anthropometric dimensions of the chest and waist girth are considered for this study and presented in Table 7.1. Measurements are given for each gender separately and mixed gender. The lowest measurement in each category is noted as Min and the largest measurement is noted as Max. In between the minimum and maximum a range of measurements are given including 5th, 25th, 50th, 75th, and 95th percentiles of populations. All measurements are in centimetres (cm). A major challenge in the design criteria was to design a life jacket prototype that fits varied anthropometry because in flood rescue scenarios, only a single sized life jacket is deployed. The front panels of the crossover style life jacket slide over each other when the webbing straps are pulled sideways to fasten around the body.

Table 7.1: Anthropometric Dimensions of Chest and Waist for Indian Populations (retrieved from Indian anthropometric dimensions for ergonomic design practice by Debkumar Chakrabarti, NID, India)

	Gender	Min	5th	25th	50th	75th	95th	Max	Mean
Chest (On Bust)	Male	67.1	75.7	80.1	84.5	89.9	100.9	142.6	85.7
	Female	67.8	67.9	72.5	77.9	82.9	124.2	136.0	81.4
	Mixed	67.1	73.4	79.3	83.5	82.9	100.9	142.6	85.2
Waist (At Navel)	Male	60.2	65.9	71.9	78.2	85.6	96.9	152.1	79.7
	Female	56.0	61.4	65.9	69.1	77.4	93.9	103.0	72.4
	Mixed	56.0	64.9	64.9	77.4	85.0	96.9	152.1	78.8

All measurements in cm

The minimum chest measurements are 67.1 cm (highlighted in yellow) and the maximum 142.6 (highlighted in green) for males and mixed gender, with a range of 75.5cm across chest dimensions. The minimum waist measurement is 56.0 cm for females and mixed gender. The maximum waist measurement is 152.1 for males and mixed gender, with a range of 96.1cm across male, female and mixed genders. The considerable difference in the anthropometric measurements of Indian populations signifies the extent to which a life jacket needs to be adjustable if only one sized life jacket is deployed. The reason for this as a design strategy is that the benefit of always having a solution that fits at hand is optimised deployment, a ubiquitous solution that provides broad utility maximises the effectiveness of emergency response, and equity as no one group or gender is left out of the available solutions.

Life Jacket Simulation in CLO3D and Physical Modelling

CLO software allows the user to create an avatar of the required body measurements in both genders, which is essentially a replication of real-world anthropometric dimensions of any specified populations. The height, chest and waist girth measurements of the avatars are modified to match the anthropometric dimensions of 5th percentile Female, 95th percentile Female, 95th percentile Male and Max. Male sizes of Indian population. The height, chest and waist measurements for each of the avatars are listed in Table 7.2.

Table 7.2: Measurements of CLO avatars modified to match Indian anthropometric dimensions

Avatar	Indian Anthropometry	Height	Chest (On Bust)	Waist (At Navel)
Avatar 1	5th Female	140.6 cm	67.9 cm	61.4 cm
Avatar 2	95th Female	161.5 cm	124.2 cm	93.9 cm
Avatar 3	95th Male	175.1 cm	100.9 cm	96.9 cm
Avatar 4	Max. Male	193.9 cm	142.6 cm	152.1 cm

Four avatars are created in CLO and the final design of 'slot n slide' panel life jacket is simulated on the avatars to evaluate the extent to which the product can be adjustable. From the simulations, it is observed that the sliding panels and side adjustments adapt to the body shape of the avatars and the life jacket fits satisfactorily on avatars 1, 2 and 3. Although the fit of the life jacket on the avatar 4 (Max. Male) is far from ideal, the simulation demonstrates the ability of the life jacket to accommodate the largest Indian anthropometric size.

To corroborate the digital simulations physical prototyping was again used. Sections of the human abdomen and waist made with medium-density fibreboard (MDF) and Styrofoam are used to demonstrate the fitment and coverage of the sliding panels around the body. Four sections, equivalent to the abdomen and waist girth measurements of 5th percentile Female, 50th percentile Mixed, 95th percentile Male and the Maximum size, are made to replicate a more expansive Indian anthropometric data.

The life jacket is fitted on these four sections to show the difference in sliding of crossover panels, expansion of right-side fabric panel, and overlapping of left-side foam panel.

The 5th percentile section is the smallest of all. In Figure 7.9, the distance between blue lines is the measurement of front panels sliding over each other, and the distance between green lines represents the expansion of the right-side fabric panel and overlapping of the left panel on top of the crossover panel. On the 5th percentile section, the front panels slide over each other by 1cm only, whereas the right-side fabric panel expands to 4.5cm and the left-panel overlaps by 16cm.

On the 50th percentile section (see Figure 7.10), the front panels slide over each other by 8.5cm and the right-side is expanded to 10cm while the left-panel overlaps by 12cm. The difference in the measurements of the 50th percentile and 5th percentile sections indicate that, with increase in waist girth the sliding panels, fabric panel and overlapping foam transform to accommodate the wearer's anthropometry.

On the 95th percentile section, the front panels slide over each other by 13cm, the right-side fabric is expanded to 16cm and left panel overlaps by 12cm (see Figure 7.11). On the Max size section, the front panels slide over each other by 30cm, the right-side fabric is expanded to 20cm and left panel beyond overlapping 22cm (see Figure 7.12).

Figure 7.9: Slot n slide life jacket on a 5th percentile Indian anthropometry

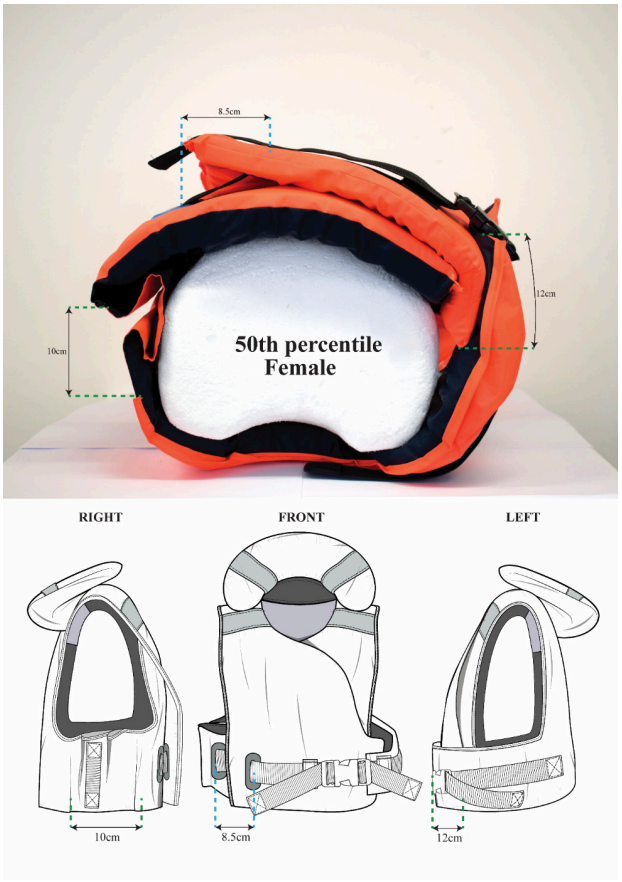


Figure 7.10: Slot n slide life jacket on a 50th percentile Indian anthropometry

Figure 7.11: Slot n slide life jacket on a 95th percentile Indian anthropometry

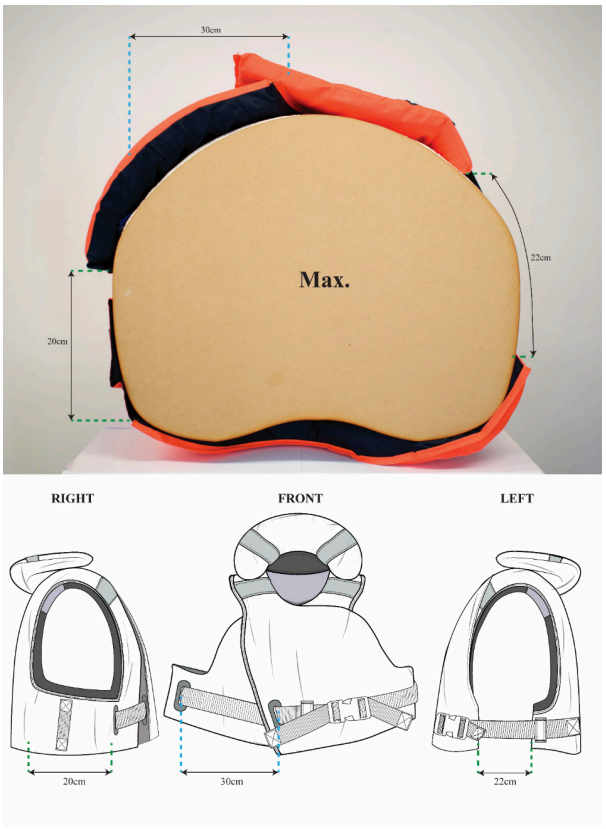


Figure 7.12: Slot n slide life jacket on Max.
Male size of Indian anthropometry

The variations in the measurements of distance between sliding panels, expansion of right-side panel and overlapping of left-side panel provide for a comprehensive size adjustment of the 'slot n slide' life jacket to a large anthropometry.

7.2.3 Ease of Donn & Doff

As observed in the dryland trial 3, the average time to donn the 'slot n slide' panel life jacket (20 seconds) is half of the average time required to donn an existing life jacket (40 seconds) with a zipper and 3 plastic buckles. The single buckle fastening mechanism makes it quick and easy for the wearer to donn or doff the life jacket. This significant drop in donning and doffing time speeds up rescue activities and helps emergency responders to evacuate more people during flood rescue and evacuation. The minimal use of fasteners aligns with Indian dress conventions and contributes to effective donning and doffing.

The six-step donning method of the slot n slide panel life jacket is illustrated in Figure 7.13.

Figure 7.13: Donning instructions of 'slot n slide' panel life jacket

7.2.4 Safety

The actual buoyancy value of the life jacket is not determined at this stage. However, as observed in the aquatic trials, the 'slot n slide' panel life jacket provides enough buoyancy for wearers up to 100Kg of weight. The recommended method for determination of buoyancy in the Indian standard for life jacket specification requires a water tank approximately in 1.5m diameter and sufficient depth for a period of 24 hours. This buoyancy determination method is out of scope in the current stage of research.

7.2.5 Performance

The non-obstructive shaping of the life jacket around the shoulder allows for comfortable hand rotation in free-style and back-stroke swimming (see Figure 7.14). The contoured fit on the wearer's body withholds the life jacket from rising at shoulder and hindering joint rotation.

Figure 7.14: Non-obstructive motion of hand rotation in free-style swimming

The slot n slide panel life jacket allows comfortable head movement both sideways and forward. The vision of the wearer is not obstructed in any ways. The position of the collar also allows for clear peripheral vision (see Figure 7.15).

Figure 7.15: Collar doesn't hinder vision to the sides

7.2.6 Handing & Storage

The slot n slide panel life jacket is a one-size fits all product. Having a one sized life jacket that accommodates varied anthropometry eliminates the need to carry multiple sizes of life jackets for emergency responders. This is a significant factor as observed from the field study and visual research. Wearing a wrong sized life jacket can put the wearer at risk of slipping out from under the life jacket. Storage of the currently used bulky life jackets is inefficient and counter-productive, negatively impacting flood event response.

The technical specifications of all materials used to prototype the above discussed flood event life jacket ('Slot n Slide' panel life jacket) together with bill of materials, production process and patterns is presented in Appendix O.

Chapter 8: Conclusion

This conceptual design of 'Slot n' Slide', a flood event life jacket offers an appropriate design responsive to India's context and conditions of flood rescue events. This concept provides new and perceivable benefits, including improvements in utility for emergency responders, and usability for end-users.

Research identified that regular and predictable flood events in India are poorly served by the quality of life jackets supplied to mitigate flood disaster events. Research identified the need for life jackets that are functionally appropriate, culturally acceptable, economically viable, and easily deployable by the Indian government disaster management authorities during flood events.

Visual analysis of published images from authorised news agencies and internationally and nationally sanctioned Disaster Management websites, provided a rich source of data for analysis allowing formative insights from secondary sources. This approach in visual analysis can be extended into other fields of enquiry. The analysis from primary and secondary research defined design criteria to support life jacket design specific to the context and conditions in India. These criteria provide cultural and anthropometric insights for future research projects that aim to design products for flood rescue scenarios in India and the rest of the worldwide.
This study identified that Indian dress conventions using wrapping to adjust for the wearers size without the need for excessive fasteners has application when designing for a one-size-fits-all situation. This has further application outside of life jacket design, and can contribute to developing greater utility in products, apparel and fashion design.

The design development was tested and validated by a series of dryland and aquatic trials. The trials used comparatives assessments with currently deployed life jackets used in India alongside the developing new design to provide a grounded reference point for assessment of the new designs progression.

Further research supporting comprehensive in-context product trials (with batch produced prototypes) in India is required. Manufacturing considerations focused on the final specification and supply of materials would support financial viability studies. Further product testing to meet international standards and India's life jacket standards would be required. The final design of the 'slot n slide' panel life jacket is a product needed by disaster rescue organizations in India such as the NDRF, military and non-government humanitarian agencies as part of their rescue activities.

Critical performance aspects of donning and doffing, comfort, and performance for end users and emergency responders was addressed. Importantly for emergency responders the ability to effectively store and deploy, a single size with broad application, and an ability to maintain their rescue activities unimpeded by a poorly designed life jacket. For the afflicted end user, having a life jacket that was understandable in its use and operation, could be adjusted correctly for a broad range of users and provided comfort and buoyancy support required was achieved.

'Slot n' Slide', is a life jacket specific to the context of India, and the organized emergency response within India. This ground-breaking design developed utility across size ranges, and leverages the potential of sliding panel features. This is achieved with a single belt adjustment involving an innovative inter-panel lacing system that locates the front panels in relation to each other, while allowing sliding between panels, in adjustment for fit. By managing the location of panels in this advanced design, enables an efficient 'slot' side entry (without confusing accessibility or understanding an issue with independent floating panels). In addition, the panels pull down on top of each other in their final adjustment, assuring correct position and form for life jacket performance.

The contribution to knowledge is expressed in the combination of performance features, across individual components presents an interrelated and supportive product architecture: the 'slot' side entry, the interlaced adjusting belt, and the over-lapping sliding front panels, collectively achieve the ability to provide broad accommodation for sizing, and a significant contribution to life jacket design sizing and utility.

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Appendices

Appendix A: Human Ethics Applications

My Applications

Template Category	Primary Investigator	Application ID	Application Title	Workflow State	Status
Human Ethics	Areef Shaik Areef	SOA 21/39	Designing lifejacket···	Complete	Approved
Human Ethics	Areef Shaik Areef	4000022573	Lifejackets for enha···	Complete_LR	Approved
Human Ethics	Areef Shaik Areef	4000020827	FUNCTIONAL CLOT···	Complete_LR	Approved

Page Size 5 10 20 Page 1 of 1 (3 items) 1

Figure A1: Approved Massey Human Ethics Application

Appendix B: Sample pages from Visual Research Diary

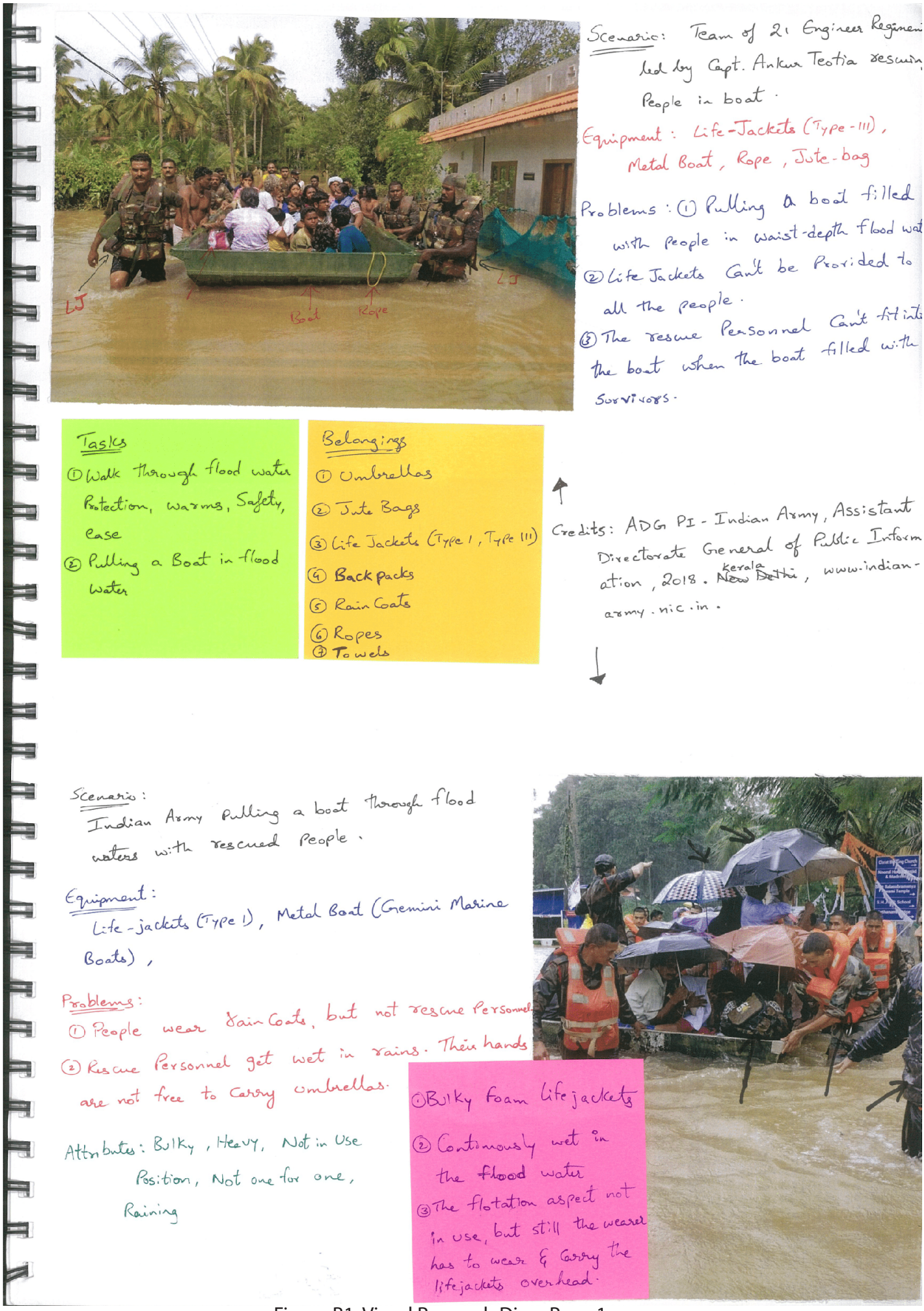


Figure B1: Visual Research Diary Page 1

Credits: AP Images, 2018. Kerala, India. www.apimages.com

Scenario: A family stranded with a dog ask for help from rescuers in a flooded area in Chengannur in the state of Kerala, India. Aug 19, 2018.

