Sentinel Product report

June **2020**

Aalborg University
MSc04 / ID3

TITLE PAGE

Title: Sentinel
Project Period: February 2nd - June 3rd
Project group: Msc04 - Group 3
Main super visor: Christian Tollestrup
Technical supervisor: Mikael Larsen
Pages: 24

ABSTRACT

The purpose of this project was to create a solution in the form of a new product meant to combat the consequences of divers having a shallow water blackout while diving. A Shallow Water Blackout is a loss of oxygen supply to the brain that causes sudden loss of consciousness. It can hit divers of all skill levels and often so fast that the diver doesn't even realize it themselves. Since spearfishing has seen a sudden increase in popularity the last couple of years, a lot of new inexperienced freedivers have come to the sport. These newcomers don't always know their own limits and are therefore also prone to pushing themselves to far, putting them at risk of a shallow water blackout.

The vision for the product is to create awareness and facilitate rescue of the victim, while having minimal impact on the usual diving rutine. This is done by creating a physcial product, capable of measuring the onset of a blackout and starting a audible alarm to warn nearby divers that a blackout has occoured. The product was designed as an MVP solution with a focus on including only what is necessary, but also as a platform for future for add-ons and expansion into other market sectors.

The solution has been developed in close cooperation with spearfishers, freedivers and medical doctors to ensure that the product meets the demands of the environment and the divers themselves.

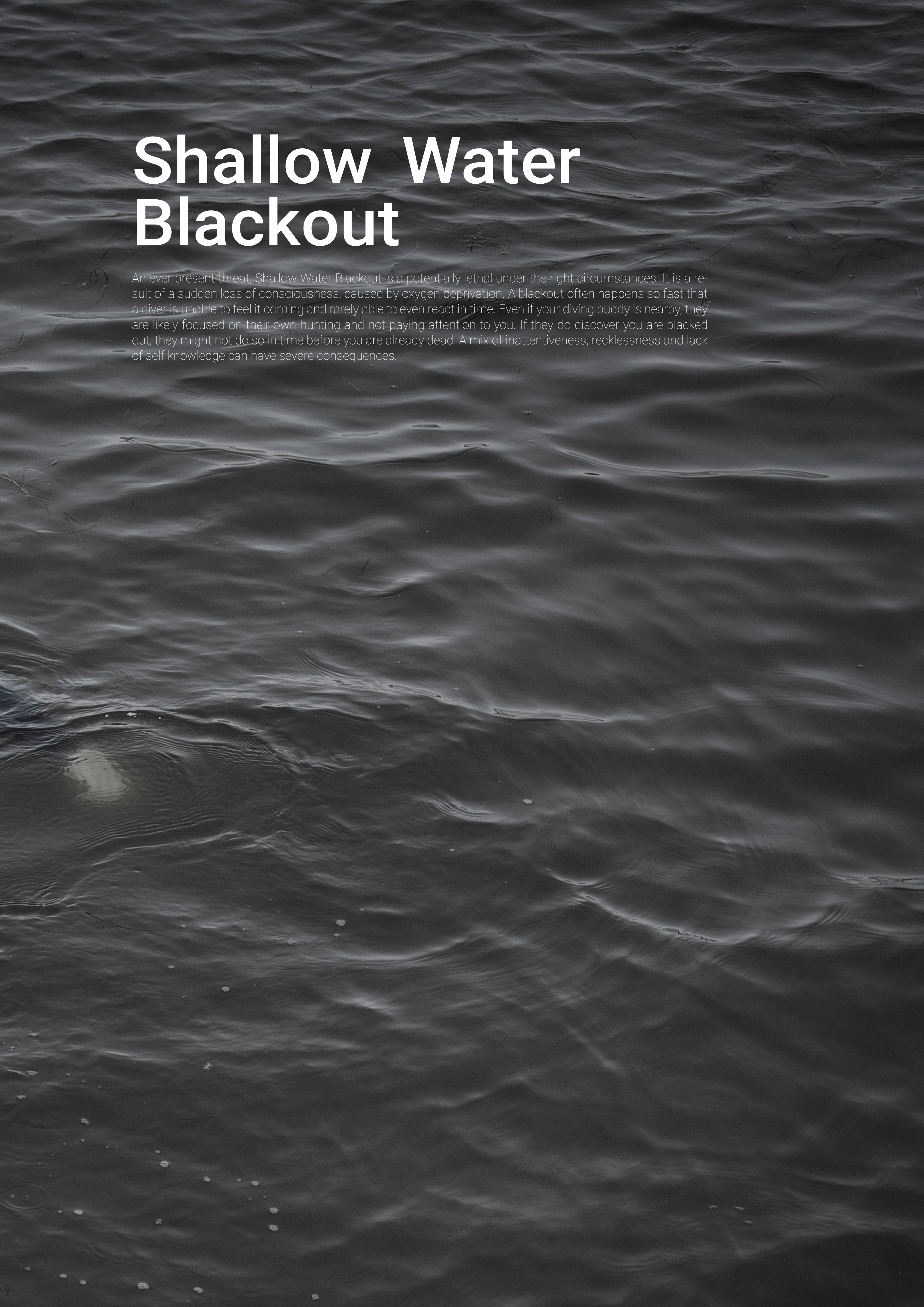
Mikkel Melchiorsen

Mads Prahl Jørgensen

TABLE OF CONTENTS

Spearfishing

The activity of spearfishing is many centuries old, to back when people had to rely on it for food. Times have changed, but it is no wonder that spearfishing still remains popular today, even if it is a more recreational activity. Nowadays, the cercumstances are a little different, but the core is still the same, hunting with a speargun and diving only using the air you bring in your lungs. The activity is not without risk even if you are carefull and always dive with a buddy. Running out of oxygen is always a lurking threat.



Shallow Water Blackout

An ever present threat, Shallow Water Blackout is a potentially lethal under the right circumstances. It is a result of a sudden loss of consciousness, caused by oxygen deprivation. A blackout often happens so fast that a diver is unable to feel it coming and rarely able to even react in time. Even if your diving buddy is nearby, they are likely focused on their own hunting and not paying attention to you. If they do discover you are blacked out, they might not do so in time before you are already dead. A mix of inattentiveness, recklessness and lack of self knowledge can have severe consequences.

Sentinel

BLACKOUT RESCUE DEVICE

Triggers an alarm and warns nearby buddies if a blackout occours. Either manually or automaticly.

BREATH MONITOR

Monitors breathing at the surface to ensure consciousness

ASCENT MONITORING

Tracks depth and time relation to ensure complete ascent

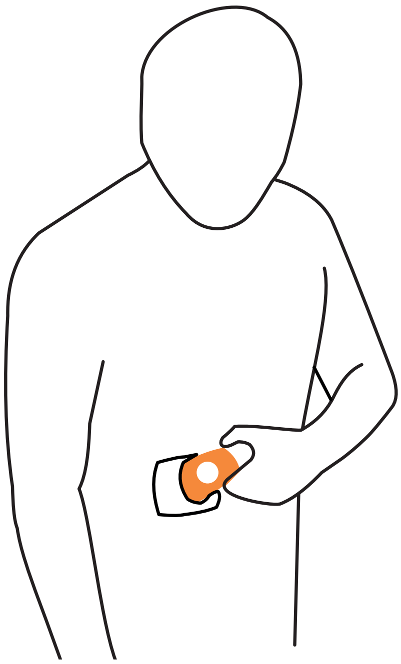
DIVE TIME LIMIT

Set your maximum dive time limit with accompanying app


SOS

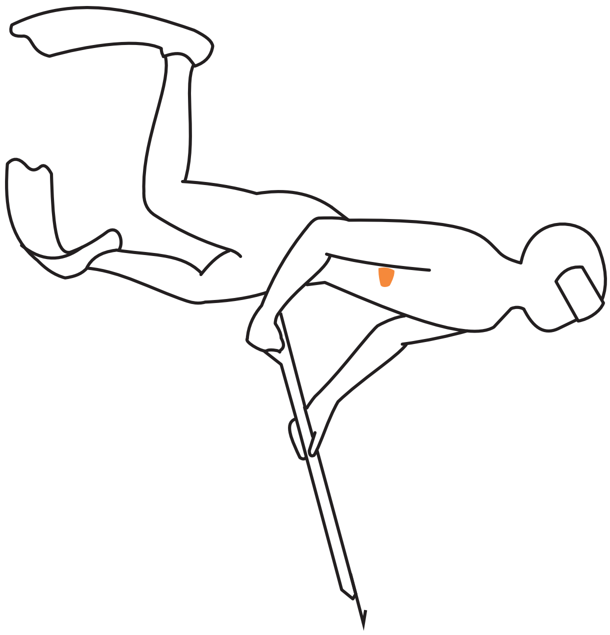

CRESSI
CHAMPION
CRESSI
SOS

1.



Turn on SENTINEL and upload your maximum dive time limit through accompanying app. Now place SENTINEL in mounted neoprene pocket. Sentinel it will now activily track your breathing, dive time and ascent in the water.

2.

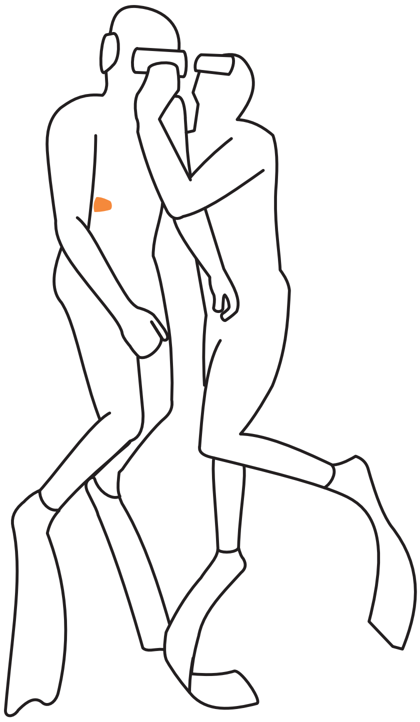


A long and deep dive increases the risk of Shallow Water Blackout in the last part of the dive. You should always be diving with a buddy at all times, but your buddy might be distant and distracted by their own hunting. They are rarely within your visual range.

3.

Due to a too long and deep dive, during the ascent, you start to feel disorientated and experience loss of motor control. Without realizing it you suddenly black out. SENTINEL detects the incomplete ascent and triggers its loud sound alarm. Due to SENTINEL's alarm your nearby diving buddy hears the distress signal and comes to the rescue.

4.



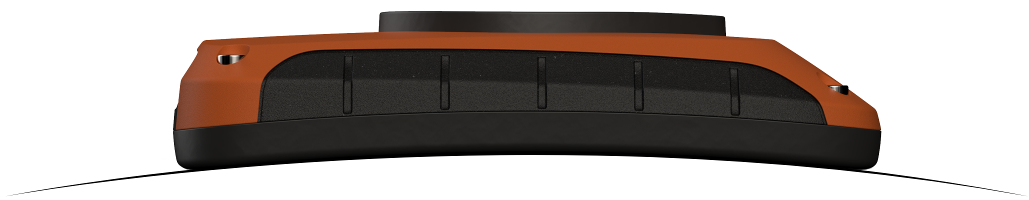
Your buddy carries your unconsciouss body to the surface and performs emergency procedures trying to wake you. Because of SENTINEL, your buddy is able to rescue you in time, increasing the chances of recovering from the Shallow Water Blackout


ALARM BUTTON WITH BUILDT-IN BUZZER ALARM
CHARGER AND ADD-ON RELEASE
SOS
DEPTH SENSOR
RUBBERIZED GRIPS
WATERPROOF DESIGN RATED FOR 50 METERS


POWER INDICATOR
INDENTED POWER BUTTON

MOUNTING

SENTINEL is mounted to the outside of the diving suit via a neoprene pocket. The pocket is attached to the suit with neoprene glue and secured with stitching along the edge. SENTINEL is placed in the pocket before every dive. After each dive, SENTINEL is easily removed from the suit.



SHAPED TO WEAR

CHARGING

A spring loaded latch secures the wired connection to prevent tearing out by accident. Simply push the latch to the side to release the lock.

INDUCTION

SENTINEL uses inductive charging, which enables better waterproofing. This connection enables future safety add-ons to be easily attached and detached even while in the water

BATTERY STATUS

For safety reason, battery status should be checked before every dive. Pressing the Power button will flash current status and holding it will turn the product on or off.

GOOD BATTERY

The LED indicator will flash green to indicate that battery status is good, and SENTINEL is ready be used.

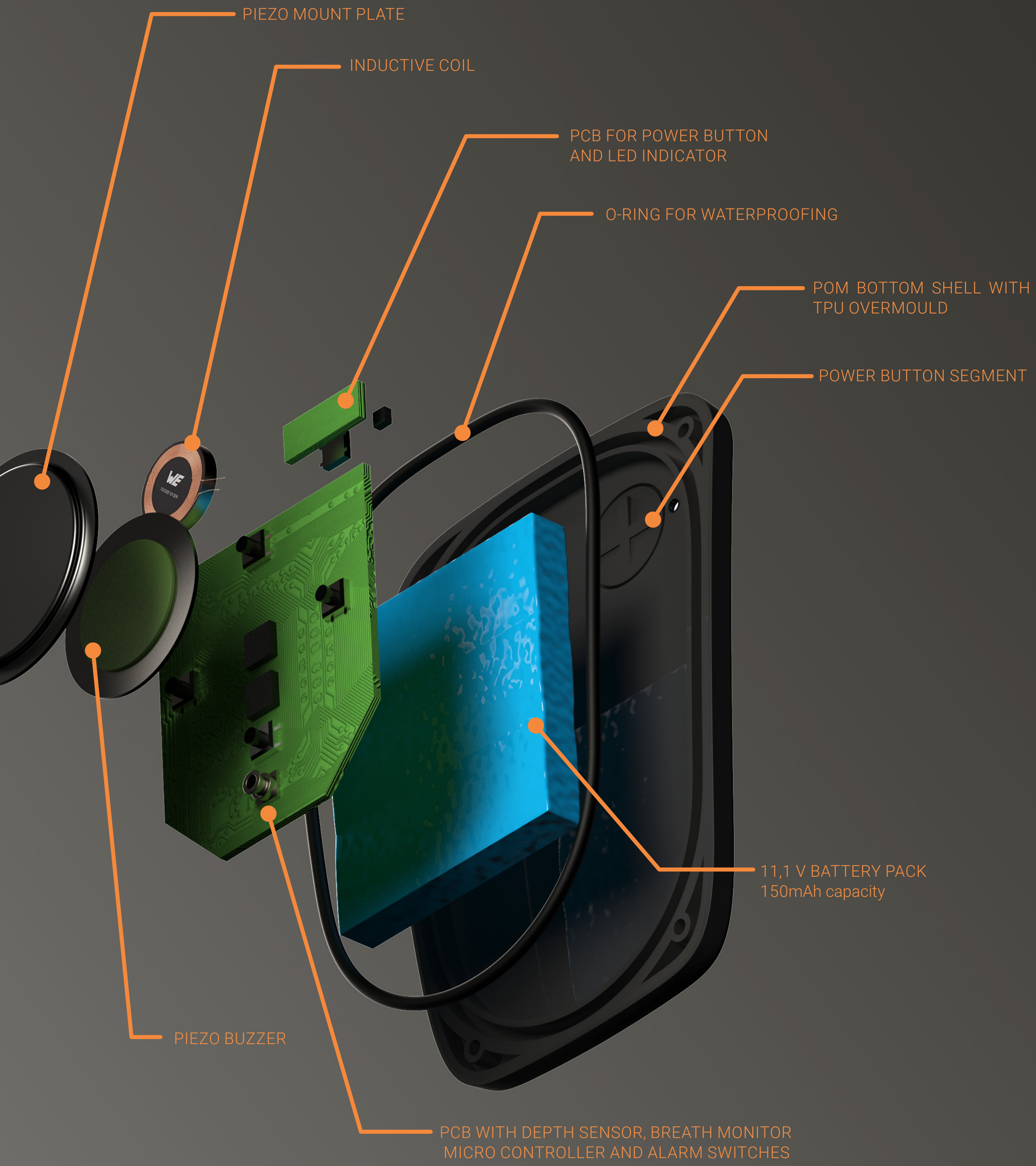
CHARGE WARNING

A yellow flash indicates that the battery will need charging soon, and it is recommended to do so as quickly as possible.