Problems: ① How can the family be brought down of the house if a rescue team arrives with a boat?

② Do the rescue team have a ladder? If not how will they manage?

③ What equipment inside the house be used be used to get down?

④ Can People all ages and abilities use that equipment?

⑤ Can the people and rescue personnel Communicate in the same language?

⑥ How can the People guide rescue personnel to reach their house.

Attributes: Climbing down/up, Sliding down, Communication with rescue Personnel

IDEA

① Foldeable Ladder or Slide that can be Carried by the rescue Personnel in their boats.

② A belt to tie around People and lift/Pull them into Boats

Scenario: An Elderly Person is being lifted by a rescue Personnel into the boat while being rescued from a flood surrounded area.

Equipment: Life jackets (Type-III), Metal Boat, Umbrella, Rain Coat

Tasks

① Pulling into a Boat

② Holding a Person and an umbrella and walk in flood water

Problems:

① The rescue Personnel has to lift the Person (old aged/disabled) into the boat. (2 Rescue Personnel + 1 helper)

② The helper has to catch umbrella in another hand.

Attributes

① Lifting People, Pulling up into Boat,

Credits: PTI, Press Trust of India, August 2018. www.ptinews.com/Pti gallery

Figure B2: Visual Research Diary Page 2

Scenario: Rescue teams evacuate People from flood affected areas, to relief camps.

Equipment: Life-raft, Life-jacket (Type I)

Problems: ① A person can slip on the roof while getting down, as it is rainy.

② No equipment with the rescue Personnel to get the People down.

Attributes: Climing down a house, Helping a person to climb down.

Credits: PTI, Press Trust of India, 2018. Kerala, www.pti~~ma~~news.c

Problems:

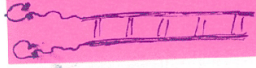
① Slippery House walls, Roof top.

② Attachment for the ladder to cling to a support

Ideas:

① If the rescue Personnel has a foldable ladder, it needs to be attached somewhere on top of the house while climbing down.

Latch System Ladder.



Scenario: Indian Army Personnel rescuing a kid and brining him to a life-raft, while walking through flood waters.

Equipment: Life-jackets (Type-III), Life-raft, Nylon ropes, Rubber Tubes (inflatable), Life-buoy

Problems: ① The rescue Personnel has to Support another person who doesn't have a life-jacket.

② Inconvenient to move through flood water while wearing life-jacket and a rubber tube

③ The rubber tube can come in contact with debris and be deflated.

④ The rescue Personnel may have to cling on to a support, with another person taking support of him.

Attributes: Double weight Support Life-jacket, Conjoining, clinging Support.

Idea:

① Conjoing life-jacket

Two life-jacket that can be conjoined.

1 for Rescuer and 2nd for a Civilian (who could be unconscious).

Credits: ADG PI - Indian Army, August 201 Kerala ~~Delhi~~, India, www.indianarmy nic.in

Figure B3: Visual Research Diary Page 3

Credits: AFP Images, 2018. Kerala, India. www.afp.com/en/Products/Picture

Scenario: A rescue Personnel and a Civillian Carrying an Elderly Person on their shoulder and hand

Equipment: Bare hands, &

Problems: ① How far can they carry the Elderly Person?

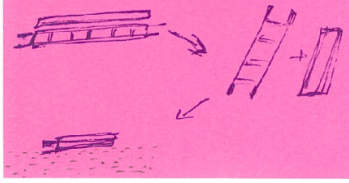
② Walking through flood water with Carrying weight is strenous.

Attributes: Carry disabled, Lift and hol weight.

Problems

① Evacuating Old, Elderly, Disabled and kids is a strenous and hectic tough job.
They always needed to be aided by lifting.

Idea:
Foldable Stretcher and floater. (Convertible) to a Ladder.



Scenario: Rescue Personnel are Carrying a Elderly Person in a long tray.

Equipment: Human Power, Body Carrier, 6 People

Problems: ① ~~Are~~ 6 People Carrying 1 Person? Is the method effective?

② Is a Carrier effective than a Stretcher?

Attributes: Carrier, Stretcher, Lifter, floater, Move in Water, float and move on water.

Credits: ADG PI - Indian Army, 2018. Kerala, India. www.indianarmy.nic.in

Figure B4: Visual Research Diary Page 4

Scenario: People being evacuated from flood surrounded houses by military personnel.
A kid is lifted and taken through flood water.

Equipment: Man Power, Backpack, Luggage.

Credits: Reuters, 2018. Indian army Soldiers re
girl from her flooded home in Srinagar. wi

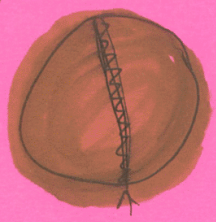
Problem: ① Risk of tripping over & falling.
② Taking important luggage.

Note-Points: People from a good household also need to evacuate Sometimes.

How well are they Prepared to face such a Scenario.

Attributes
① luggage Carrier
② water proof backpack, Suit Case.
③ What are the important things they take?

IDEA
Luggage carrying Spher



Scenario: Same as in South Indian floods image.

Credits: Farooq Naeem, 2014. Pakistani citizens ass
woman in the flood area of rawalpindi.
www.the atlantic.com/photo/2014/09

Washing hands in flood water.
Indians are immune to harsh conditions.

Foot wear are Carried

Figure B5: Visual Research Diary Page 5

Credits: ADG-PI - Indian Army, Jun 2013, www.Indianarmy.nic.in

Scenario: A military Person giving water to an exhausted victim of the disaster.

Equipment: water bottle, water.

Emergency Responders have to carry water to Provide to victims on the way.

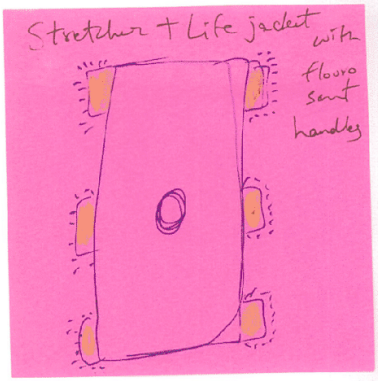
Attributes: Thirst, hungry, exhausted,

IDEA

① Water Bottle hidden in their uniform or Lifejacket or Life buoy

TASK

① Drinking water when exhausted and providing water to victims / Survivors.



Source: Scenario: A woman is seen Carried on a stretcher by 4 emergency responders. (Wooden & Metal type Stretcher).

Equipment: Stretcher, Man Force (4).

Note Points: ① Stretcher Can also be re designed to be used as a ladder / floater.

② A new innovation Can be done by Combining functional features of a stretcher into Res an object in People's household.

③ The weigh of the stretcher Can't be heavy.

④ Night time rescue.

Attributes: Stretcher Light weight, Portable, good grip, Lights on the handles, fluorescent handles.

India Ministry of Defence, 2013.
Army Personnel Carrying a person on a stretcher in the affected areas of Uttarakhand.
www.floodlist.com/asia/India

Figure B6: Visual Research Diary Page 6

Credits:
PTI Images, 2015. Army personnel evacuate a woman from her flooded house using a rope & lifejacket. www.ptiimages.com/Photo

No Lifejacket

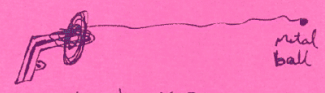
Scenario: Two responders are seen evacuating a women from her house using a rope.

Equipment: Rope, Lifejacket

Problem: ① The water is not deep for the men - They walk without lifejacket.
② Even after wearing a buoyancy aid, the women needs two people to aid to walk through flood water.
③ How did they through the rope to the affected people in first case?

Attributes: Throw rope, assist with buoyancy aid.

IDEA
① Throwable Rope device.



Gun shoot rope

PROBLEM
The lifejackets can only help you to float.
The wouldn't help a normal person to navigate through flood water.

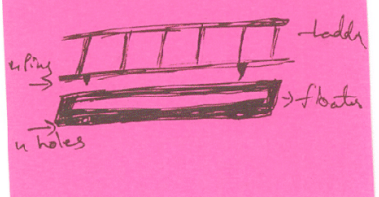
Scenario: ~~A~~ A hurt dog is carried on a ~~(a)~~ ladder by 3/4 men.
~~A~~ ladder is used as a Stretcher.

Equipment: Man-force; Ladder, jute carrybag.

Problem: ① Unavailability of stretcher.
② How can a ladder for multiple purposes?

Attributes: Ladder, Stretcher, Convertible stretcher.

IDEA
① Convertible Ladder

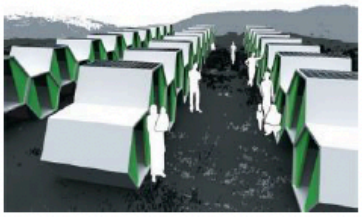


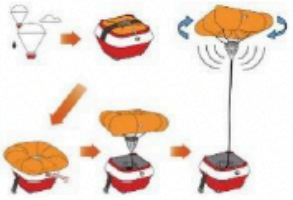
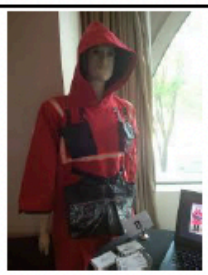
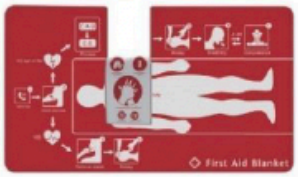
Credits: STR/AFP/Getty Images, 2015. Indian flood-affected people move an injured dog in rain-hit areas on the outskirts of Chennai on Nov 17, 2015. www.gettyimages.fr/detail/Photo

Figure B7: Visual Research Diary Page 7

Appendix C: Design Concepts/ Products Designed for Disaster Response Scenarios

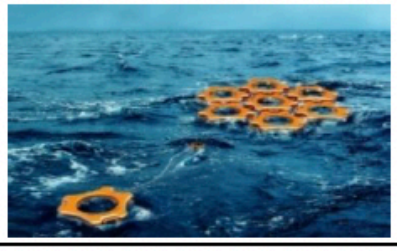
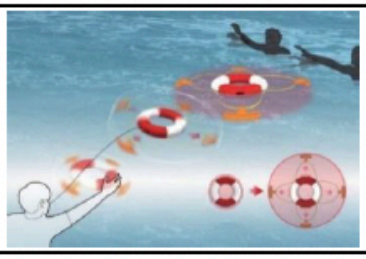
Table C1 : Design Concepts/ Products Designed for Disaster Response Scenarios

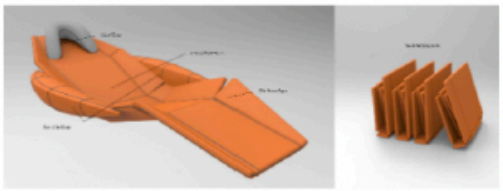
General disaster response designs/ products			
No.	**Name of the concept/ product**	**Designed by**	**Image**
1	Transformable Stretcher	Se Jin Yoon	
2	Lumin-Aid	Anna Stork and Andrea Sreshta	
3	Haven	Song Kee Hong, Timothy Hoo, Felix Lee	
4	Accordion Tent	Ye Haoyu, Zhang Hao, Shen Yiqing	
5	Parachute Shelter	Kim Seok-woo and team	
6	Sanctuary Emergency Shelter Concept	Jonathan Kim	
7	A.C.R. Automated Cardiopulmonary Resuscitator Concept	Chen Kuei-Yuan and team	

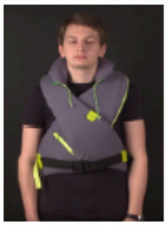
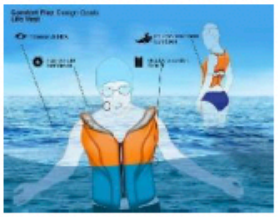
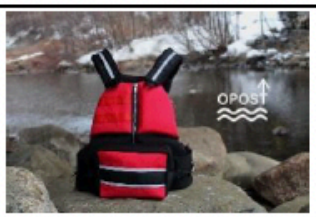
8	Float Base Station	Huang Hsin Ya, Huang Pin Chen	
9	Solar Carton	Wu Jiang and team	
10	V Plus Emergency Relief Tent	Li Bowen, Zhou Zhijun and team	
11	Survival Plus	Nabeela Ahsan	
12	The Carton Closestool	Homwee Technology Co.	
13	Life Box	Adem Onalan	
14	Second skin emergency protection blanket	Nick Dephoff	
15	Amphibious Stretcher	Cheng, Jin, Wang, Wei	
16	First Aid Blanket	Cheng, Jin, Li, Ma, Shao, Yu	

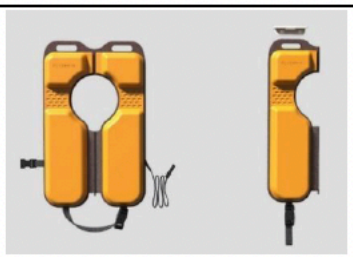
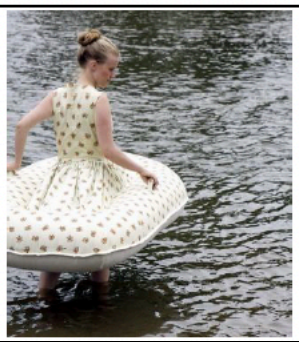
17	Duckweed Survival House	Zhou Ying and Niu Yuntao	
18	Life Bag Wearable Medical Kit	Kyuho Song	
19	Tent Jacket	Angela Luna	
20	Convertible Tent and Sleeping Bag (2015)	Design students' team, Royal College of Art, London, UK	
21	FINDER - Finding Individuals for Disaster and Emergency Response	Jet Propulsion Laboratory and the Department of Homeland Security's Science and Technology Directorate	
22	Better Shelter Tent	IKEA	
23	Handheld Air bag jack	Design students' team, Dalian Minzu University, China	
24	Telescopic tent	Chen Yu, Dong Jia and team	
25	Airborne Tent	Han Wenjia and team	

26	Stack-up Stretcher	Wu Chunmao, Zheng Difei	
27	Survival Capsule	Julian Sharpe, Scott Hill	
28	Crutch for Scavengers	Jiang Jigfan	
29	Lattice Disaster Tent	Rodney Adank, Drain, Jones, McCafferty, Mcintyre	
30	D.R. Toilet System	Rahim Bhimani	
Aquatic hazard response designs/ products			
31	Life Net	Ying Fangtian and team	
32	Rez-Q Kayak	Jacob ballard	
33	Self-Rescue Bracelet	Wu Xuexing, Zhu Linghui, Zhu Peizheng	

34	Network Tube	Son Kijo and team	
35	Flood Float Torch	Lee, Yun Wen	
36	Folding Boat	Prof. Ying Fangtian and team	
37	Expand Lifebuoy concept	Min Hao-Siang and Lin Hong-Wei	
38	Life Jacket Plus	Zhang Bin, Lin Xingmin, and Jiang Ying	
39	The Otter Personal Disaster Backpack	Benson Lee	
40	RC Buoy	Peng Shanzhong, Ju Xinxin, Li Weilin	
41	Floodhopper	James Barford	

42	Air Rope Inflatable Rescue Tunnel	Lee Jee Won, Lee Juan, and Lee Yong Ho	
43	Net Rescue Boat	Jang, Lee	
44	Duckweed Survival House	Zhou Ying and Niu Yuntao	
45	Connect	Jialin Song, Kun Xu, Yumo Jiang, and Chaojun Zhang	
46	Self-aid rescue kit for floods	Tushar Wankar	
47	Kingii Wearable	Mike Gyorfi	
48	Signal Life Jacket	Huang ko ping	
49	Connect: A Life Jacket and Floating Device in One	Zhang Chaojun, Wang Shuyu and team	
50	A Life Buoy that can distil seawater	He Yue, Wang Dading, Yuan Huaiyu	

51	Connect the Life Jackets	Zhejiang University design students	
52	POD Multifunctional Lifesaving Furniture	Kin Pan Lo	
53	VEST	Kinga Krężel	
54	IUW	Julia Grochal	
55	Comfort Flex Life Vest	Jessie Kate Brown	
56	OPOST	Loubert Maxime	
57	D-Rescue Can	Tae Hoon Jung	
58	The Extendable Lifeboat	Haimo Bao	
59	Rescue Tube	Baek Mi Young	

60	Rescue Buoy Concept	Jens Andersson	
61	Flask Pak	Yaokun Wu	
62	O-Drone	Jack O'farrell	
63	USLON	Katerina Semenko	
64	Boat Dress	Jacqueline Bradley	
65	Foam Filled Jacket	Michael Garman	

Appendix D: Preliminary Concepts

Water-proof storage for mobile phone/radio in a life jacket I incorporated multiple features into this single life jacket design to make it highly functional in a flood context. Some of these features are LED bulbs, seal-proof storage pockets for mobile phones, storage pockets for first-aid kit, and chlorine tablets to purify water for drinking. A mock-up of water-proof pouch for storing mobile phone is made to test the ideal placement of the pouch on the body for best-reach of arms.