LOW BATTERY

When the LED indicator is red, the product is on low battery and does not have enough power to cover an entire diving session of 5 hours. It is strongly advised that you do not use SENTINEL before charging.


STAINLESS STEEL SCREWS
LATCH SPRING
CHARGER LATCH
SOS
POM OUTER SHELL
TPU RUBBERRIZED GRIPS
TPU OVERMOULDED BUTTON
POM MID SHELL


PIEZO MOUNT PLATE
INDUCTIVE COIL
PCB FOR POWER BUTTON AND LED INDICATOR
O-RING FOR WATERPROOFING
POM BOTTOM SHELL WITH TPU OVERMOULD
POWER BUTTON SEGMENT
11,1 V BATTERY PACK 150mAh capacity
PIEZO BUZZER
PCB WITH DEPTH SENSOR, BREATH MONITOR MICRO CONTROLLER AND ALARM SWITCHES

BUSINESS STRATEGY

SENTINEL is designed as a platform for future extensions and add-ons. The product architecture allows for adaption into other diving activities such as freediving or SCUBA. It could also be used as a performance device, for breath hold training exorcises. This requires a minimum of changes to the product. The mouinting solution allows for easy customization of the neoprene patch, to fit the aesthetic preference of the user.

PRICING

The pricing of SENTINEL is very similar to other diving devices, like watches and diving computers. The set price ensures a proper perception of safety and trust.

COST & INVESTMENT

The initial development investment is co-styl part of SENTINEL, when compared to the direct production cost. The internals of SENTINEL are standard components, so designing and programming the software will be costly. Producing a safe algorithm for automatic triggering of the alarm with-out false positives will require time and money.

PRODUCTION COST

239 DKK

INVESTMENT

1.780.0000 Dkk

SALES REQUIRED

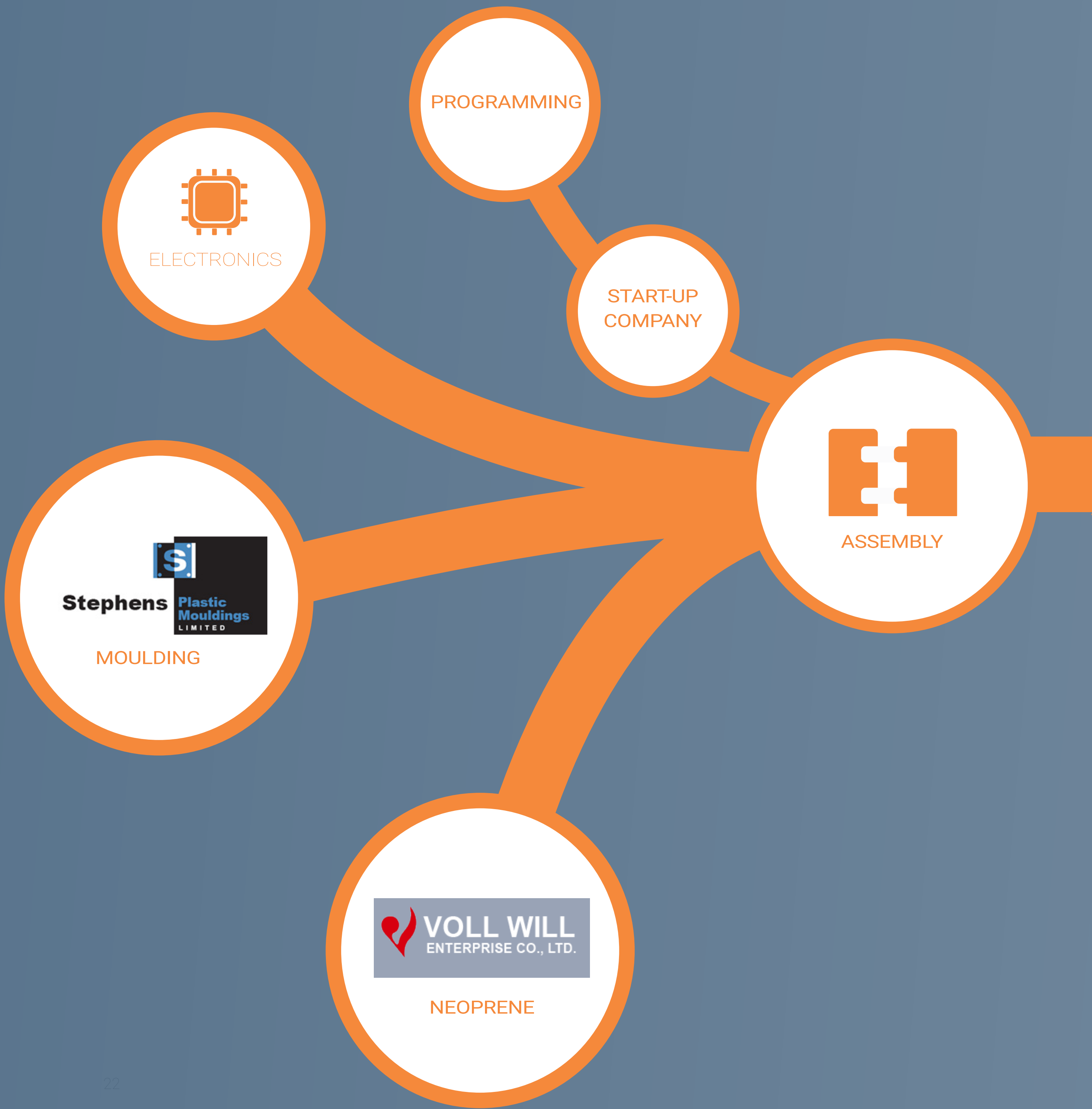
525 pcs.

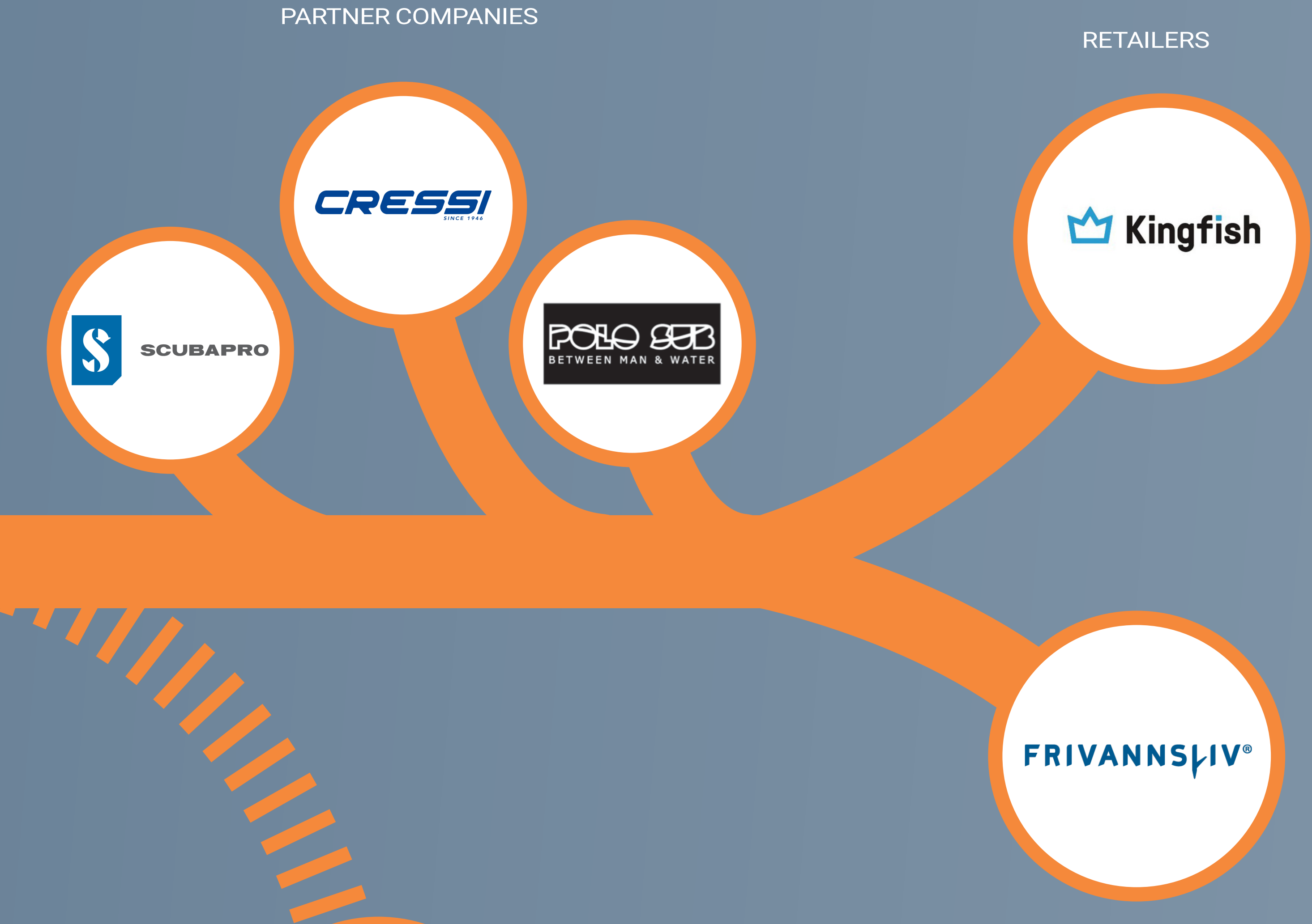
BREAKEVEN

3 years

OPERATIONAL VALUE CHAIN

The supply chain for SENTINEL is designed to utilize the market share and connections of established brands, while still internalizing the most vital part of the product, which is the software. Subsuppliers will provide the individual parts and ship them to assembly, which is shown in the illustration as a third party. The finished product will then be shipped off to retailers, with partner companies such as Cressi or Polosub providing customized neoprene patches to users that desire it. Users can also choose to buy a complete package and attach the mount themselves with neoprene glue.





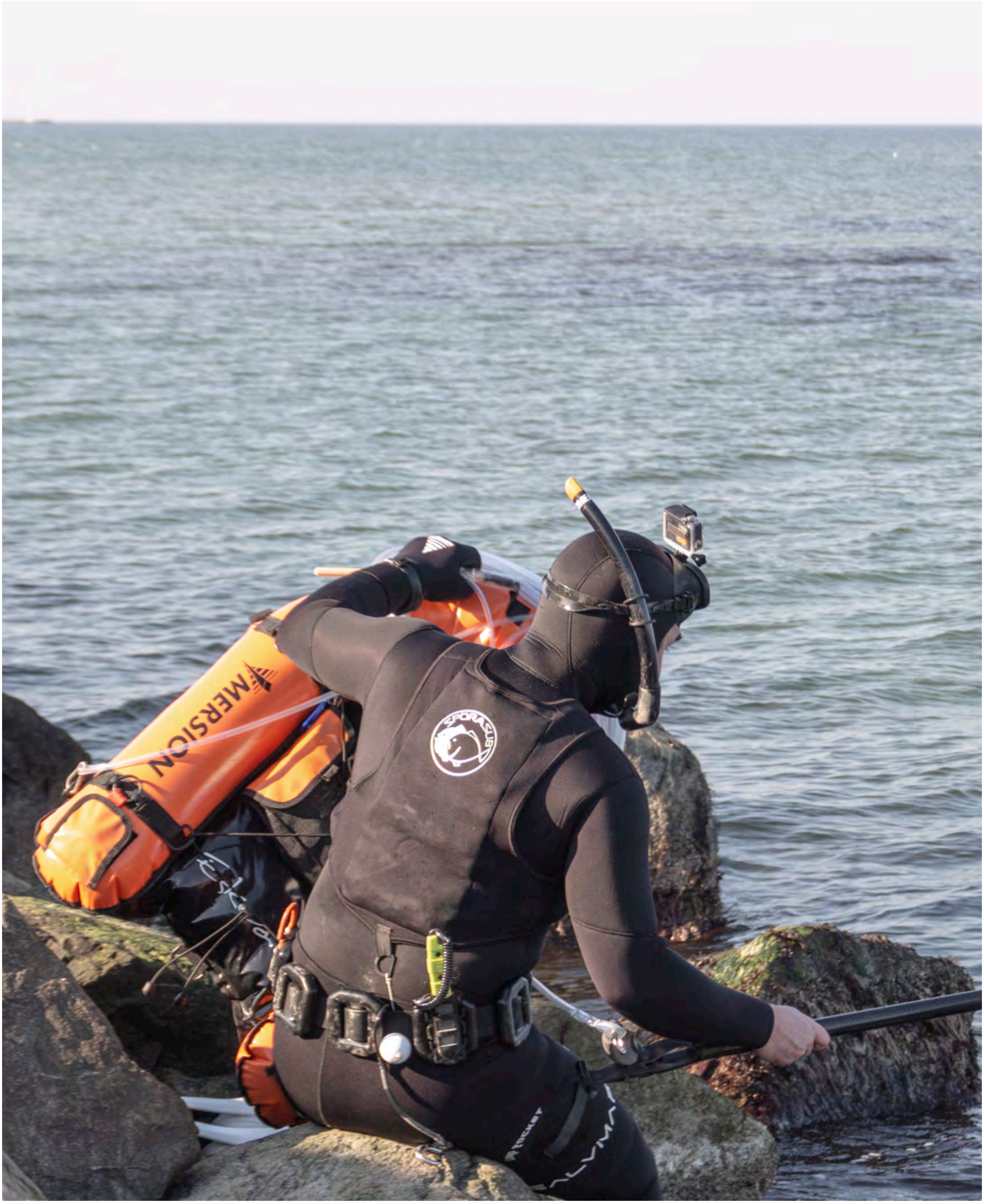
GLOBAL MARKET ACCESS

Another option would be to partner with a widespread and well known company like Garmin. With their focus on wearable technology, SENTINEL would fit right into their product portfolio. In exchange for more control and their name on the product, Garmin would provide access to a global market and a well known brand, which is well known to the target group.