Figure D1: Mock-up of water-proof pouch for storing mobile phone

2. Life jacket with a pull-down ladder that can float
This prototype is a critique on the vacuous transformable clothing being designed worldwide and also a reminder for me to focus on the primary functions of rescue-wear without getting diverted. This pr prototype features an inherently buoyant foam type life jacket with a handy pouch on the chest area for water-proof storage with an extended cord to operate the phone (even while standing or floating on water). Additionally, a detachable ladder is placed on the backside usable for reaching people in danger.

Figure D2: Life jacket with a pull-down ladder

3. Stretcher + Life jacket. Life jacket laid flat and be used as a stretcher with the help of two poles

A major issue that I found in visual research is that life jackets fit poorly on women, children, people with disabilities, and pregnant women. This inspired me to come up with a life jacket concept without side-seams, so that it can be pulled over the wearer's head and fastened around the body using straps. Another issue is that emergency responders will have to carry people who are tired, exhausted or unconsciousness or people with special needs to safer locations during disaster response. In such cases, if a life jacket can convert into a stretcher the load of wearing it is reduced and can be used for carrying a person. This inspired to design the concept of a life jacket that can transform into a stretcher.

Figure D3: Stretcher + Life jacket

4. Flat-pack life jacket

This mock-up was made to create a life jacket shape from one-piece flat pattern that sits flat. The benefit of creating a one-piece flat pattern is that multiple pieces can be stacked on each other. Its economical and has broad utility.

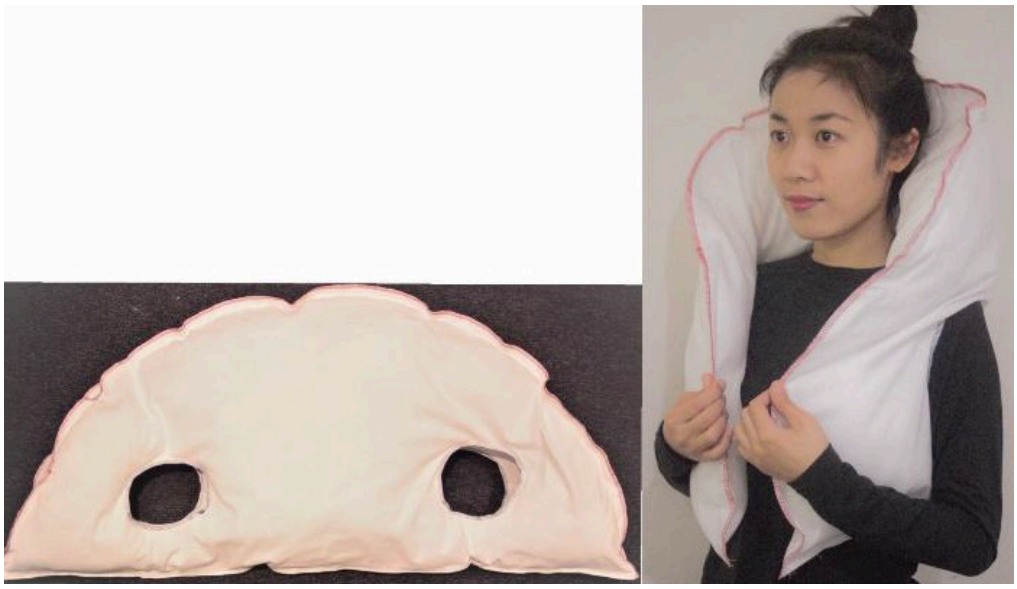


Figure D4: Flat-pack life jacket

Appendix E: Focus Group

Focus Groups – List of questions
Journey Mapping Activity
Identify the list of activities performed by rescue personnel and map them in the order of their occurrence. Pinpoint challenging activities and the issues related.
1. Describe the activities that you/ your agency performs during flood rescue?
2. List all the people, groups/ communities and organizations that are involved in these activities?
3. Place all the listed-out activities on a timeline in the order of their occurrence? Place the people involved alongside the related activity.
4. Formulate themes in the activities performed.
5. Classify the identified activities into dangerous, strenuous, and other categories.
6. Elaborate on the reasons for putting these activities into each of the category.
170
Discussion 1 - Life jacket general information
7. What type of life jackets and other clothing items do you wear during flood rescue operations?
8. During which of the activities mentioned earlier, do you usually wear the life jackets?
9. Of these, which of the activities compulsorily require you to wear life jackets?
Discussion 2 - Life jacket performance and features
10. What are your thoughts about the life jackets worn by you? Would you say you are satisfied with the current situation? If not, what are the things you are dissatisfied with?
11. Tell your thoughts about the following aspects in the life jackets currently used by you
a. Safety & Protection
How reliable are your life jackets in making you float on water? What do you do when you have to assist another person who is drowning in water?
b. Comfort
How convenient do you think your life jacket is to perform the activities mentioned earlier? Do they restrict the movement of your body parts? Which parts of the life jacket do you want to be comfortable for performing rescue activates?
c. Feel and texture
How is the feel and texture of the life jacket fabric? Do you like the fabric? Do you think they influence your comfort or performance ability?
d. Fit
What are the size ranges in the life jackets used by you? Do they cater all sizes of the personnel in your team?
e. Size/ volume,
What do you think about the size of your life jackets? Are they too bulky or compact? How do you want this to be improved?
f. Transportation and stowage
171
How are the life jackets transported to a flood affected location? How many of them are taken in the rescue boats? Where do you store life jackets when not worn during flood rescue activities?
12. How about life jackets with advanced technology - like inflatable life jackets and special type PFDs, would you be interested in them?
Discussion - Life jackets suggestions/ proposals
13. According to you, what are the ideal features needed in life jackets to perform flood rescue activities more efficiently?
14. What kind of changes would you like to see happen in the current life jackets designs? How should it be changed?
15. Are there any recommendations that you have, or suggestions you would like to make?

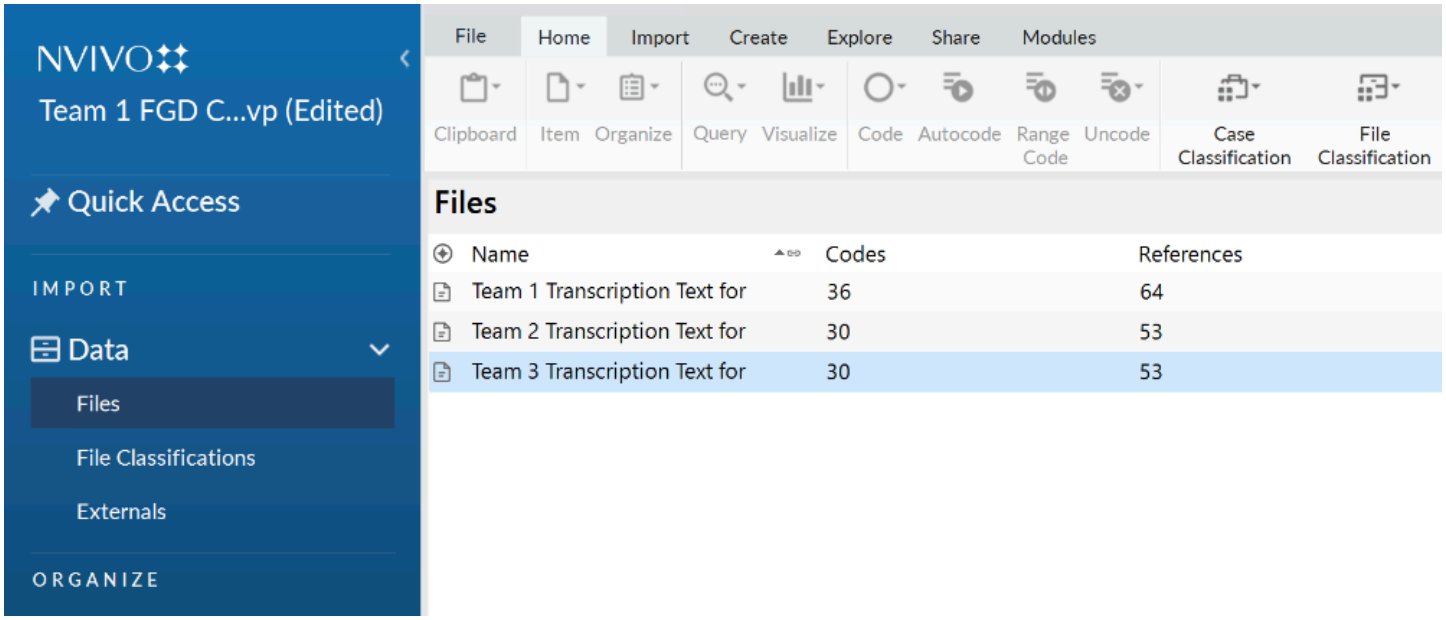


Figure E1: Saved transcription files of teams 1, 2 and 3 in NVivo

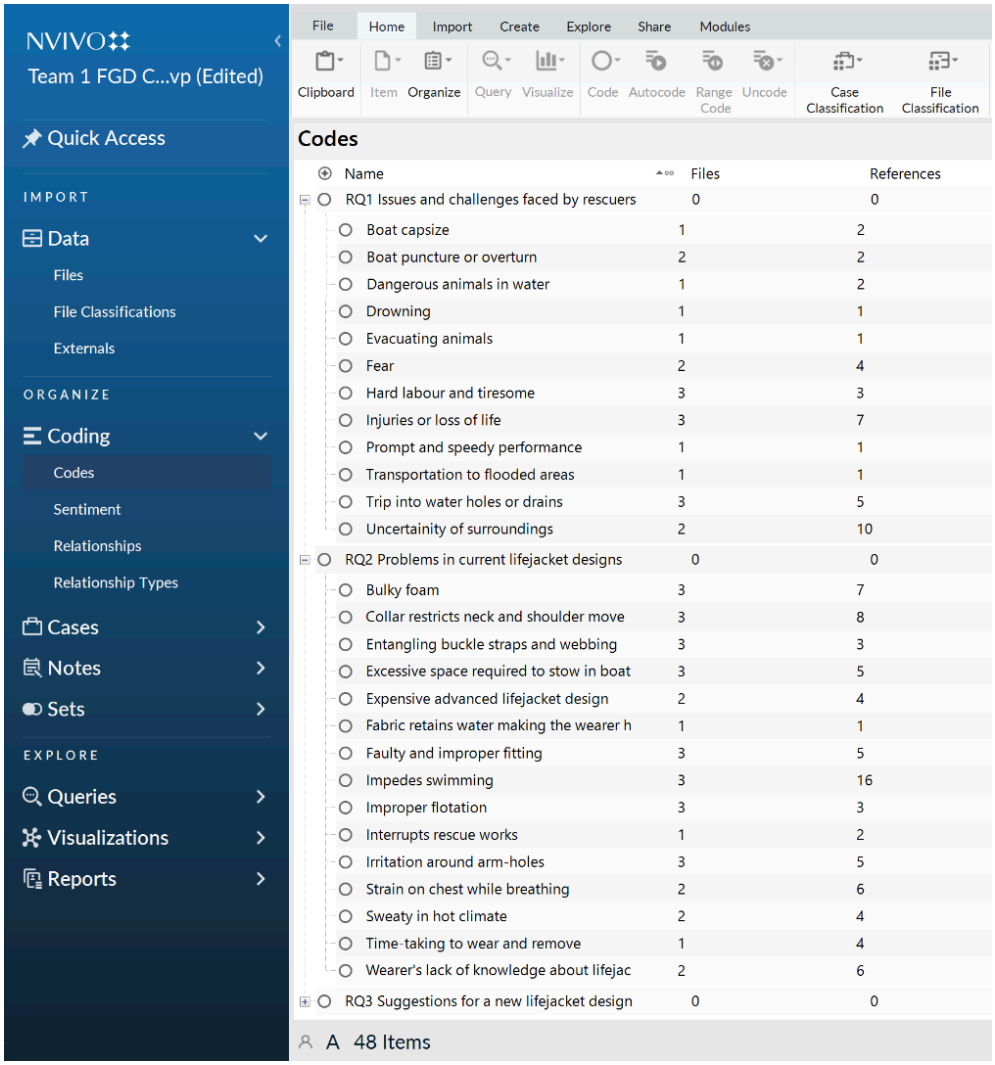


Figure E2: Data from focus groups coded under three research questions in NVivo

Appendix F: Sub-Themes Identified Under Each Research Question In Focus Groups

Table F1: Issues And Challenges Faced
By Emergency Responders

Issues and challenges	Frequency
Injuries or loss of life	6
Uncertainty of surroundings	5
Trip into water holes or drains	3
Boat capsize	2
Dangerous animals in water	2
Fear	2
Hard labour and tiresome	2
Boat puncture or overturn	1
Drowning	1
Evacuating animals	1
Prompt and speedy performance	1
Transportation to flooded areas	1

Table F2: Problems In Current Life Jackets Designs

Problems with current life jacket designs	Frequency
Impedes swimming	9
Collar restricts neck and shoulder movement	6
Bulky foam	5
Time-taking to wear and remove	4
Excessive space required to stow in boats	3
Irritation around armholes	3
Strain on chest while breathing	3
Faulty and improper fitting	3
Wearer's lack of knowledge about life jacket functionality	3
Improper flotation	2
Interrupts rescue works	2
Expensive advanced life jacket design	2
Entangling buckle straps and webbing	2
Sweaty in hot climate	2
Fabric retains water making the wearer heavy	1

Table F3: Suggestions For
A New Life Jackets Design

Suggestions for a new life jacket design	Frequency
Easy and quick to wear and remove	4
Safe and reliable (Protection, Flotation)	4
Comfortable	3
Mobility of neck and shoulder	3
Adjustable to varied body sizes	2
Ergonomic silhouette of foam	2
Less bulky	2
Durable fabric (long-lasting)	1
Easy to handle and carry	1
Facilitate swimming	1
Highly visible	1
Less expensive	1
Low maintenance	1
Minimum space to stow in boats	1
No Collar	1
Quick dry fabric	1
User-specific designs (for rescuers and victims)	1
Well-fitted	1

Appendix G: Questionnaire - List of Questions

Flood rescue activities
1. In how many flood rescue events have you been deployed till now?
a. None b. 0-10 c. 10-20 d. 20+
2. According to you, how dangerous are the following activities during floods? (Rate on a scale of 1 to 5: 1 being least dangerous)
Swimming in swift water 1 2 3 4 5
Save drowning people 1 2 3 4 5
Evacuate people 1 2 3 4 5
Assist people to walk 1 2 3 4 5
Move/push boats 1 2 3 4 5
Help disabled people 1 2 3 4 5
Pulls people into boats 1 2 3 4 5
Rope rescue on bridges 1 2 3 4 5
3. According to you, how difficult/hard are the following activities during floods? (Rate on a scale of 1 to 5: 1 being least difficult/hard)
Swimming in swift water 1 2 3 4 5
Save drowning people 1 2 3 4 5
Evacuate people 1 2 3 4 5
Assist people to walk 1 2 3 4 5
Move/push boats 1 2 3 4 5
Help disabled people 1 2 3 4 5
Pulls people into boats 1 2 3 4 5
Rope rescue on bridges 1 2 3 4 5
Life jackets general information
4. What is your main purpose of wearing life jacket?
a. Flotation b. Protection from hazards c. Imposed by authorities e. Not sure why
5. How necessary is to wear life jacket while performing rescue activities during floods?
a. Very necessary b. Necessary c. So so d. Least necessary e. Doesn't make difference
User satisfaction with life jackets
6. How happy are you with the life jackets you are currently using?
a. Very happy b. Fairly happy c. So so d. Not that happy e. Very unhappy
7. If you are happy, go to question 9. If you are not happy, what are the main causes of your dissatisfaction?
a. Bad Flotation
b. Blocks/disturbs body movement
c. Improper Fitting