AALBORG UNIVERSITY
DENMARK

Sentinel Process report June **2020**

Aalborg University
MSc04 / ID3



TITLE PAGE

Title: Sentinel
Project Period: February 2nd - June 3rd
Project group: Msc04 - Group 3
Main super visor: Christian Tollestrup
Technical supervisor: Mikael Larsen
Pages: 84 pages, not including appendix

PREPHASE & ACKNOWLEDGEMENTS

This project is a master thesis in Industrial design and is made by a team of two Industiral Design students. The project has been going for 16 weeks before submission and the development has been documented through this report and the accompanying product report.

The team would like to thank main supervisor Chrisitan Tollestrup and technical supervisor Mikael Larsen for continued feedback and guidance through the project. We would also like to thank the following people for their time and engagement into the project.

Martin Jørgensen
Tom Pedersen
Sigurd Van Hauen
Mikkel Huse

THE TEAM

Mikkel Melchiorsen

Mads Prahl Jørgensen

ABSTRACT

The purpose of this project was to create a solution in the form of a new product meant to combat the consequences of divers having a shallow water blackout while diving. A Shallow Water Blackout is a loss of oxygen supply to the brain that causes sudden loss of consciousness. It can hit divers of all skill levels and often so fast that the diver doesn't even realize it themselves. Since spearfishing has seen a sudden increase in popularity the last couple of years, a lot of new inexperienced freedivers have come to the sport. These newcomers don't always know their own limits and are therefore also prone to pushing themselves to far, putting them at risk of a shallow water blackout.

The vision for the product is to create awareness and facilitate rescue of the victim, while having minimal impact on the usual diving rutine. This is done by creating a physcial product, capable of detecting a blackout and starting a audible alarm to warn nearby divers that a blackout has occoured. The product was designed as an MVP solution with a focus on including only what is necessary, but also as a platform for future for add-ons and expansion into other market sectors.

The solution has been developed in close cooperation with spearfishers, freedivers and medical doctors to ensure that the product meets the demands of the environment and the divers themselves.

READING GUIDE

This report consists of 3 parts. It is recommended to read the product report first, then the process report. It is recommended to view the reports in spreads.

1: The Product report, which presents and describes the final design solution.

2: The Process report, which in detail describes the process, reflections and conlcusions behind the final design solution

3: Appendix, which contains worksheets, datasheets and technical drawings that is referred to throughout the Process report.

All sources are given with the Harvard method, with the sources placed directly in the text, with a full list at the end of the report.

All illustrations are number in sequence, with a full list at the end of the report as well. All illustration with no given source, is the groups own illustrations.

All worksheets will also be referred to directly in the text, and can be found in the appendix.

?

- This box indicates that the investigation or task has given insight that requires further investigation or is relevant to the process.

!

- This box indicates that the investigation or task has resulted in a new user need, requirement or opportunity relevant to the solution.

TABLE OF CONTENTS

INTRODUCTION

Diving provides a window into a completely different world that most people can take for granted. Not only this, but diving can also be a fun recreational activity and help provide a basis for good physical and mental health through exorcise. Diving is not without its dangers though, and can in rare cases can prove fatal.

The initial inspiration for the project was to investigate the dangers of diving and how some of these dangers could be alleviated. The team decided to focus on one specific risk, shallow water blackout, that are constant and present for all divers that dive without oxygen tanks. The project involved complex understanding of human anatomy as well as diving methods, habbits and the general mindset of diver. It also juggles the design dilemmas of providing safety while allowing freedom and providing the right course of action, even if it is against the users natural reflexes.

USER PANEL

User feedback has been essential for this project, so it will be referred to throughout the report. Below is a short introduction to each of the users mentioned.

Martin Jørgensen
Spearfisher

Sigurd Van Hauen
Competetive freediver & spearfisher

Tom Helm Petersen
Medical doctor & Spearfisher

Mikkel Huse
Freediver

INITIAL THOUGHTS

The team had some prior knowledge and experience with diving before the start of the project, which served as a basis for inspiration and provided some fundamental understanding of diving in general.

Diving is inherently dangerous and there are many things which can go wrong over the course of a dive. It could be equipment failure, inexperience, ghost nets, pressure sickness, dangerous animal life or even loss of consciousness that can pose a threat to the wellbeing of a diver. Having issues in an underwater environment can quickly lead to panic and panicking can prove fatal to the diver.

However, very early on, the team encountered the phenomenon of Shallow Water Blackout, or SWB for short. This phenomenon resulted in the diver losing consciousness under water, often without themselves realizing it. It is an issue that mainly occurs in freediving. Compared to SCUBA diving where you have a continous oxygen supply during a dive, freedivers' only oxygen supply is from the air they bring in their lungs.

RESEARCH

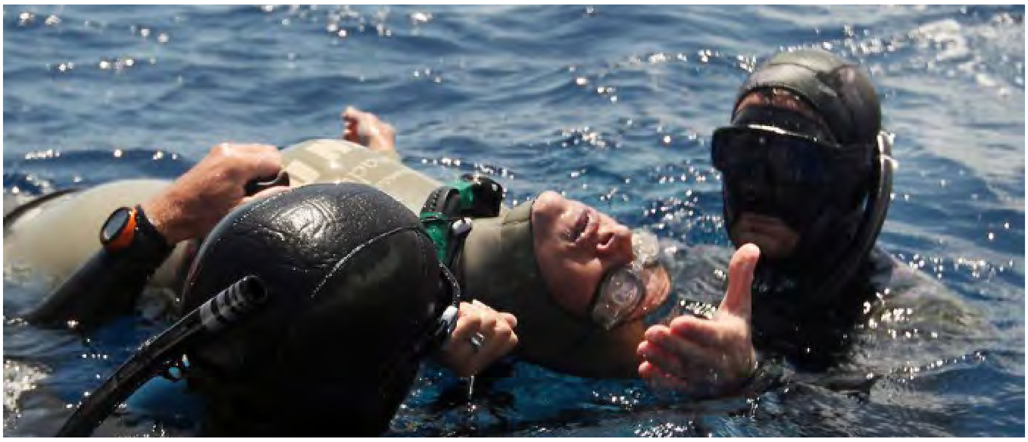
CHAPTER SUMMARY

This chapter provides an overview over the research and investigations made, which founded the background for this project.

The phenomenon of Shallow Water Blackout will be presented, alongside how it affects the divers, what physical consequences it has and what the current coping strategies are. The outcome of this section will be to create a framework, for which a more narrow solution space will be defined.

1.1 INITIAL RESEARCH

Following the decision to investigate the problem of Shallow Water Blackouts (SWB), an intital research session into the problem was started. It was necessary to get a better understadning of what the phenomenon was, how it occours and how many people it affects. The full research can be seen in worksheet 1.



ill. 1 Passed out diver

WHAT IS IT?

Shallow Water Blackout (SWB) or Freediver Blackout is a phenomenon in which one loses consciousness underwater. It happens because of the limited supply of oxygen to the brain. The initial research suggested that the body does in fact have indicators for when it is about to run out of oxygen. However, this indicator is tied directly to the amount of CO2 in the bloodstream, rather than O2. This means when the amount of CO2 bloodstream goes up, so does the urge to breathe. A very common breathing technique, hyperventialtion, removes CO2 from the divers system. If a diver hyperventilates before a dive and reduces the amount of CO2 in the blood, they remove their natural indicator for the need to breathe. As a result, divers feel they can hold their breath for longer periods of time.

This affects the intuite reaction of oxygen need, ultimately causing a "faint" or blackout before feeling the urge to breathe. Hyperventilation is therefore nowadays highly discouraged in relation to any underwater activity.

Through the initial research session, the group found, that hyperventilation was not the only reason. Newer research suggest that depletion of O2 and bad restoration of the same is as much an important problem as lowered levels of CO2 due to hyperventilating. This supports the importance of the problem in doing many repetitive breath-holding dives (White 2017). The research even states that oxygen deprivation continues for up to a minute after normal breathing has started after breath-holding. This window also poses a risk of one blacking out due to the delayed drop in oxygen. This subject would require further investigation at a later stage in the project for a better understanding what exactly causes a blackout and what the indicators are.

NEVER DIVE ALONE

A Shallow Water Blackout is always a risk when diving. It is not restricted to any specific water temperatures or water types. Likewise, it is not restricted by depth either and can happen even above the surface. It is also not restricted to certain types of diving. Blackouts can happen in freediving, spearfishing and scuba diving, mostly due to equipment failure. Usually it happens without warning, even to professional divers. (Emotions Blue 2020)

General rule in diving: Never dive alone! When diving, most divers use a dive buddy, which is another person diving in the same area. This is a safety precaution, which ensure that divers are within range to help each other should an issue occur. The dive can start from either a boat or any platform in the water. Freedivers usually bring a buoy with them, to either mark their location above water or to have an underwater line to follow up and down while diving.

When underwater, the general advice is to keep each other in sight and keep an eye on your buddy at all times, however, SWB can happen very fast and in most cases without the victim or the diving buddy realising it. The diving buddy is therefore essential to help if anything happens.

- More research is needed into the physiology of blackouts.
- More research is needed into the behavior and coping strategies of divers.

IT IS NOT REGULAR DROWNING

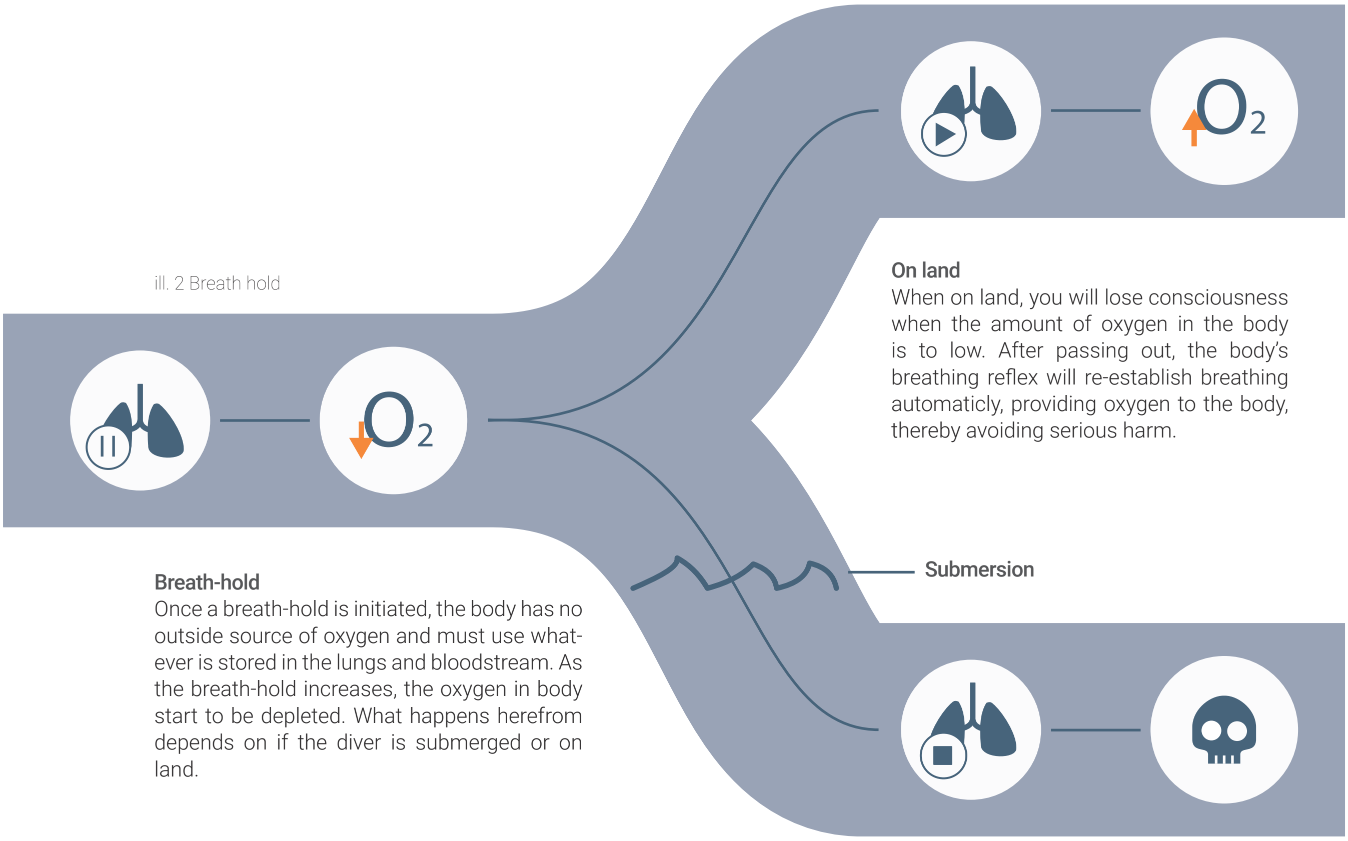
Contrary to popular belief, a drowning due to an underwater blackout is not considered a regular drowning. The consequence of a blackout is not in itself a deadly phenomenon. It can be considered lethal as a result of the environment it occurs in, since passing out from oxygen deprivation in itself is not lethal.

Under normal conditions on land the body would just reestablish breathing after a loss of consoiusness. However under water, the body is unable to do so, due to the body's natural defense mechanism to preserve the remaining oxygen reserve. Eventually, this means the body will deplete this reserve over time, resulting in total body shutdown. When this shutdown occours, the body is at risk of taking water into the lungs, which results in drowning (ill. 2).

The initial issue is therfore not actually drowning, but rahter suffication under the water. The process of drowning due to a shallow water blackout is also different compared to regular drowning. A regular drowning typically occours within 20 to 60 seconds (The Active Times 2018). This involves taking water into the lungs immediatly, often due to panic.

Because the process is different and involves oxygen deprivation, this means higher risk of brain damage if oxygen supply is not restored in time. Course of action needs to happen fast, as lowered oxygen supply to the brain might have started minutes prior to the blackout. Therefore the first 2 to 2,5 minutes after a SWB are very important, if permanent brain damage is to be avoided. (Dr. Brothers 2020)

ill. 2 Breath hold



Breath-hold
Once a breath-hold is initiated, the body has no outside source of oxygen and must use whatever is stored in the lungs and bloodstream. As the breath-hold increases, the oxygen in body start to be depleted. What happens herefrom depends on if the diver is submerged or on land.

On land
When on land, you will lose consciousness when the amount of oxygen in the body is to low. After passing out, the body's breathing reflex will re-establish breathing automaticly, providing oxygen to the body, thereby avoiding serious harm.

Beneath the surface
Similarly to above water, the body will start shutting down after a certain oxygen amount has been depleted. After passing out, the body is unable to re-establish breathing automaticly because of the surrounding water. If the diver is not rescued in time, they risk brain damage or death.

» Quick action is important due to the risk of brain damage.

SIZE OF THE PROBLEM

Now, with SWB and following risks more clarified, an investigation was made into how widespread the phenomenon is. The investigation was also to explore if SWB is a more common issue or just a freak occourence.

SWB in numbers

Definite numbers on the amount of cases of shallow water blackout resulting in deaths can be difficult to find, since some countries dont always list a SWB as a cause of death, but rather as a drowning accident. However, numbers from Swimming Canada in 2018 estimates 140.000 deaths a year worldwide due to drowning. 28.000 of these deaths are estimated to be caused by Shallow Water Blackout (Dr. Brothers 2020) (see ill. 3).