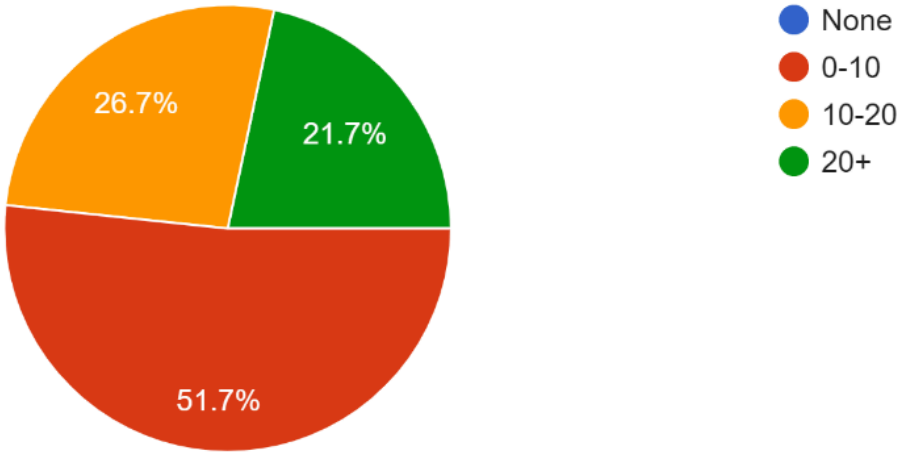
d. Difficult to wear
e. Lack of protection
f. Fabric (comfort/texture/feel)
g. Too cold while wearing the garment
h. Too hot while wearing the garment
i. Size/Volume
j. Weight
k. Aesthetics (Style/ Color / Shape)
l. Other:
8. What is/are the items of rescue-wear you are most unhappy with or think need the most improvement?
a. Foam life jacket (with collar)
b. Foam life jacket (without collar)
c. T-shirt (half sleeve / full sleeve)
a scale of 1 to 5: 1 being less convenient)
Swimming in swift water 1 2 3 4 5
Save drowning people 1 2 3 4 5

d. Shorts / Pants
e. Other:
9. How convenient are your life jackets in performing the following activities? (Rate on a scale of 1 to 5: 1 being less convenient)
Swimming in swift water 1 2 3 4 5
Save drowning people 1 2 3 4 5
Evacuate people 1 2 3 4 5
Assist people to walk 1 2 3 4 5
Move/push boats 1 2 3 4 5
Help disabled people 1 2 3 4 5
Pulls people into boats 1 2 3 4 5
Rope rescue on bridges 1 2 3 4 5
10. How good or bad are the following features in the life jackets used by you currently (Rate on a scale of 1 to 5: 1 being very bad)?
Flotation 1 2 3 4 5
Comfort 1 2 3 4 5
Protection 1 2 3 4 5
Fabric 1 2 3 4 5
Size/Volume 1 2 3 4 5
Fitting 1 2 3 4 5
Restriction of body movement 1 2 3 4 5
Overalls Performance 1 2 3 4 5
11. How important are the following features to be present in your life jackets? (Rate from 1 to 5; 1 being least important)
Flotation 1 2 3 4 5
Protection 1 2 3 4 5
Lightweight 1 2 3 4 5
Water—proof 1 2 3 4 5
Durable fabric 1 2 3 4 5
Uni-size 1 2 3 4 5
Heat friendly 1 2 3 4 5
Small and Compact 1 2 3 4 5
Adjustable 1 2 3 4 5
12. If your life jackets incorporated latest wearable technology what features would be the most important to you?
a. Inflation Jacket
b. Automatic flash light
c. GPS tracker
d. Water purifier
e. Water-proof storage pocket
Other questions
13. Is there anything you would like to add to this research?
14. What is your age?
a. 18-30 b. 31-40 c. 41-50 d. 50+
15. For how long have you been working with the Indian National Disaster Response Force (NDRF)?
a. 0-10 years b. 10-20 years c. 20+ years

Appendix H: Summary of Responses to the Questionnaire

1. In how many flood rescue events have you been deployed till now?

60 responses

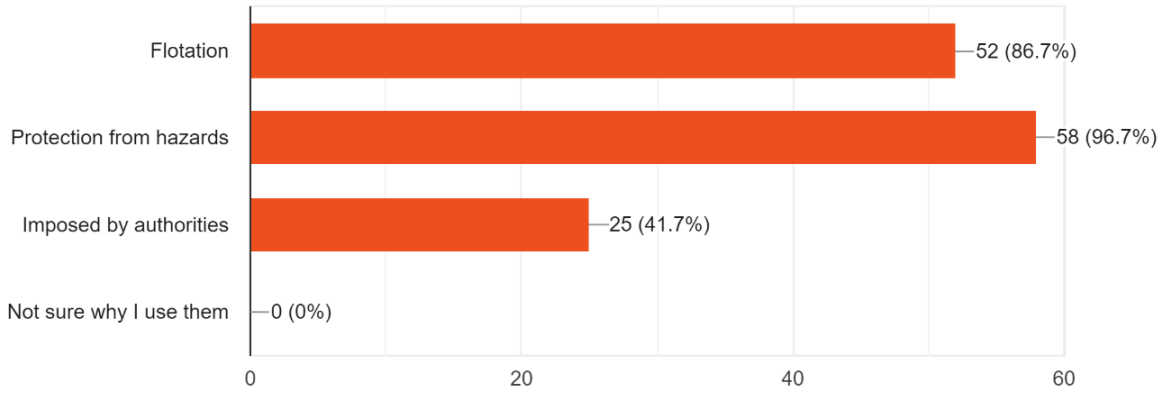


2. According to you, how dangerous are the following activities during floods? (Rate on a scale of 1 to 5: 1 being least dangerous)

3. According to you, how difficult/ hard are the following activities during floods? (Rate on a scale of 1 to 5: 1 being least difficult/hard)

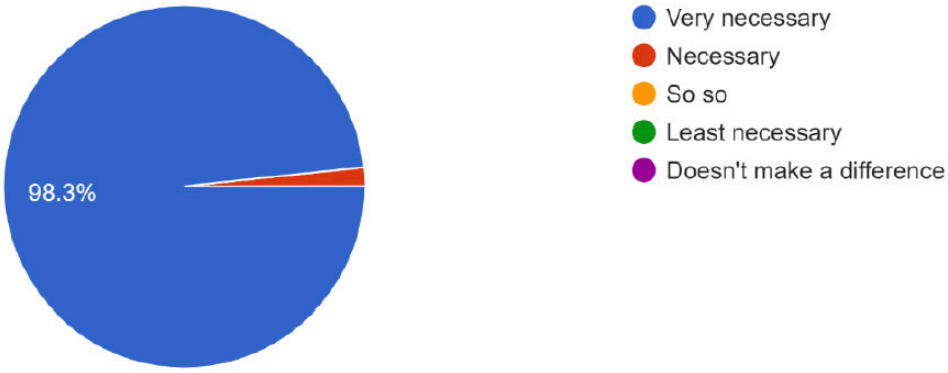
4. What is your main purpose of wearing life jacket?

60 responses



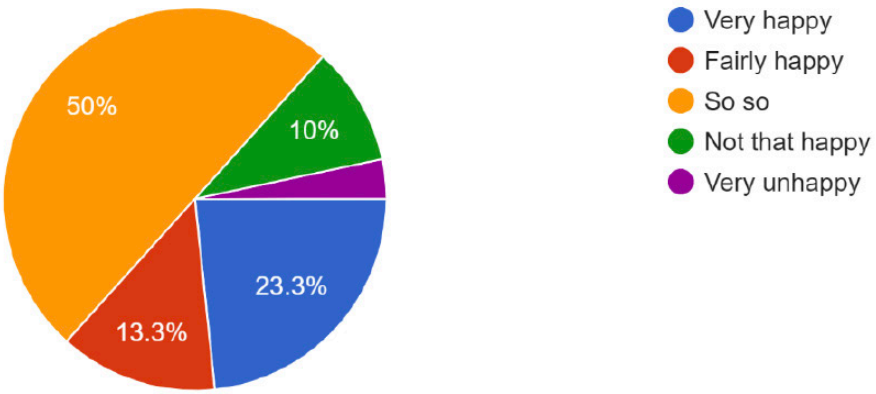
5. How necessary is to wear life jacket while performing rescue activities during floods?

60 responses



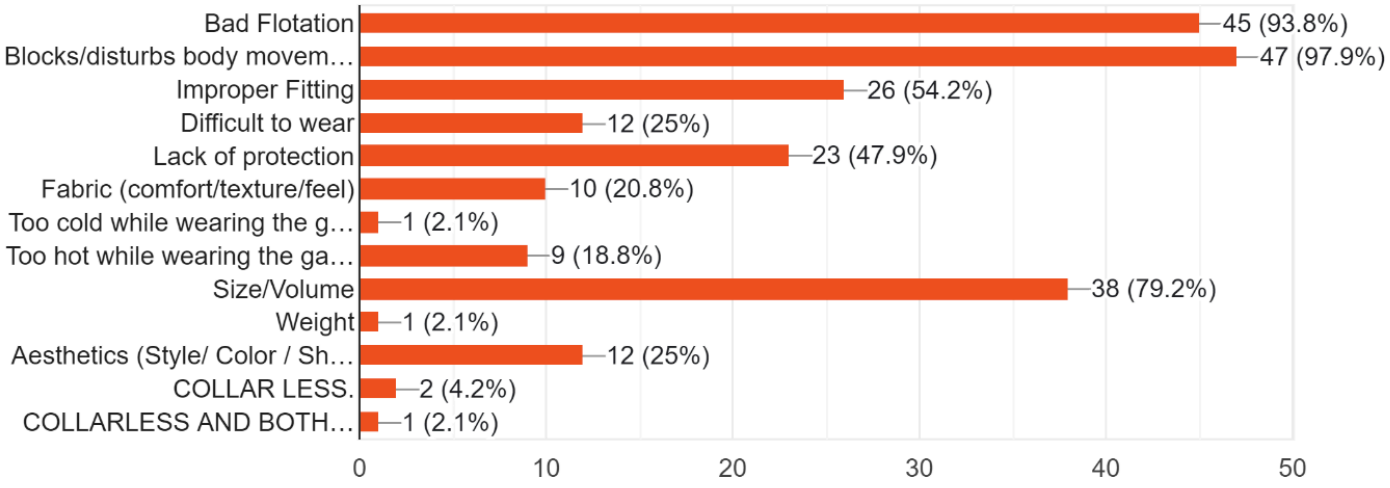
6. How happy are you with the life jackets you are currently using?

60 responses



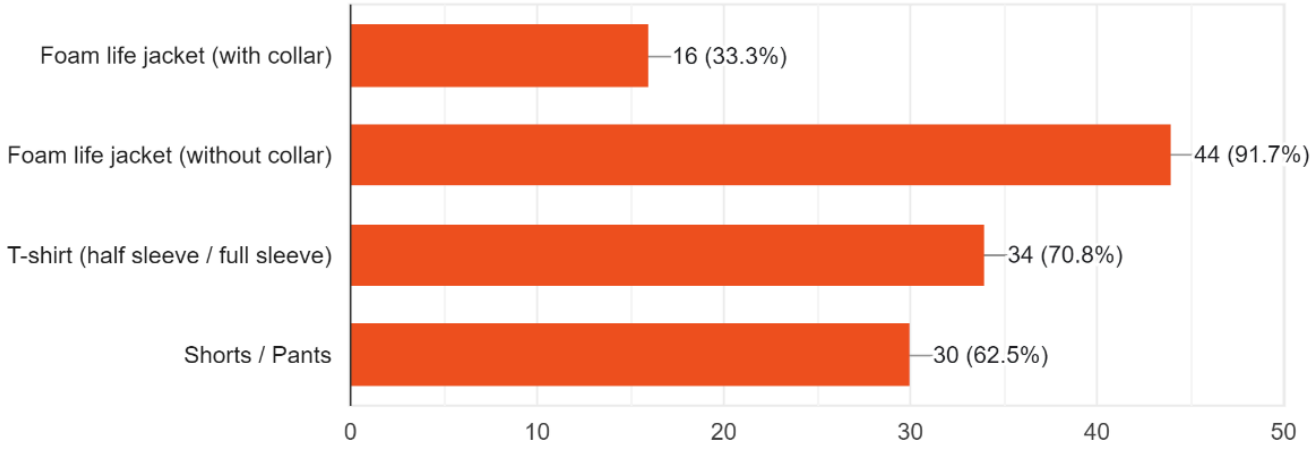
7. If you are happy, go to question 9. If you are not happy, what are the main causes of your dissatisfaction?

48 responses



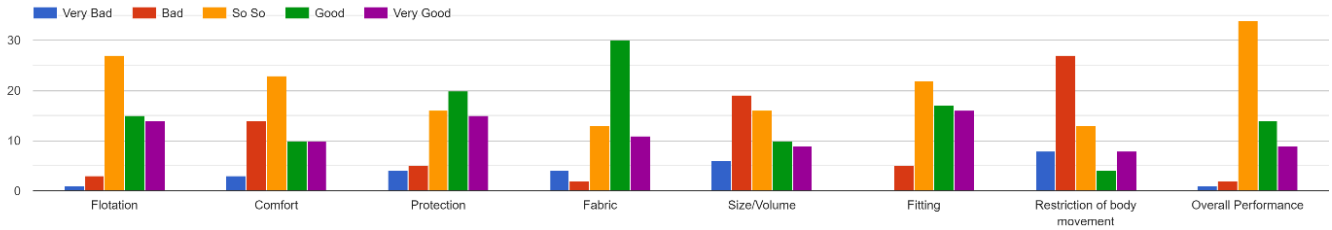
8. What is/are the items of rescue-wear you are most unhappy with or think need the most improvement?

48 responses

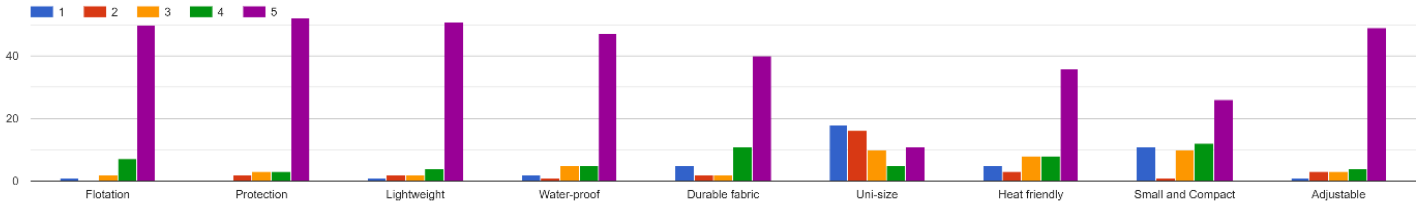


9. How convenient are your life jackets in performing the following activities? (Rate on a scale of 1 to 5: 1 being less convenient)

10. How good or bad are the following features in the life jackets used by you currently?

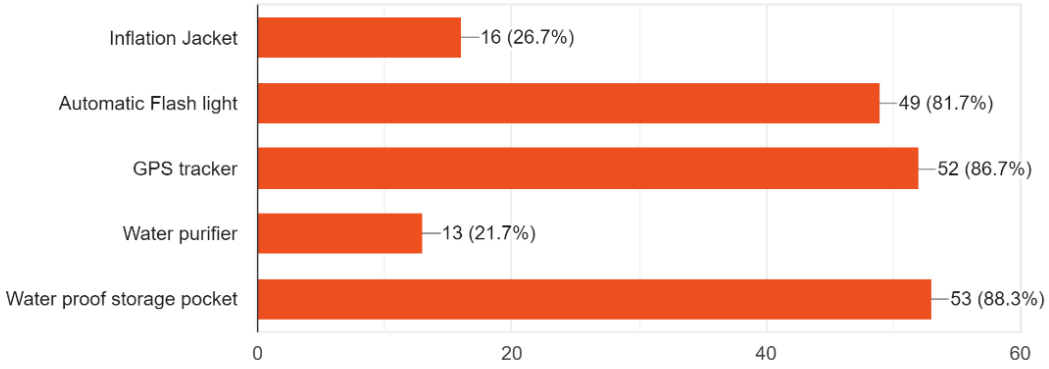


11. How important are the following features to be present in your rescue-wear? (Rate from 1 to 5; 1 being least important)



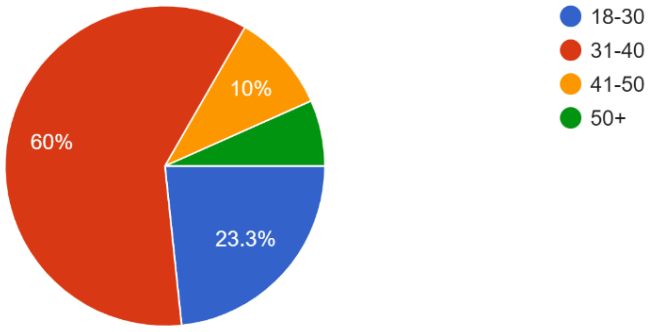
12. If your life jackets incorporated latest wearable technology what features would be the most important to you?

60 responses



14. What is your age?

60 responses



Appendix I: Matrix Evaluation of Concepts Generated

Each of the concepts developed is marked out of 5 points for each of the modified design criteria established. The reversible life jacket and crossover life jacket concepts scored 22 and 26 each out of 30 points. The crossover style concept scored significantly higher than the rest.