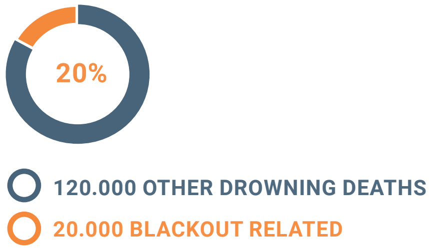
Freediving market

Numbers on certified freedivers from certification agency PFI (Scuba Diving International n.d.) combined with a survey from Deeperblue (Deeper Blue 2013) give a rough estimate of the freediving market. Combined, the numbers estimate 256.000 certified freedivers in top 8 certification agencies. Only 37,7% of the survey participants was certified. This estimates more than 680.000 freedivers in total worldwide (see ill. 4).

In addition, Divers Alert Network (DAN) in 2006 acknowledges freediving as an underwater sport increasingly growing in popularity. This could be due to the fact that people are seeking to test their endurance limitations (Lindholm et al. 2006). Since the sport doesn't require any certificate, there is nothing stopping completely new people from going out and trying the sport for themselves. Bret Gilliam, diving veteran and member of WC spearfishing team; states in an 2014 article in "DiverMag" that awareness of risk involved are important in correlation with freediving becoming increasingly popular. This includes more advanced breath-holding activities like spearfishing and competitive freediving (Gilliam n.d.).

As freediving activities do not require any certificate or test, most people can try the sport themselves, without proper education. Experience and self-knowledge is important and new people might not know their own limits. This increases the risks of having a SWB. This is especially relevant in countries with clear and deep waters, which makes depth judgement much harder. Correspondingly, these countries naturally include higher risk (ill. 5). Eg., from 2014 to 2016, 51 people died during freediving activities in Brazil. 79% of these incidents happended during spearfising activities (DAN Annual Diving Report 2017).

ill. 5 High mortality rates



ill. 3 Deaths pr year

ill. 4 Certified divers

EVALUATION

This initial research session was a good confirmation that shallow water blackouts are common enough occurences. It is observed that there could be a market for a potential solution. This section clarified that most divers are not certified, which means they havn't gone through a formal course or are a part of an diving organisation. Likewise, it made it clear more research was needed into the physiology behind blackouts, freediving habbits and coping mechanisms. It also clearified that the process of drowning due to SWB is different than regular drowning.

However, this was a quantitive investigation and to get a better understanding of the issue, a more qualititve approach was needed moving forward. The reason was to gain a better understanding of the users themselves and freediving in general, in addition to a better understanding of the different activities taking place under water where SWB is a risk.

?

» Increasingly popular sport
» The majority of freedivers are not certified
» Higher risk in countries with clear and deep waters.

1.2 UNDERSTANDING FREEDIVING

ill. 6 Observation of training session at Freedivng Aalborg

THE IMPORTANCE OF MENTALITY

Fridykning Aalborg was visited to have a talk with Sigurd Van Hauen, chairman of the association, to get a better understand of freediving in general. This included observing a training session in their indoor pool and an interview about freediving, its mentality, what it means to freedive and spearfish (ill. 6). This was also to seek an opportunity to establish a project collaboration with potential user-group. See worksheet 3 for more details on the visit at Fridkyning Aalborg.

Sigurd made it clear that freediving relies on and affects the mentality of the diver by quite a lot. It is generally accepted, that in diving, the better mentality you have, the better your diving will be. If the diver is too disctracted, their mentality is affected, and they deplete oxygen faster. Factors like visibility and temperature can affect the mentality which affects the duration and depth of a dive. A better understanding of how you are effected is buildt over time, making amateurs that don't know their limits more at risk of SWB. Sigurd Van Hauen refers to this as "I got this" syndrome, meaning false confidence can lead to making cricital errors that can have vital consequences. Different disciplens and activites in freediving have different factors infuencing the mental state of the divers. The two main activities observed are competetive freediving and spearfishing.

COMPETETIVE FREEDIVING

The first activity is competitive freediving. The main objective in this activity, is to cover as a large a distance as possible, either with or without dual/mono fins. Here, there is a large focus on being as streamlined in the water as possible (ill. 7).

There are different degrees of competitive freediving, some being more extreme than others. The most common for competitive freediving is distance and depth, which takes place in a pool and open ocean, respectivly. The most extreme version of depth diving is referred to a as "No limit" and has the diver placed on a weighted sled, which brings them down to more than 100 meters depth. It is extremely dangerous.

Freedivers tend to push themselves in an effort to go deeper and further, which means that blackouts are likely to occour. However, this also means that there often is a large focus on blackout prevention and rescue during competitions, as to minimize the risk of a fatal accident.

ill. 7 Sigurd freediving with monofin

ill. 8 Spearfishing

SPEARFISHING

The second activity, spearfishing, has gathered more attention the last couple of years. It differs from freediving in the diving methods and overall goal. For example, a speafisher can sometimes hunt fish while stationary at the sea floor. They often bring more weight, in order to achieve more negative buoyancy than in regular freediving.

The general objective between the two activites is also different. The objective in competitive freediving is often trying to push yourself. Spearfishing doesn't have the same objective. Instead, the main goal is to catch fish. This means that spearfishers have a tendency to not push themselves as far. However, there are a lot more distractions that can influence your dive time and the amount of oxygen that your body consumes. Seeing and trying to catch fish can all contribute to a rising heart-rate and usually leads to bad decision-making. For example, a diver can suddenly find themselves tempted to push beyond their normal boundries. Sigurd Van Hauen also expressed that spearfishers are terrible at keeping an eye on each other, even though they dive close together.

EVALUATION

Competitive freedivers have much more focus on mentality and movement efficiency. In comparison, spearfishers tend to dive using more weight to reach the bottom of waters to lie stationary making it easier to hunt prey.

Common denominator for the two types of freediving is that blackouts can occur due to deprivation of oxygen in both sports. Competitive freedivers seem to be more aware of each other during underwater dives than spearfishers are. This is because competitive freedivers are pushing themselves to absolute limits more often. This risk is different for spearfishers, who instead tend to get caught up in the moment when hunting prey, and sudden oxygen deprived conditions might surprise the diver.

Safety in freediving competitive and spearfishing has shown to be interesting prior to, during and straight after an underwater dive. The core problem in both cases is blacking out due to deprivation of oxygen. This seems to be a reoccurring and constant risk when freediving. It leads to questioning if the existing safety precautions and measures are enough to effectively combat the risks and consequences of a blackout.

An interesting conflict noticed regarding the core problem is that freedivers naturally dive with as little gear as possible. This begs the question, if there is a conscious decision to limit your gear to preserve a sense of freedom at the cost of using potential safety gear. It becomes a conflict between balancing the following two factors; Sense of freedom and amount of safety.

The initial visit at Fridykning Aalborg was mostly focused on initiating contact with Sigurd Van Hauen. Not much contact with the other freedivers at the training session was made. It would have been advantageous to converse with other freedivers at the session to gain a broader perspective.

The next step was to take a closer look at how much gear they bring, what they bring, and if they already bring any equipment that is meant to combat the risk of Shallow water blackout or drowning.

!

- » Two target activities; Competitive freediving and spearfishing.
- » Core dillema; Safety vs Sense of freedom

1.3 FREEDIVING EQUIPMENT

Following the visit at Fridykning Aalborg, it was decided to get at better understanding of what equipment was usually brought on an average diving trip. This was with regards to both spearfishing and freediving, since after interveiws with users Sigurd van Hauen and Martin Jørgensen the equipment turned out to be quite similar, but spearfishing being typically the most gear intensive of the two. See worksheet 6 for interview with Martin Jørgensen.