Table I1: Evaluating concepts in relation to modified design criteria

Design Criteria	**Concept 1 (Raglan Sleeve Padded)**	**Concept 2 (Modular Life jacket)**	**Concept 3 (Reversible Life jacket)**	**Concept 4 (Ventilated Life jacket)**	**Concept 5 (Crossover Life jacket)**
Comfort	5	3	5	4	5
Fitting	5	4	4	2	5
Ease of Donn & Doff	1	1	5	1	5
Safety	4	5	2	3	3
Handling & Storage	2	2	2	2	3
Performance	4	4	4	2	5
Total Score	21	19	22	14	26

Appendix J: Materials used to prototype cross-over style concept iterations

Table 6.1: Textile Materials Used to Prototype Crossover Style Concept Iterations

Fabric	Outer fabric – Oxford Nylon, 210 Denier (Fluoro Yellow color)
Foam	Lightweight Expanded Polyethylene foam (EPE); closed-cell, hard feel
Trims	Plastic Buckle (Width: 5cm and 3.2cm)
Webbing	Polyester (Width: 5cm)
Sewing thread	Nylon; 120GSM
Hook n Loop	Sew on; Black color (Width: 3cm)

Appendix K: Dryland trial 1

Photographs of all participants donning Existing and Crossover life jacket designs

Figure K1: Photographs of all participants donning E1

Figure K2: Photographs of all participants donning E2

Figure K3: Photographs of all participants donning E3

Figure K4: Photographs of all participants donning V1

Figure K5: Photographs of all participants donning V2

Figure K6: Photographs of all participants donning V3

Figure K7: Photographs of all participants donning V4

Figure K8: Photographs of all participants donning V5

Figure K9: Photographs of all participants donning V6

Figure K10: Photographs of all participants donning V7

Appendix L: Dryland trial 2

Table L1: Dryland Trial 2 Participants' details

Participant Number	Gender	Age	Chest (in cm)	Height (in cm)
P1	Female	18-30	109	185
P2	Female	31-40	83	165
P3	Male	31-40	103	189
P4	Male	18-30	95	177
P5	Female	18-30	118	157
P6	Male	50+	115	173
P7	Male	41-50	107	175
P8	Female	18-30	89	179
P9	Female	18-30	77	157
P10	Female	18-30	84	165

Photographs of all participants donning R5 life jacket in Dryland trial 2

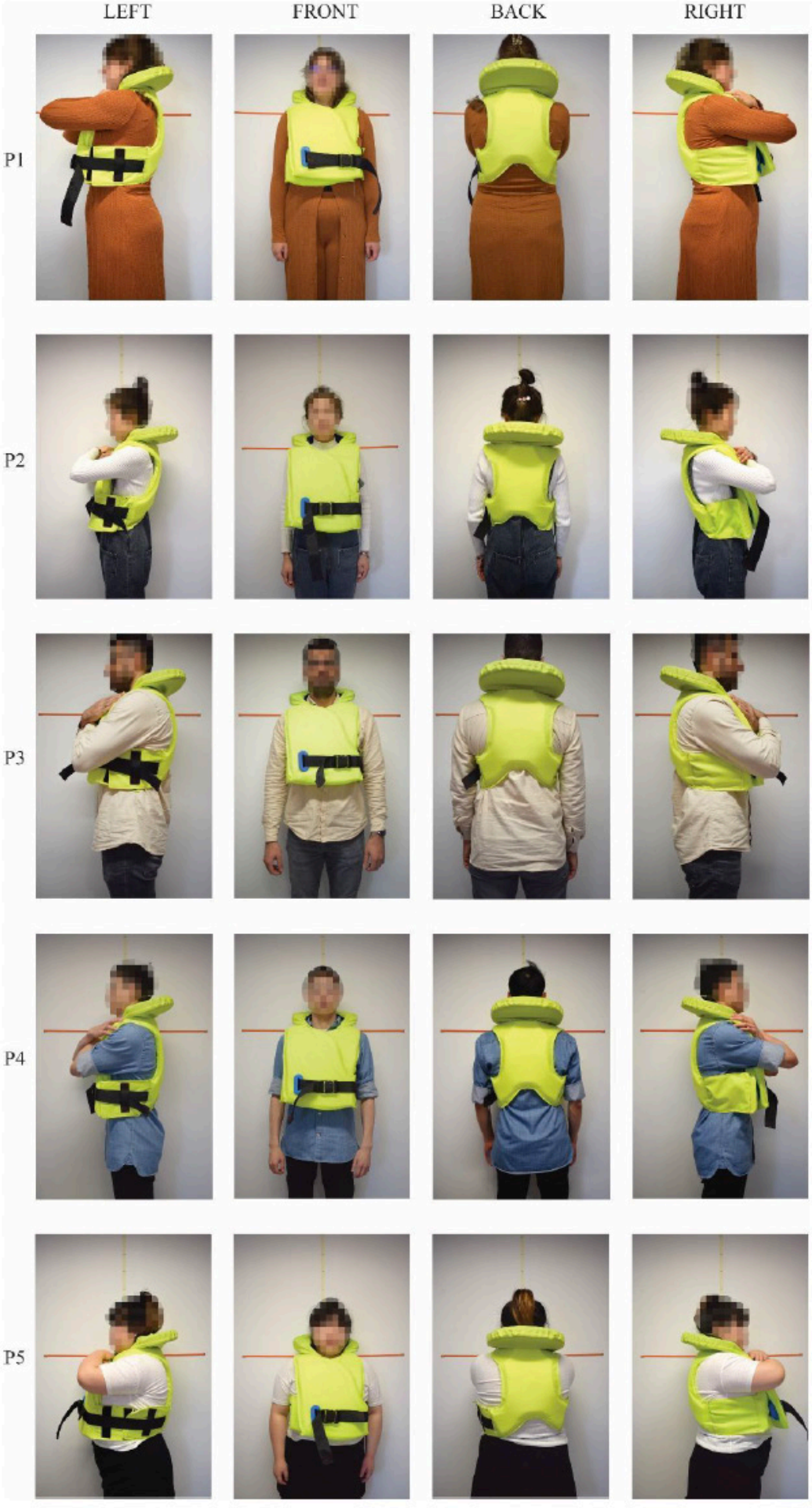


Figure L1: Photographs of participants P1 to P5

Figure L2: Photographs of participants P6 to P10

Table L2: Intuitiveness to donn and doff

Participant Number	R5 Intuitiveness / Easy to wear	R5 Intuitiveness / Easy to remove	E1 Time to wear	E1 Time to remove	R5 Time to wear	R5 Time to remove
P1	4	5	38	8	22	5
P2	3	5	35	8	61	10
P3	2	4	26	7	31	9
P4	2	2	34	8	42	7
P5	3	4	50	8	65	13
P6	4	5	50	7	39	7
P7	3	5	41	11	74	12
P8	5	5	21	7	17	7
P9	3	4	30	7	30	7
P10	3	4	66	12	58	12
Average	**3.2**	**4.3**	**39.1**	**8.3**	**43.9**	**8.9**

Table L3: Comfort

Participant Number	Torso	Head	Arms	Sit/Stand	Bending	Rowing	Irritation
P1	4	5	5	5	5	5	No
P2	3	5	5	5	5	3	No
P3	2	4	4	4	3	2	No
P4	5	5	5	5	5	5	No
P5	4	4	4	5	5	4	No
P6	4	4	5	5	3	5	Yes
P7	5	5	5	5	5	5	No
P8	3	4	4	4	3	5	No
P9	4	5	4	5	4	2	No
P10	4	5	3	4	5	2	No
Average	**3.8**	**4.6**	**4.4**	**4.7**	**4.3**	**3.8**	**NO**

Table L4: Fit, Adjustability and Volume

Participant Number	Fitting	Adjustability	Bulky
P1	2	5	4
P2	2	4	5
P3	3	4	2
P4	5	5	5
P5	4	3	5
P6	4	4	4
P7	5	5	5
P8	3	3	2
P9	4	4	4
P10	4	5	4
Average	**3.6**	**4.2**	**4**

Table L5: Overall comments of the participants

Participant Number	Comments
P1	The experience was much more comfortable, I had more room to move around. Yes, I would prefer the new life jacket.
P2	I felt that my back was very supportive by the back shape of the life jacket. But my chest was pressed by the jacket. The jacket fits me well and is not bulky. I prefer the new jacket to the old one.
P3	I felt a bit confused when I wore the new life jacket, but it is good when performing all the activities compared to the existing life jacket. The foam panels are too flat and put pressure on my chest. Because the form is hard, the contoured shape doesn't help with anything. The wide foam obstructs rowing action at the shoulder.
P4	Yes, I prefer the new life jacket because it is easier to move and perform all activities. Entry into the life jacket was a bit confusing, but once I knew how to enter, the wearing time reduced drastically.
P5	The left side panel is falling back. It needs to stay forward for easy catching in reach of the hand and attach to Velcro. A hard panel like that in backpacks would be good for easy holding. Some extra inches of fabric needs to be added on the right side panel.
P6	It is quick and easy but catches me under the chin a little, could be adjusted with some recontouring.
	Left side Velcro panel is hard to reach.
P7	The side panel needs to be easier to lock.
P8	Yes, I believe the new life jacket is better than the existing design. Having good back movement is excellent for rowing, plus it did not feel too bulky. Psychologically feels strangled around the neck. The width of the foam at the front chest level can be reduced a little bit inwards to provide more range of motion to the hands. Make the front panels at waist contoured to the body shape so that they don't stay hard and hit the hand.
P9	I felt very secure in the new life jacket and it doesn't ride up easily when I'm sitting, bending or rowing.
P10	Yes, it was much easier to adjust to my size. The wide foam panel on the front restricts hand movement at chest level to reach the other side.

Appendix M: Dryland trial 3

Table M1: Dryland Trial 3 Participants details

Participant Number	Gender	Age	Chest (in cm)	Height (in cm)
P1	Female	18-30	89	157
P2	Male	18-30	96	181
P3	Female	18-30	108	185
P4	Male	50+	107	175
P5	Female	31-40	98	177
P6	Male	31-40	103	188
P7	Male	50+	97	168
P8	Female	18-30	76	157
P9	Male	18-30	84	175
P10	Female	18-30	108	162
P11	Male	18-30	98	180
P12	Female	31-40	95	150
P13	Male	18-30	104	182
P14	Male	18-30	128	195
P15	Male	41-50	102	181
P16	Female	18-30	84	166
P17	Female	31-40	83	165

Photographs of all participants donning
R6 life jacket in Dryland trial 3

Figure M1: Photographs of participants P1 to P5

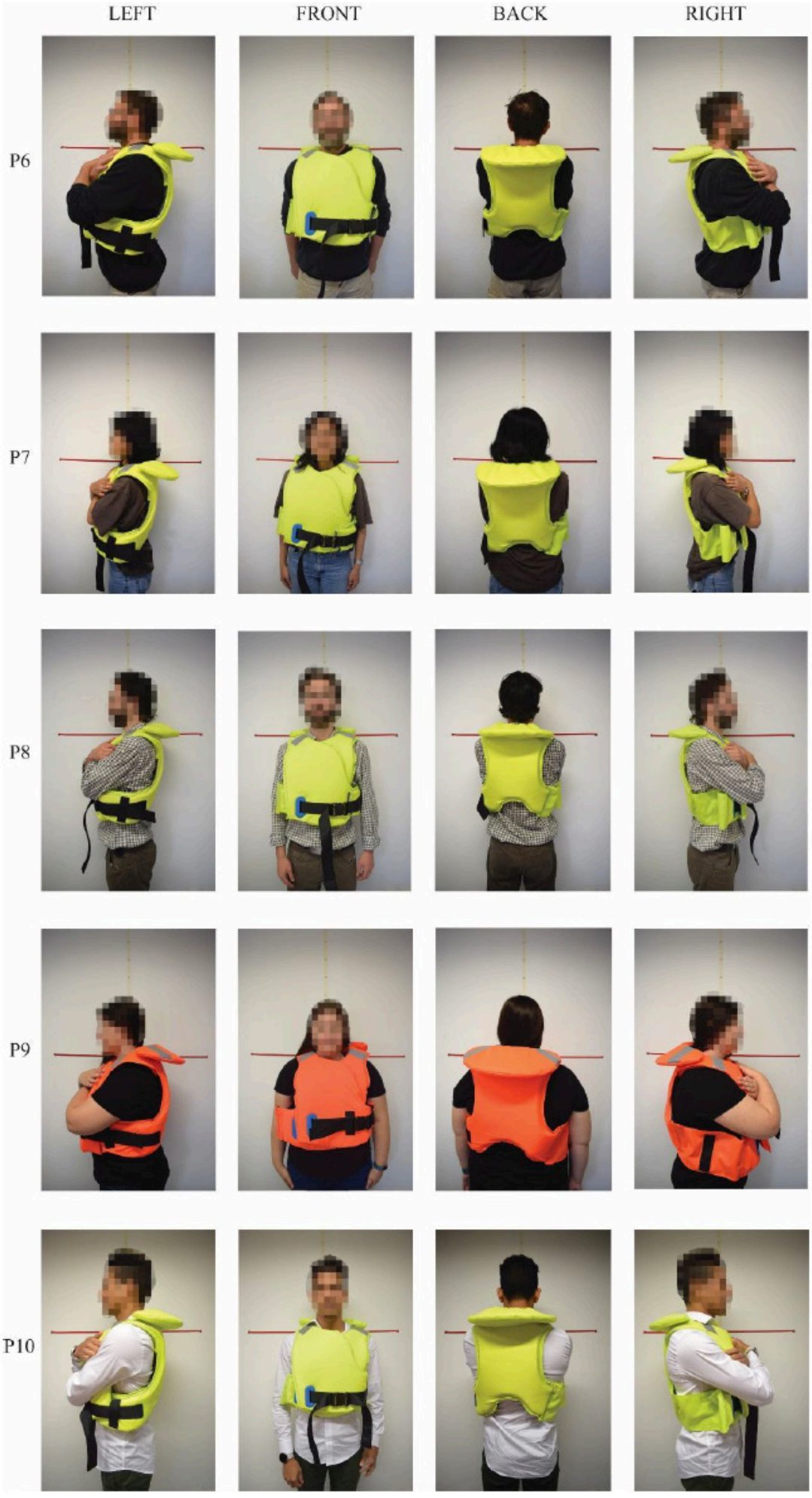


Figure M2: Photographs of participants P6 to P10

Figure M3: Photographs of participants P11 to P15

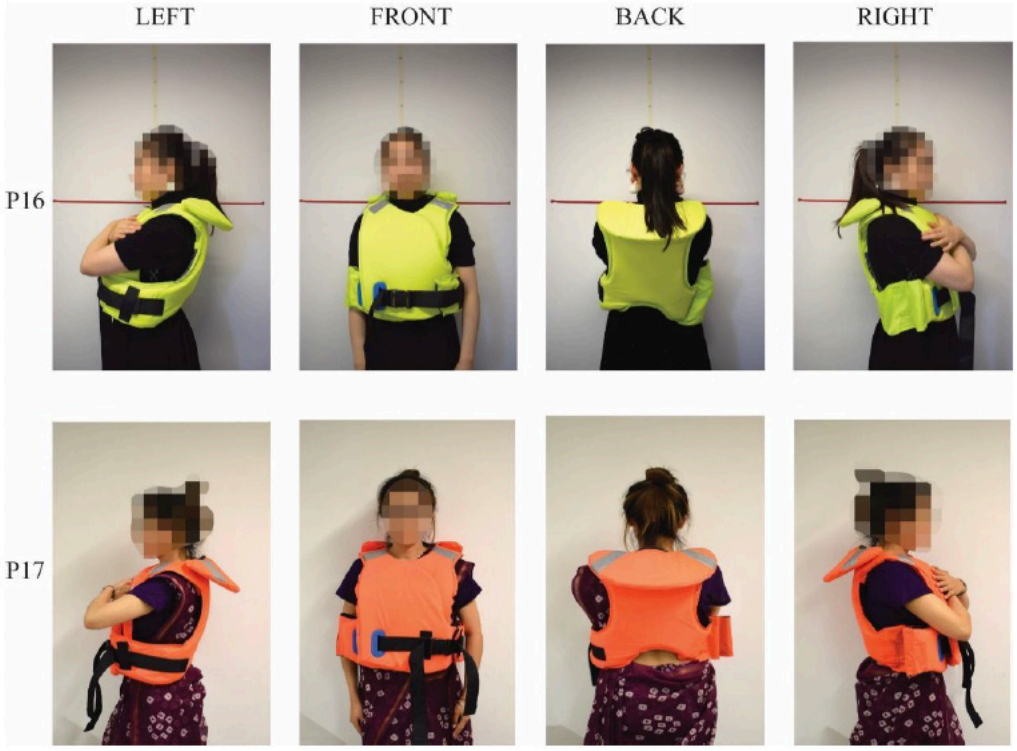


Figure M4: Photographs of participants P16 to P17

Participants' responses to the questionnaire

Table M2: Intuitiveness to donn and doff

Participant Number	Intuitiveness / Easy to wear	Intuitiveness/ Easy to remove	E1 Time to wear	E1 Time to remove	R6 Time to wear	R6 Time to remove
P1	4	4	40	10	21	5
P2	4	5	26	6	18	4
P3	5	5	38	8	16	5
P4	5	5	41	10	38	5
P5	4	4	38	6	19	6
P6	3	4	26	7	35	4
P7	4	5	38	9	28	5
P8	5	5	40	8	15	4
P9	4	4	34	9	15	8
P10	3	4	55	10	22	6
P11	5	5	16	6	10	3
P12	5	5	30	8	24	5
P13	3	5	54	8	44	4
P14	5	4	65	6	6	4
P15	5	5	54	12	8	4
P16	4	5	43	9	15	7
P17	5	5	47	10	15	3
Average	**4.3**	**4.6**	**40.3**	**8.4**	**20.5**	**4.8**

Table M3: Comfort

Participant Number	Torso	Head	Arms	Sit/Stand	Bending	Rowing	Irritation
P1	4	4	4	4	3	4	No
P2	5	5	5	5	5	5	No
P3	5	5	4	5	5	4	No
P4	5	5	5	5	5	5	No
P5	4	5	5	4	5	5	No
P6	4	5	4	4	4	4	No
P7	5	5	5	5	5	5	No
P8	5	5	5	5	5	5	No
P9	5	5	5	5	4	5	No
P10	5	4	4	4	4	4	No
P11	5	5	4	5	4	4	No
P12	4	5	5	5	5	4	No
P13	5	5	5	5	5	5	No
P14	5	5	5	5	4	5	No
P15	5	5	5	5	5	5	No
P16	5	5	5	5	5	5	No
P17	5	5	5	5	5	5	No
Average	**4.8**	**4.9**	**4.7**	**4.8**	**4.6**	**4.6**	**NO**

Table M4: Fit, Adjustability and Volume

Participant No.	Fitting	Adjustability	Bulky
P1	4	4	4
P2	5	5	4
P3	4	5	4
P4	5	5	5
P5	5	4	4
P6	4	4	3
P7	5	4	4
P8	5	5	5
P9	5	5	4
P10	4	3	4
P11	5	5	4
P12	5	5	5
P13	5	5	5
P14	5	5	4
P15	5	5	5
P16	5	5	4
P17	5	5	5
Average	**4.8**	**4.6**	**4.3**

Table M5: Overall comments of the participants

P1	The new life jacket fits me much better than the traditional life jacket and movement during sitting, bending and rowing is much easier. Technical suggestion: Join the right-side panel to the back using a flat felt stitch for a better finish. Smooth the edges of the collar on the outside curve. Smoothen the edges of the contoured foam steps in the front panel with darts.
P2	The new life jacket is very comfortable to wear. It feels snug and secure while allowing me to perform any movement. Compared to the traditional life jacket, this jacket is more comfortable for sitting, bending forward and performing rowing action. As long as it performs the same function and is safe, I'd prefer to use this life jacket. Especially in high stress scenarios needing a wide range of movement or scenarios where I'd have to sit and row for a continuous periods of time.
P3	Very comfortable compared to other life jackets, especially regarding the movement of the head and arms. I would prefer this one.
P4	-
P5	This new life jacket is more adaptable to the human's body. It is well designed according to the height and chest measurement. The traditional one is way looser on my body compared to the new life jacket.
P6	I saw a good improvement from the first prototype, so I felt comfortable. Round the edges of the front panels at the waist, so it doesn't hit the hand. Also, contour the front panel edges to the body at waist level (curve it to the body).
P7	-
P8	Yes, this life jacket was way more comfortable in comparison to the traditional life jacket. The material (foam) felt more breathable. I could move around my arms and body comfortably even with a tighter fit.
	Suggestion: Think about where the wearer can put the hands after wearing the new life jacket and maybe provide handles or a cue for comfortable hold.
P9	The new life jacket has better range of movements, snug fit and quick to put on and adjust.
P10	I would prefer this life jacket to a traditional one. Even with my short torso, it fits better and allows me to move freely while walking and bending over. The width of life jacket at shoulder is too wide.
P11	-
P12	Since I'm of the size NZ 10-12 and 5 feet in height, I found existing life jackets were always bulky and bigger. It always covers my ears when I'm sitting. I prefer the crossover life jacket because it is very comfortable and adjustable with my body type.
P13	The life jacket provides a good range of movement for my arms. The fit is very good and body-hugging which I like. I was confused a little bit while putting my hand through the life jacket.
P14	I would prefer this new jacket because it looks promising and comfortable.
P15	Overall feeling of the life jacket is great. I prefer this a lot to the existing life jacket. Also, the new life jacket design does not hit my back when bending forward or in a sitting position.
P16	The new life jacket design is strongly different and yes I would prefer to wear this than the existing life jacket.
P17	This prototype is much better than the previous one I tried. The foam is very comfortable and feels lighter on my body. The contouring of the life jacket to my body makes it feel secure and a snug fit. Bending, rowing and lifting tasks are easy to perform in this life jacket.

Appendix N: Aquatic Trials

Participants' details

Table L1: Dryland Trial 3 Participants details

Participant Number	Gender	Age	Chest (in cm)	Height (in cm)	Weight (in Kg)	R6 Life Jacket Color Chosen
P1	Male	18-30	97	189	82.3	Citrus Yellow
P2	Female	18-30	90	169	69	Bright Orange
P3	Female	18-30	87	182	70	Bright Orange
P4	Male	18-30	95	180	76	Bright Orange
P5	Male	18-30	112	180	98	Bright Orange
P6	Male	18-30	105	175	83.7	Citrus Yellow

Participants' responses to the questionnaire

Table L2: Intuitiveness to donn and doff

Participant Number	E1 Intuitiveness to donn	R6 Intuitiveness to donn	E1 Intuitiveness to remove	R6 Intuitiveness to remove	R6 Donning time
P1	4	3	5	4	19
P2	5	4	5	5	18
P3	4	3	4	4	25
P4	5	4	5	4	13
P5	5	4	5	3	35
P6	5	4	5	4	19
Average	**4.7**	**3.7**	**4.8**	**4.0**	**21.5**

Table L3: Comfort

Participant Number	Torso		Head		Freestyle Swimming		Backstroke Swimming	
	E1	R6	E1	R6	E1	R6	E1	R6
P1	3	4	4	4	5	5	2	4
P2	4	3	4	4	4	5	2	5
P3	3	4	2	4	4	4	3	4
P4	5	5	5	5	4	5	3	4
P5	5	2	5	4	5	4	5	3
P6	3	3	5	5	4	4	4	4
Average	**3.8**	**3.5**	**4.2**	**4.3**	**4.3**	**4.5**	**3.2**	**4.0**

Table N4: Fit and Adjustability

Participant Number	E1 Fitting	R6 Fitting	E1 Adjustability	R6 Adjustability
P1	3	4	2	3
P2	4	5	3	5
P3	3	4	3	4
P4	3	4	4	4
P5	5	2	5	2
P6	4	5	3	4
Average	**3.7**	**4.0**	**3.3**	**3.7**

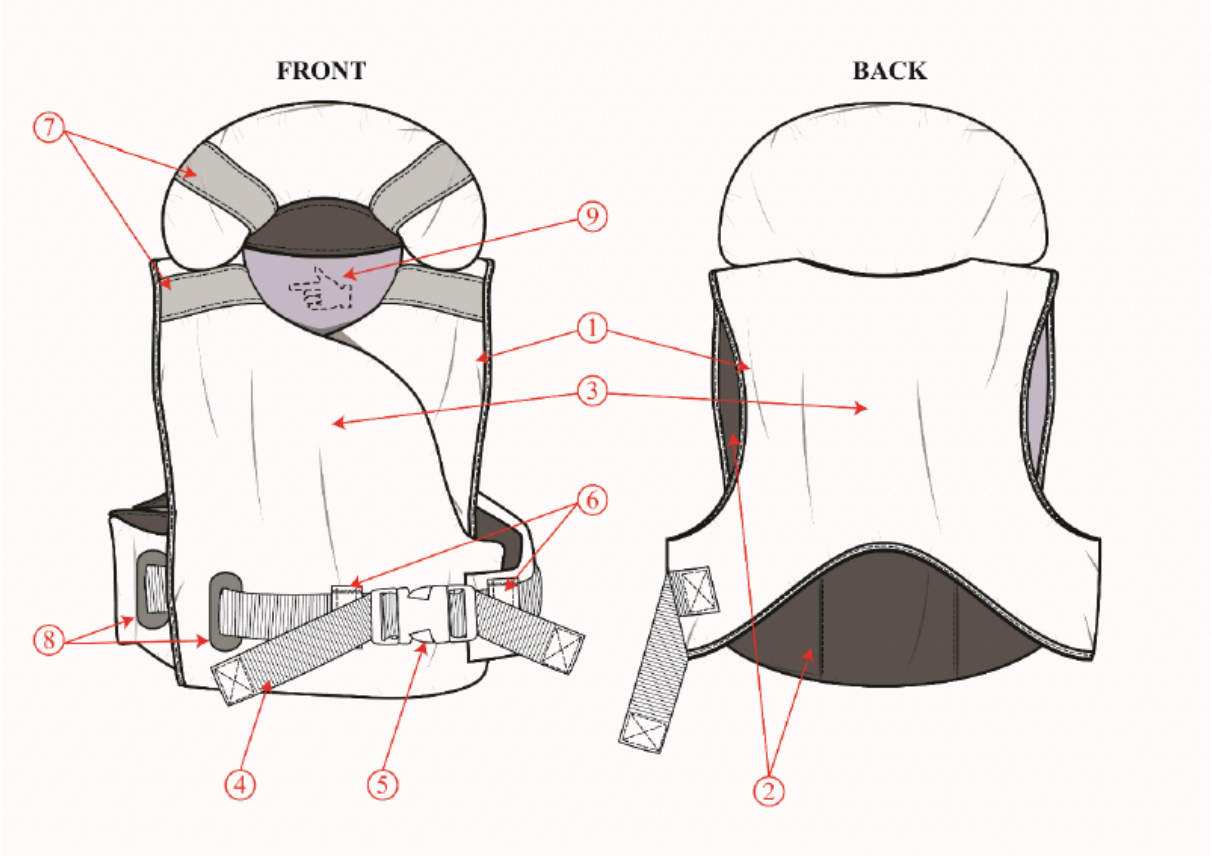
Table N5 Flotation

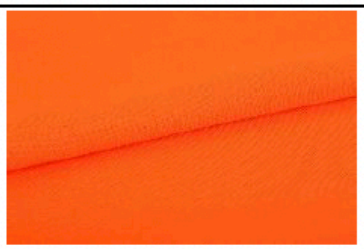
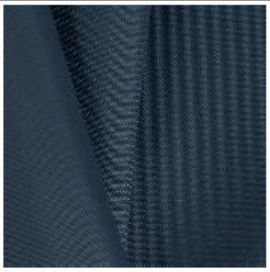
Participant Number	Flotation		Self-Righting		Self-Righting Status	Freeboard Status	Rescue
	E1	R6	E1	R6	R6	R6	R6
P1	4	4	4	4	Yes	Yes	5
P2	4	5	3	5	Yes	Yes	5
P3	4	5	4	4	Yes	Yes	4
P4	5	5	4	4	Yes	Yes	5
P5	5	3	5	2	No	No	2
P6	5	5	4	4	Yes	Yes	5
Average	**4.5**	**4.5**	**4.0**	**3.8**	**YES**	**YES**	**4.3**

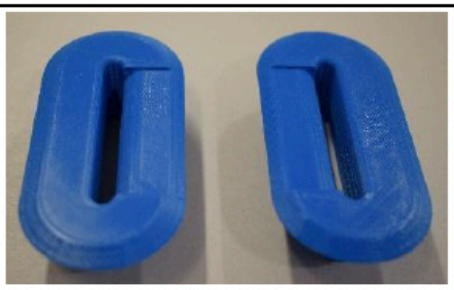
Appendix O: Technical Specifications of the 'Slot n Slide' Panel Life Jacket

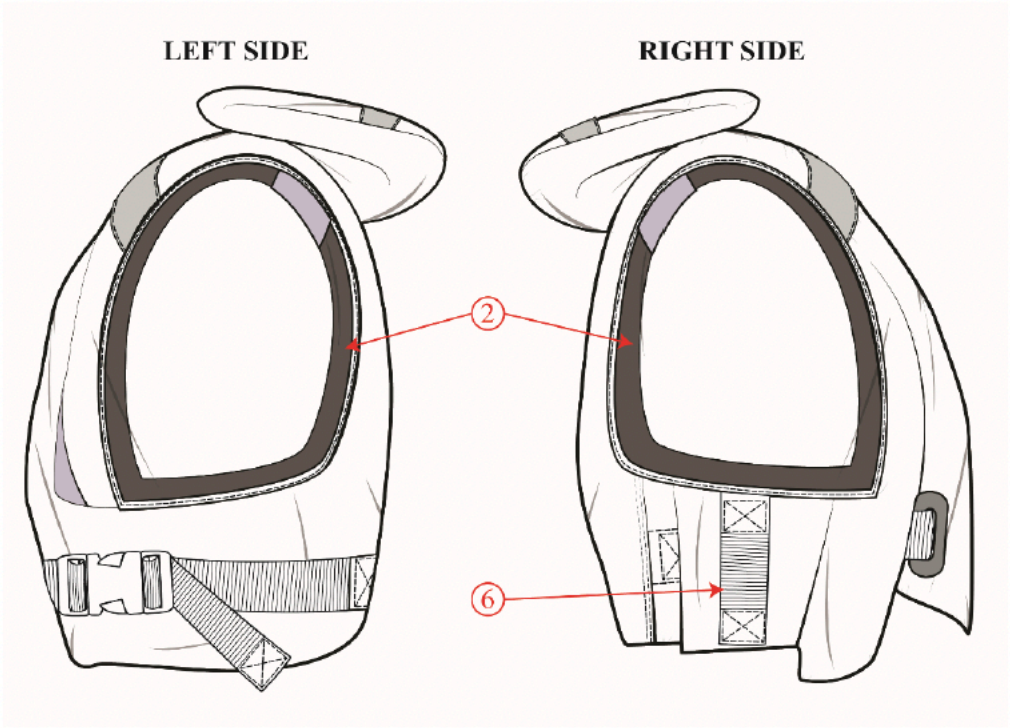
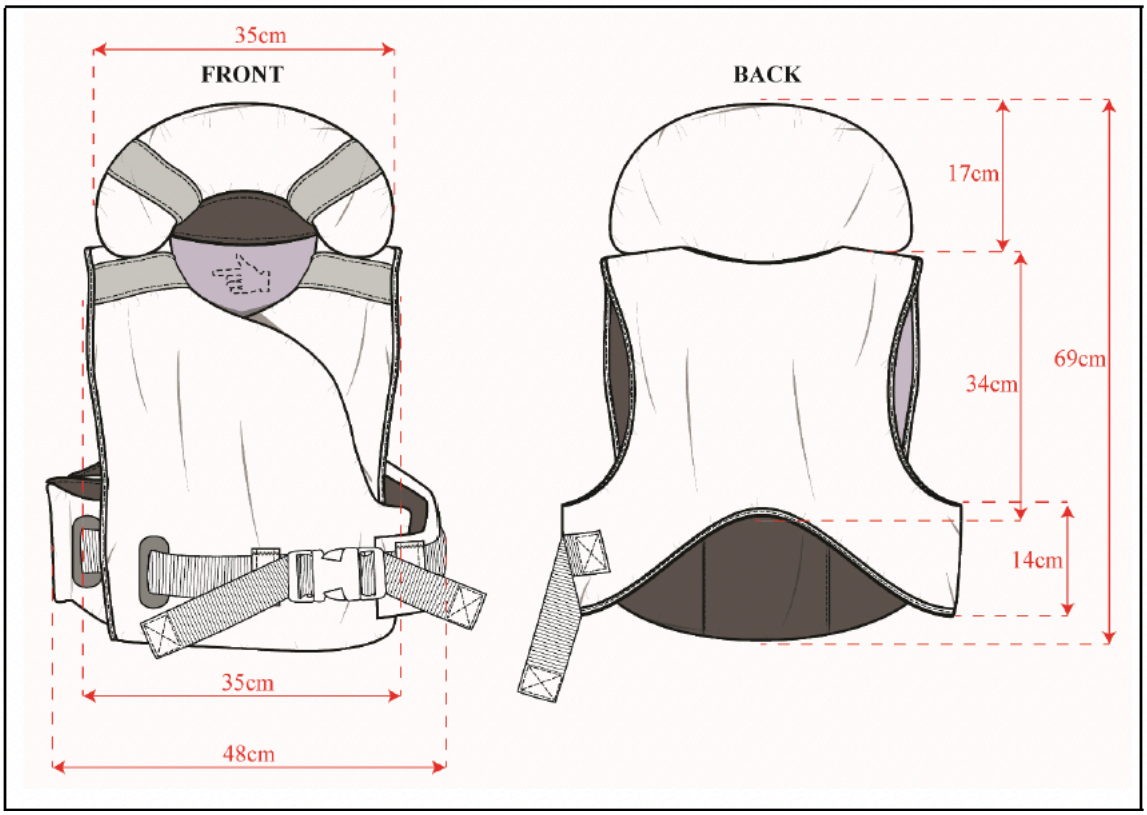
Product: Life jacket **Description:** Crossover style	**Main fabric:** Oxford Nylon **Size range:** One size fits all (Adult)

SKETCH



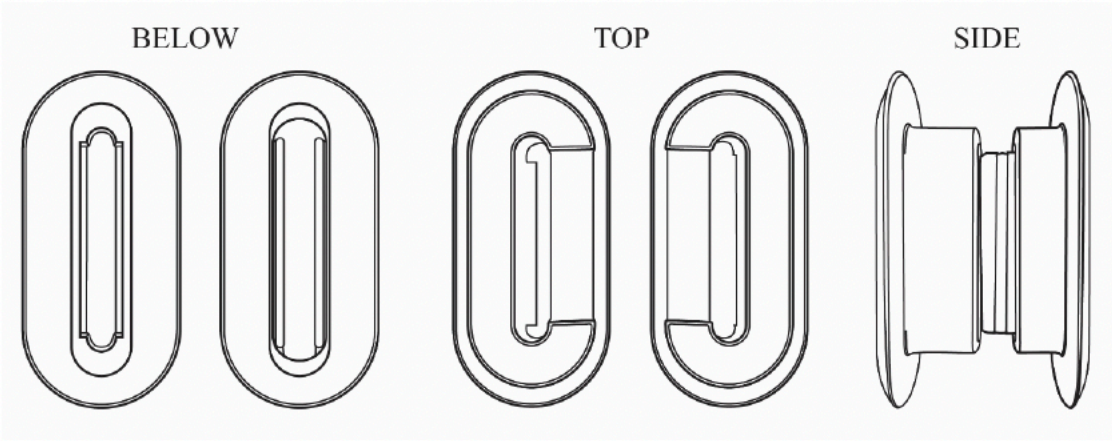
No.	Item	Description	Colour	Sample Image
1	Main Fabric	Oxford Nylon fabric 210 Denier	Fluorescent Orange PANTONE 16-1364 TPX	
2	Lining	Oxford Nylon fabric 210 Denier	Navy Blue PANTONE 1969 EOX	

3	Foam	PVC–NBR foam	White	
4	Waist-belt	Polyester Black Webbing Width: 5cm	Black	
5	Buckle	Shida plastic buckle	Black	
6	Loops	Polyester Black Webbing Width: 5cm	Black	
7	Strap guide	3D printed ABS filament	Blue	
8	Reflective tape	Safety warning bright silver flash fabric – Sew on clothing	Bright silver	

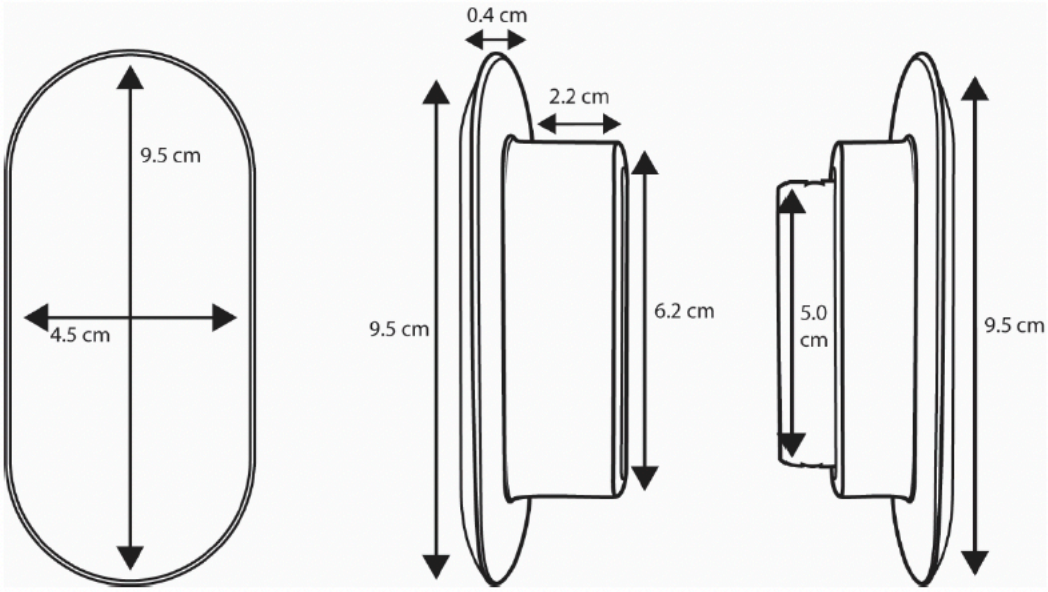
SIDE VIEW SKETCH				
				
MEASUREMENTS OF THE PRODUCT				
				

Innovative componentry: 3D printed strap guide

Component views:



Component dimensions:



Bill of Materials (BOM)

No.	Description	Colour	Supplier	Qty	Price per Unit	Total Price
1	Oxford Nylon fabric (durable and shower-proof)	Fluorescent Orange PANTONE 16-1364 TPX	The fabric warehouse, Wellington, NZ	1.5m	NZD 9.00	NZD 13.50
2	Oxford Nylon fabric (durable and shower-proof)	Navy Blue PANTONE 1969 EOX	The fabric warehouse, Wellington, NZ	0.6m	NZD 9.00	NZD 5.40
3	Foam	PVC–NBR foam (140cm x 210cm)	Texspec NZ Ltd, Auckland, NZ	0.5	NZD 64.00	NZD 32.00
4	Webbing Strap	Polyester Black Webbing Width: 5cm	WT Distributors Ltd. Auckland, NZ	2.5m	NZD 1.38	NZD 3.45
5	Buckle	Shida plastic buckle	Yongsheng Rubber & Plastic Co., Ltd. China	1	NZD 2.50	NZD 2.50
6	Reflective tape	Bright silver Width – 5cm	Xin safe tape store, China	0.4m	NZD 2.11	NZD 0.84
7	Strap guide	3D Printed ABS filament	Massey University	255g	NZD 10.00	NZD 10.00
8	Sewing thread	100% Polyester Count: 120s	Massey University	0.10	NZD 5.40	NZD 0.54
Total price						**NZD 68.23**

Production Process

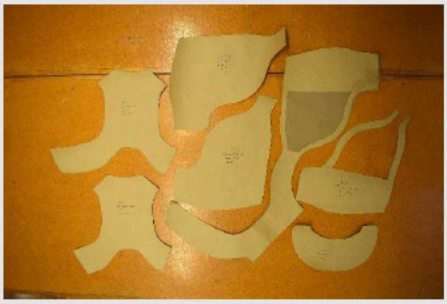
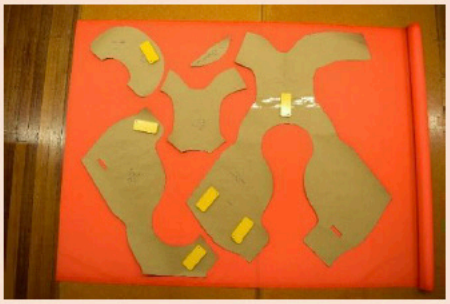
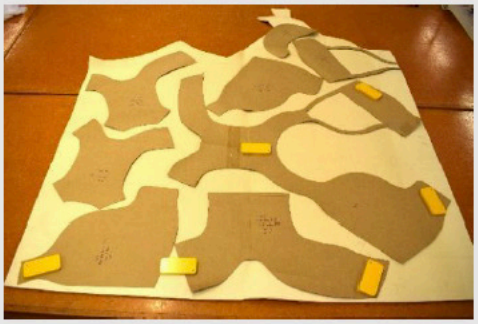
The production process to develop the crossover style life jacket is divided into 2 stages:

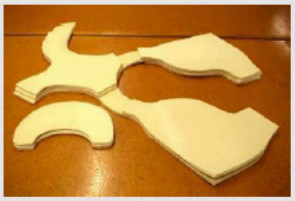
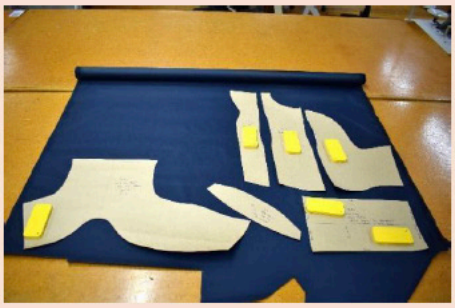
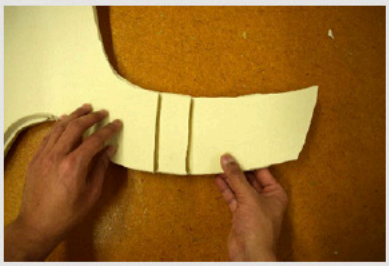
1. Patternmaking and Cutting and 2. Construction

Patternmaking and Cutting

The patternmaking and cutting process includes preparing patterns, laying out and cutting fabric and foam followed by preparing trims including plastic buckle, 3D printed guide, reflective tape and webbing straps. The patternmaking and cutting processes of fabric and foam are done simultaneously. Hence, the detailed steps of pattern making and cutting of fabric and foam are listed in parallel columns

Patternmaking and cutting process

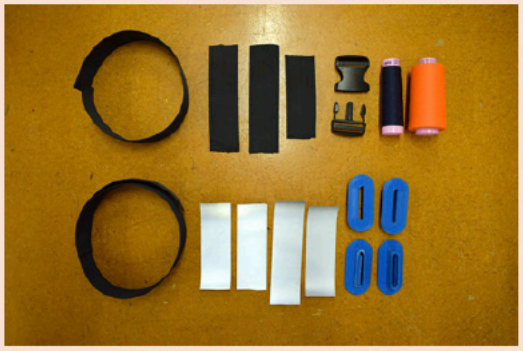
Fabric		Foam
Step 1: Draft all patterns for fabric 		Step 1: Draft all patterns for foam 
Step 2: Place appropriate patterns on the outer fabric 		Step 2: Place appropriate patterns on a foam sheet 
Step 3: Trace fabric patterns onto the outer fabric using a chalk 		Step 3: Trace foam patterns onto the foam sheet using a marker 
Step 4: Cut the traced patterns on the outer fabric using a fabric scissor.		Step 4: Cut the traced patterns on the foam sheet using a scissor.

		
Step 5: Place aside all patterns cut from the outer fabric. 		Step 5: Glue the foam patterns on top of each other to create a one-piece layered foam + separate collar. 
Step 6: Place appropriate patterns on the lining fabric. 		Step 6: On the left panel, slit 2 lines on the inner side and pull out foam (1cm wide and 1cm deep). 
Step 7: Trace fabric patterns onto the lining fabric using chalk. 		Step 7: Apply glue in the slit and fold-in the left panel as shown in the image. 
Step 8: Cut the traced patterns on the lining fabric using a fabric scissor.		Step 8: Press and hold until the glue sets in to create a contoured shape in the left panel.

Step 9: Place aside all patterns cut from the lining fabric.

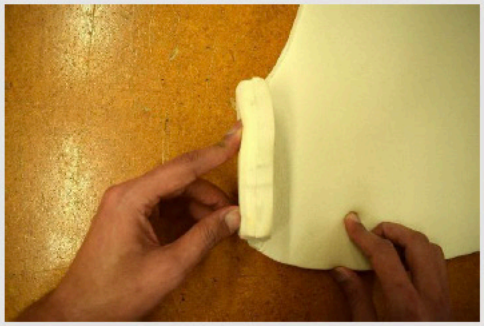
Step 9: On the left crossover panel, slit 1 line on the inner side and pull out foam (1cm wide and 1cm deep).

Step 10: Cut webbing straps of required length for waist belt on both sides and loops. Cut reflective tapes of required length, and place aside with a plastic buckle, two sets of 3D printed guides and sewing threads.



Step 10: Apply glue in the slit and fold-in the left panel as shown in the image.

Step 11: Press and hold until the glue sets in to create a contoured shape on the left crossover panel.



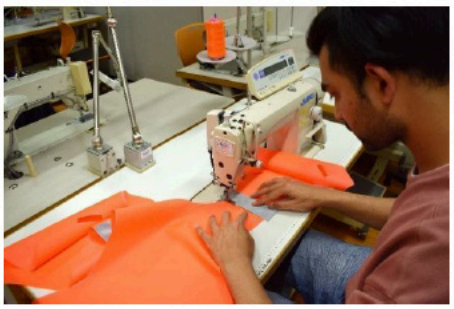
Step 12: Cut holes in the fabric and foam panels for the 3D printed guide to pass through.

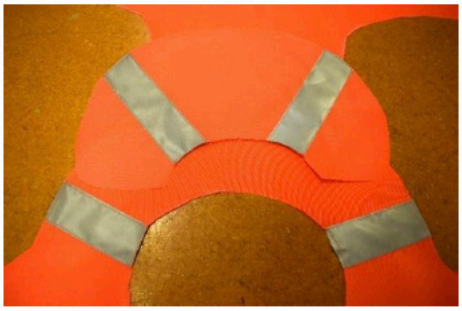
Construction Process

The construction process involves the sewing of all fabric panels including the collar, placing the foam inside the fabric, inserting 3D printed guides, attaching reflective tapes, webbing straps and a plastic buckle. The detailed steps of construction are listed in the following table.

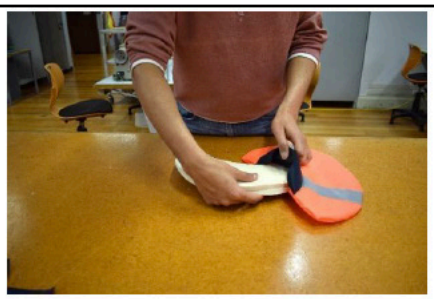
Construction process

Step 1: Sew reflective tapes on the collar and outer crossover panel.

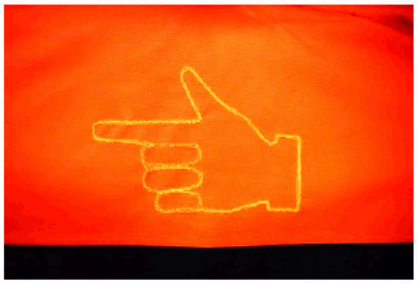




Step 2: Sew the collar panel and attach the collar stand. Insert foam into the collar

Step 3: Attach the lining panels to the under crossover panel. Embroider/ machine stitch the hand signal at the upper back position on the Fluoro orange fabric.

Step 4: Prepare the outer and under layers of the crossover panel and place the collar in between them.

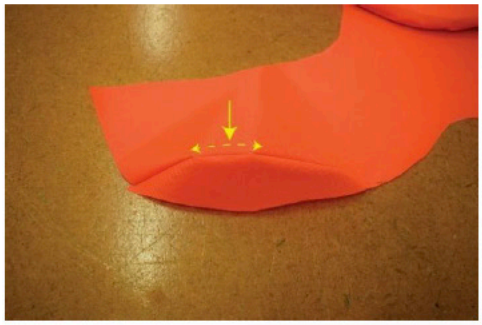

Step 5: Attach the collar to the outer and under layers of the crossover panel.

Step 6: Sew webbing straps on both sides of the right-side fabric panels.

Step 7: Attach the right-side fabric panel to the crossover panels at the front and the opposite side to the back.

Step 8: Sew waist-belt strap on top of the right-side panel.

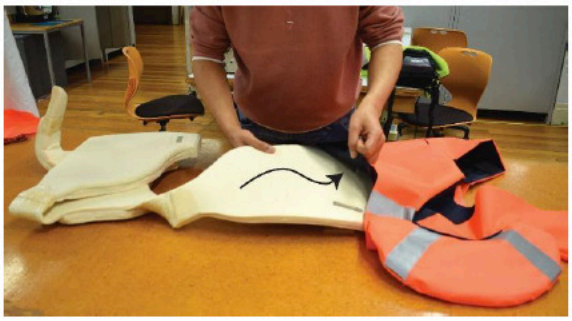
Step 9: Attach the under gusset to the left-side panel..



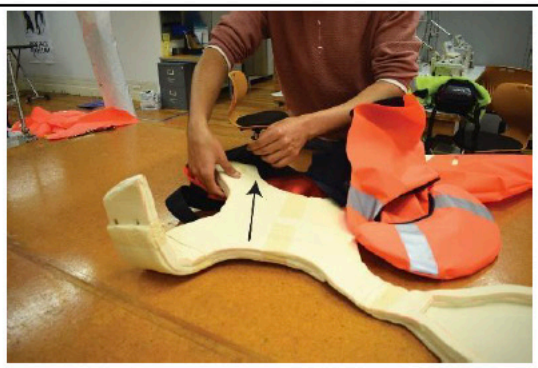
Step 10: Sew webbing loop and waist-belt strap on top of the left panel; Join the lining fabric to the outer fabric.


Step 11: Prepare the crossover fabric panel, foam, 3D printed guides and plastic buckles.

Step 12: Insert right crossover foam panel through the left fabric panels and then place inside the right fabric panels.

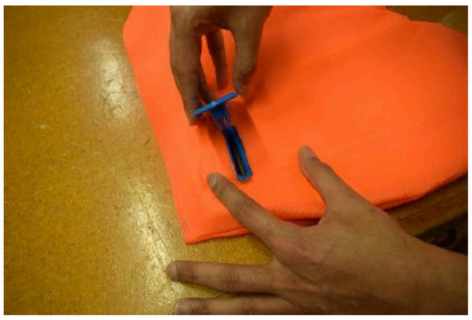


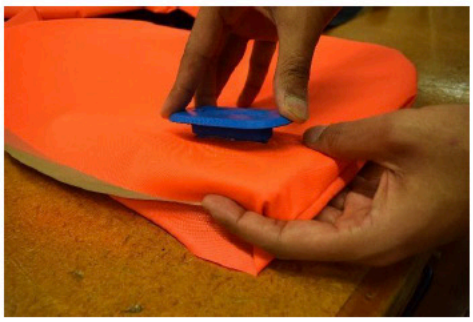

Step 13: Insert the back foam panels into the back fabric panels.



Step 14: Insert the right foam panels into the right fabric panels.

Step 15: Insert two pairs of 3D printed guides, one in each crossover front panel.

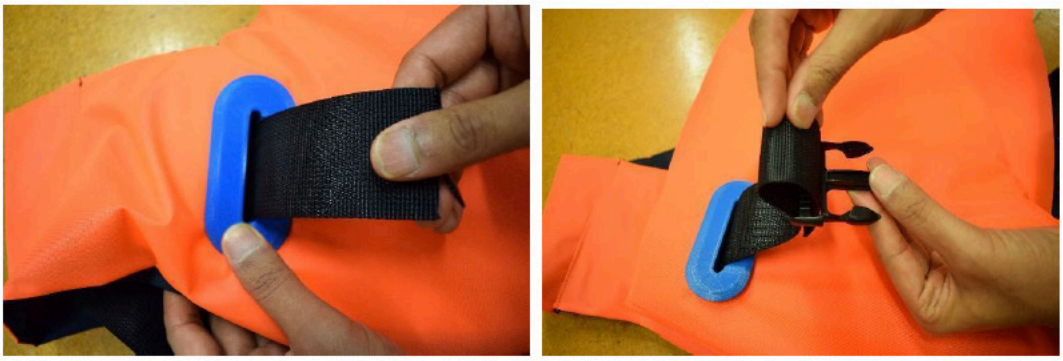




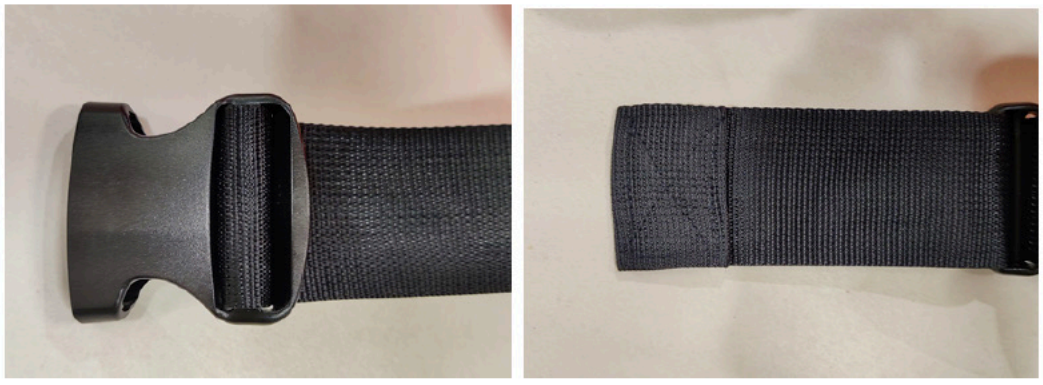
Step 16: Bind the outer edge of lower back seam line with a bias binding (Width = 4cm).

Step 17: Bind the outer edge of the main panel on both sides, starting from the front and ending at back, with a bias binding (Width = 4cm).

Step 18: Pass the webbing strap on the right-side through the 3D printed guides and pass through the appropriate plastic buckle.

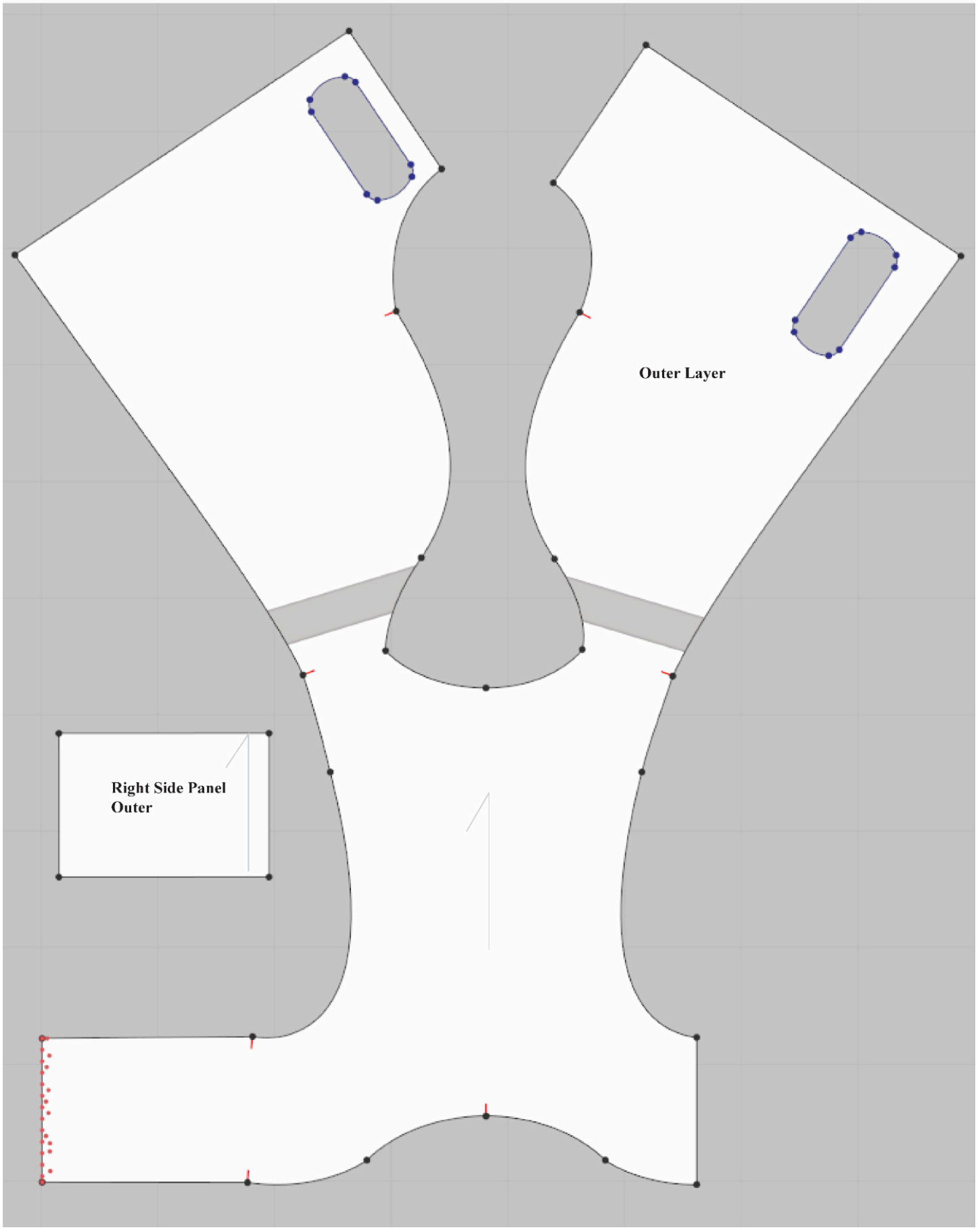


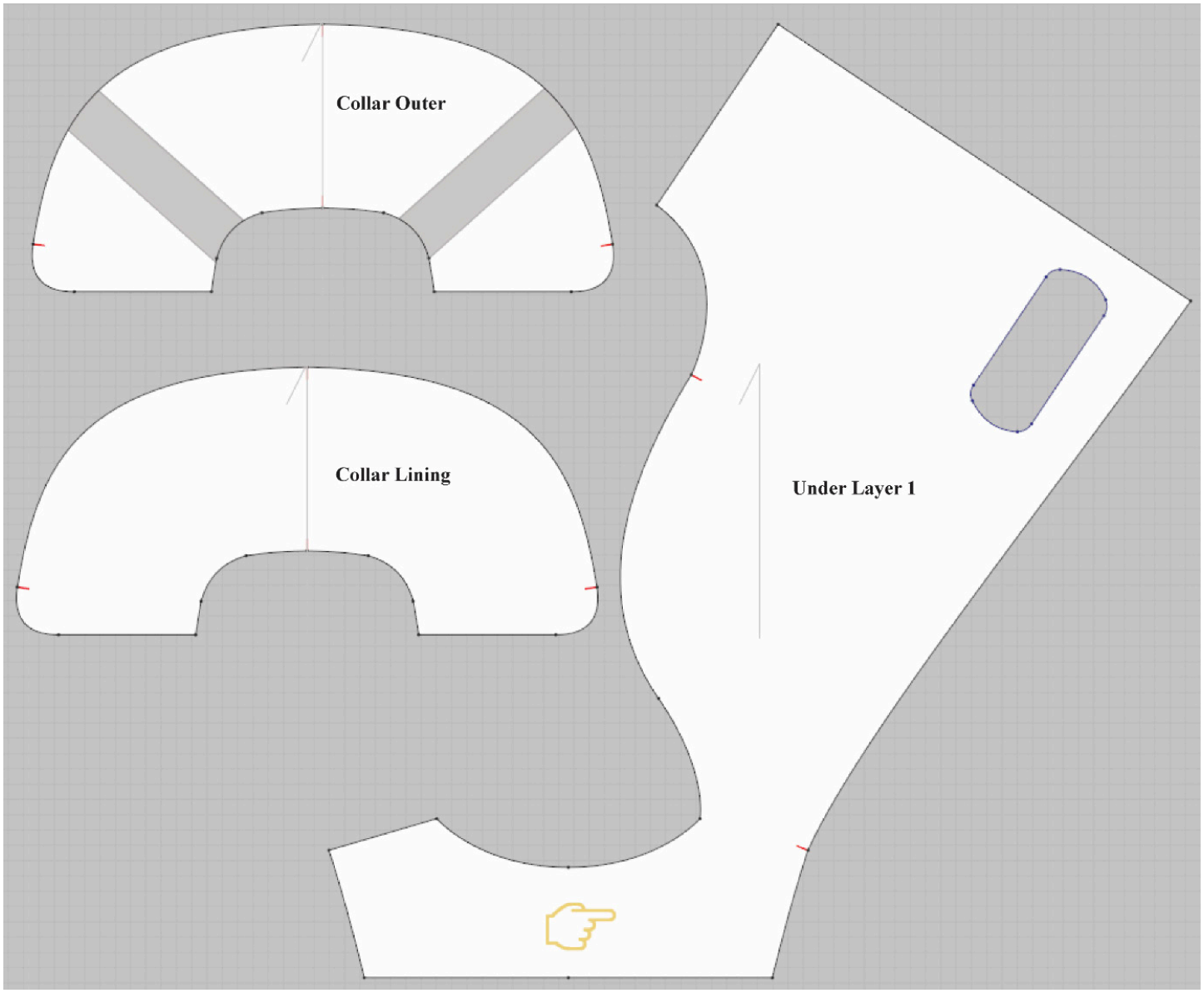
Step 19: Pass the webbing strap on left side through the appropriate plastic buckle. Double fold and top-stitch on both the webbing straps to secure the plastic buckles.



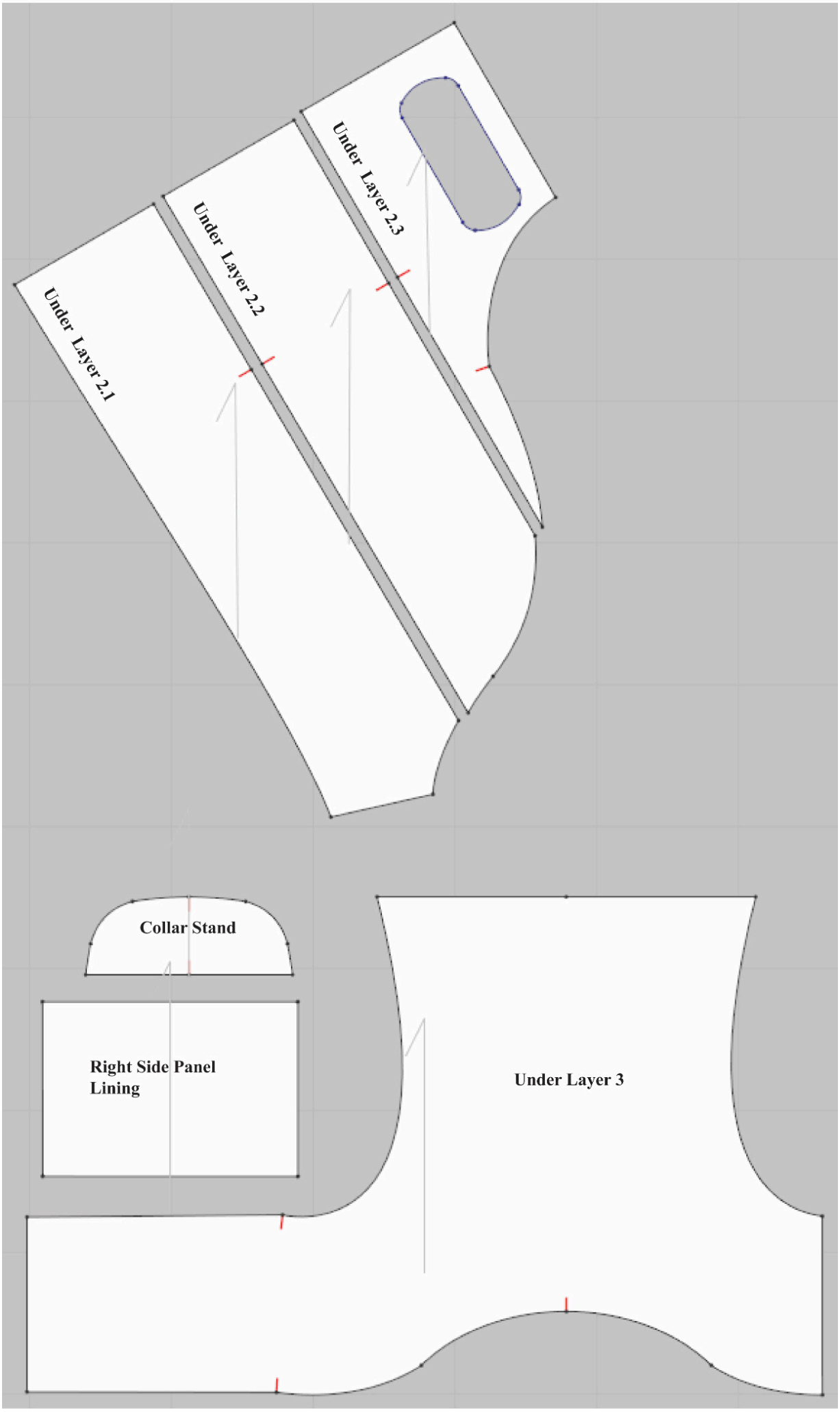
The final product is ready.

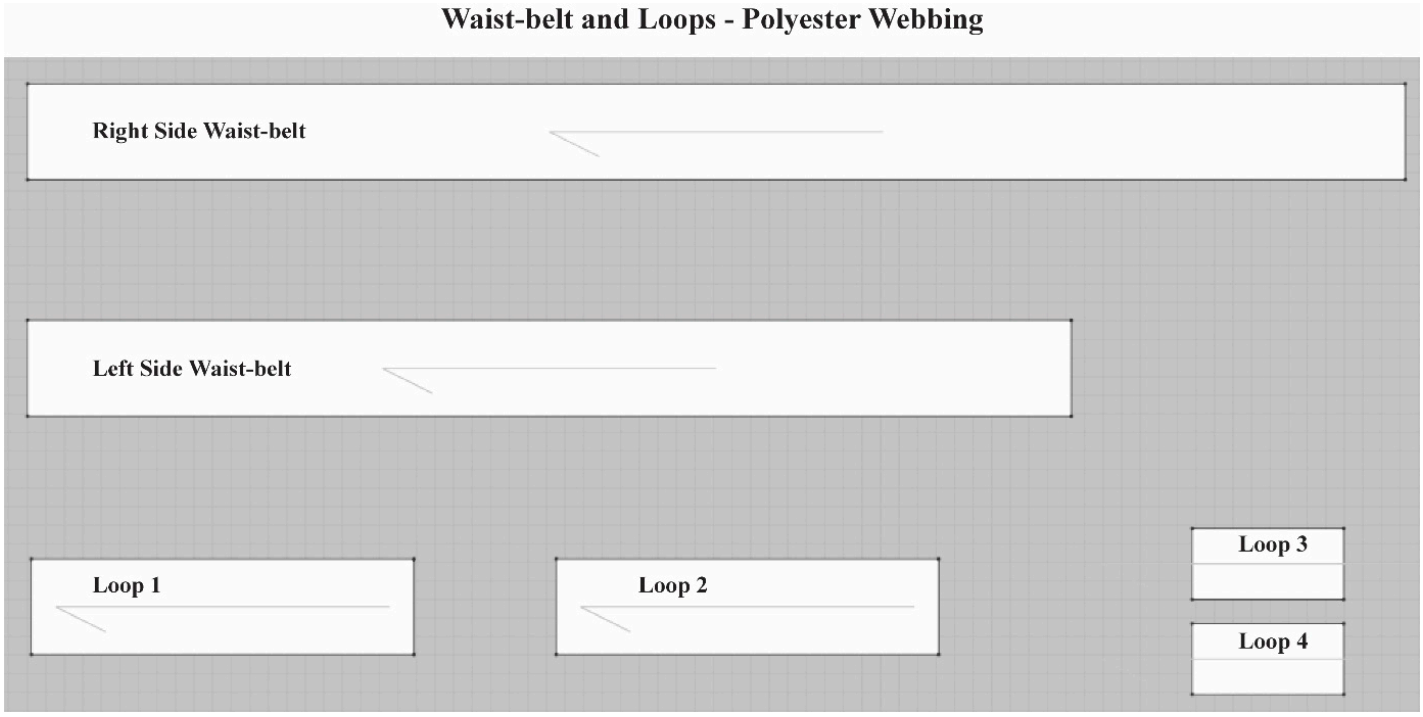
Main Fabric - Fluoroscent Orange 210D Oxford Nylon




Collar Outer
Collar Lining
Under Layer 1

Lining Fabric - Navy Blue 210D Oxford Nylon




Waist-belt and Loops - Polyester Webbing
Right Side Waist-belt
Left Side Waist-belt
Loop 1
Loop 2
Loop 3
Loop 4

Appendix P (Supplementary): Emendations after PhD Oral Exam

Graphic sign to aid with donning and doffing:

In place of the hand-sign (embroidered on the inner side of the back panel - see Figure 6.37), a three-step graphical illustration demonstrating how to a wear the life jacket will be used (see Image O1). This graphical illustration can be printed on to the life jacket's inner side using Vinyl or Sublimation Printing techniques. Printed samples using both techniques are submitted as part of the oral examination.

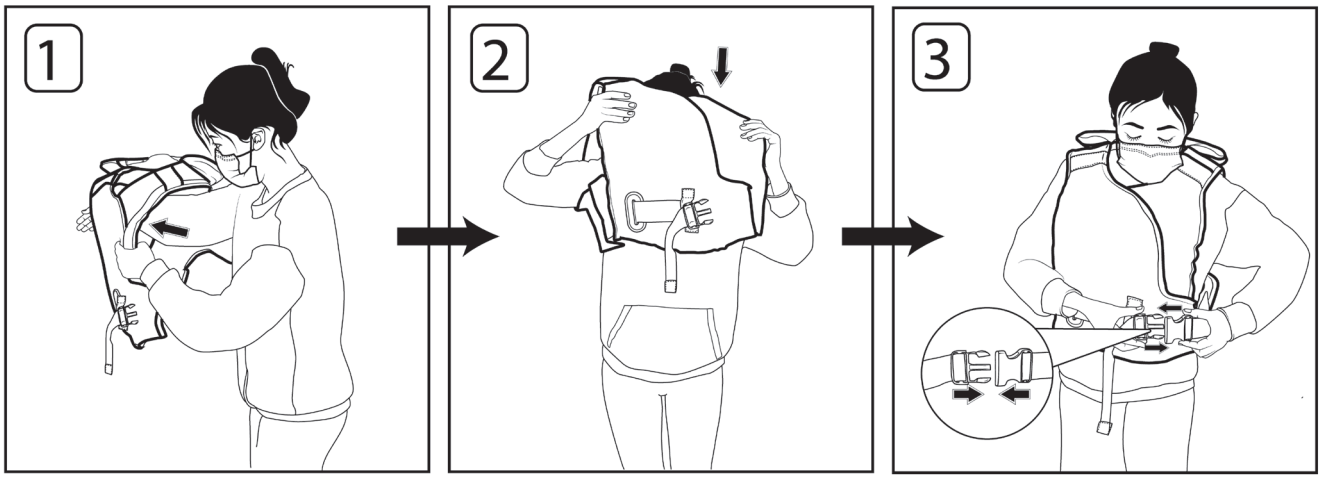


Figure O1: Three-step Graphical Illustration of Donning Method

Which is more appropriate color for life jacket: fluorescent orange or yellow?

Discussions with first responders in India identified that the context in which the life jackets were being used often had green backgrounds (trees, plants, grass and associated debris). The contrast of the existing life jackets' colour which is orange seemed to be favourable to them and hence the final life jacket prototype in this PhD project was made using a fluorescent orange fabric. However, this particular specification in relation to the product can be further resolved by reference to international and national life jacket standards.

How is the Slot n' Slide panel life jacket different from VEST (see page 28)?

	VEST life jacket design	Slot n' Slide life jacket design
		
1	Worn over the head, draped and tied around the body.	Right-hand 'slot' side entry.
2	Front overlapping panels are locked at the mid-point.	Front crossover panels can slide over each other.
3	No back panel.	Single-cut foam pattern for front crossover and back panels.
4	Waist-belt tied around for adjustment.	Inter-panel strapping system with integrated side adjustments and guides.