They also expressed that more experienced divers have a tendency to spend more money on equipment, so the equipment presented is a generalized representation. It should be noted that the equipment listed can easily amount to 15.000 - 20.000 DKK. ill. 9 shows one of the project members wearing the regular equipment for spearfishing. Much of the basic equipment can be used for freediving as well. Each number represent a piece of equipment, with a more detailed explanation on the next page. This is also meant as a general introduction to the equipment for future reference throughout the report.

ill. 9 Equipment

① GLOVES

These Gloves are made of neoprene, often between 2mm to 5mm thick. They are mostly used in cold waters, since frozen hands can lead to great discomfort and difficulty in handling equipment when diving.

② WETSUIT PANTS

The wetsuit is usually split into two pieces, the pants and the shirt, both made of neoprene. The pants can feature rubber kneepads for sitting on the seabed without tearing the suit.

③ WETSUIT TOP

This is the upper part of the wetsuit. Made out of neoprene, it is kept in place with a section that wraps around the crotch of the wearer. It can also feature rubber reinforcements. In freediving, a one-suit is typcially used instead of top and pants.

④ FLIPPERS

These are very usefulll for diving underwater, since they vastly reduce the amount of effort it takes to swim. They come in different degrees of rigidity, types and sizes, depending on what activity and experience level the diver is at.

⑤ MASK AND SNORKEL

These are pretty much essential for diving underwater, otherwise it would be impossible to see. The snorkel helps you relax at the surface, since you can remain face down at the surface and still breathe.

⑥ BUOY

A buoy serves as a marker for the diver. The law requires a diver to have an alpha flag when diving at sea, no matter what sort of diving activity (Retsinformation 2000). The flag is mounted on a buoy. The buoy serves as a storage space for different items like water and car keys. The diver is tied to this buoy via a float line, which can be either elastic or plastic cord.

⑦ WEIGHT BELT

This belt holds several blocks of lead, meant to counteract the buoyancy of the diving suit and the divers lungs. Without this additional weight, it would be next to impossible to dive without massive effort. It should be noted that the belts release mechanism is designed so that its easy to release in case of an emergency.

⑧ WEIGHT VEST

This is a typically an addition to the weight belt, rather than a replacement for it. It allows the diver to bring a couple of extra kiloes on their body without having to mount it on the belt. Some divers dive without this vest, and only use the belt.

⑨ DIVE WATCH

This is a very common gadget amongst divers. It provides a series of different fucntionalities, such as depth meter and timers. They come in a wide range of different price and complexities, but are generally recommended to bring when diving.

⑩ SPEARGUN

The speargun is powered by strong elastic bands and only used in spearfishing. When the trigger is pulled, It propels a long steel spear forward at considerable speed. It is enough to penetrate and kill most fish and even other divers if diver is not carefull. A wire is attached from the speargun to the spear, like a fishing line, so the spear can easily be retrieved after firing.

EVALUATION

There is an extensive amount of equipment commonly used for diving. In addition to the listed equipment, divers usually bring their smart-phones in bags or even out with them on the buoy in watertight cases. With a better understanding of what equipment is typically brought along, it was observed that the average diver didn't usually bring any equipment with them that was specifically aimed at combating a Shallow Water Blackout. Instead, they seemed to rely on procedures, in case anything should happen. These procedures will be explained in depth in the next section.

» No common product is used to directly combat a Shallow Water Blackout.

1.4 COPING STRATEGIES

EMERGENCY PROCEDURES:

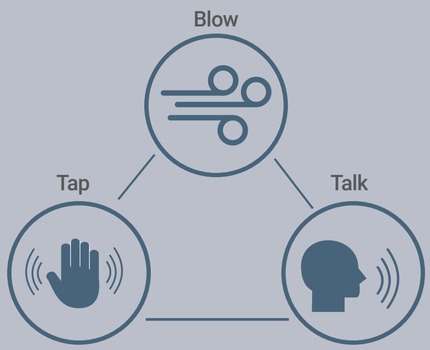
Through interviews with Sigurd Van Hauen and Martin Jørgensen, knowledge towards typical emergency procedures were found.

It is commonly accepted that there is no way to completely prevent a Shallow Water Blackout. If a diver is having one, they are not always able to tell in time by themselves. However there are precautions which can be taken to reduce the risk of one. Currently, it is up to the diving buddy or medical staff to keep an eye out, and bring the victim to the surface in case a blackout does occour. It is generally advised that you do not push your body further and swim deeper than you are used to. You must be decisive and consequent and never change your mind mid dive.

If an accident does occur, and rescuers manages to spot it in time, the rescuer must bring the blackout victim to the surface as soon as possible to initiate a wake up sequence (ill. 10). It is highly advised that the divers do not hesitate to drop their weight belt when experiencing problems. The weight belt can tie them down under water and/or make resurfacing much harder.

When a rescuer brings a blacked out victim to the surface there is no garantee that the victim will start breathing, because the body still believes it is under water. If there is no response after 15-20s, mouth to mouth techniques must be initiated. If the victim does not wake up after this, they must be brought onto a hard surface, like the floor of a boat, to perform CPR. If succesfull, the victim must breathe pure oxygen for several minutes, to replenish the O2 in their system (Kelley 2019).

The wake-up procedure
The wakeup sequence consists of 3 parts; blow tap and talk. The first part is blow. Blow means removing the mask of the victim, and gently blowing air in their face around the eyes. This activates receptors in this area, lettting the body know that the head is above water. The second is gently tapping the victims chin with an open hand, trying to wake them up. Talk is the third part, and involves simply talking to the victim and trying to get a response from them. These three parts are meant to help the body realise it is now above water and bring the victim back to consciousness .



ill. 10 Blow, tap, talk

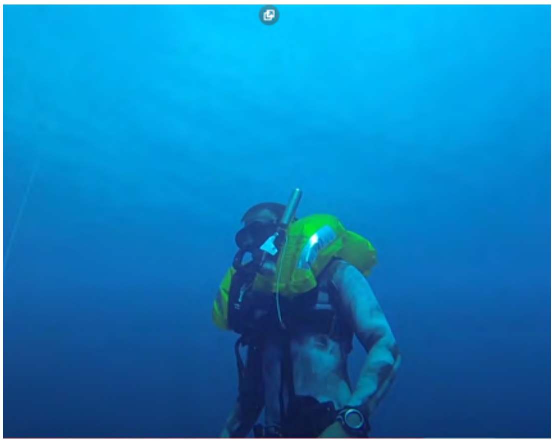
EXISITING PRODUCTS:

ill. 11 FRV

ill. 12 FRV Deployment

Fredivers Recovery Vest (FRV)
Through investigation of existing products used to combat SWB, two were found. The first is called Freedivers Recovery Vest, shown on ill. 11 & ill. 12. It features inflatable elements that are supposed to bring the diver to the surface and ensures proper orientation during the blackout. However, the vest only triggers if two vaules are overstepped; maximum depth and time. Both of these have to be set manually before the dive. The vest also features a dead mans switch, which is a button mounted on the upper arm, that must be pressed 15 seconds after resurfacing. Otherwise the vest will deploy. The FRV never gained traction and is now almost impossible to buy anywhere and the company producing it now seems shut down.

ill. 13 Sens07Vest



ill. 14 Sens07Vest inflated

Sens07Vest
The second product is the Sens07 inflatable vest, shown on ill. 13 & ill. 14. It is extremely similar in functionality to the FRV. It is however a great deal smaller and less cumbersome (Deeper Blue 2020). This product entered the market in 2020 with more modern features compared to the FRV, like app control. However, maximum depth and time must be set beforehand like the FRV. It also features the same dead mans switch, that has to be pressed when the diver resurfaces or the vest inflates. It is priced around 5.000 DKK.

Exisiting product feedback
The existing products were presented to the users during interviews, to gain more clearity why these very similar products were not more commonly used.

From the feedback gathered, it was clear that there were some main points, that users found problematic. Firstly, that they appeared too cumbersome and could easily get in the way or slide around during diving. The products also created unecessary distraction, as they needed to be constantly intacted with during resurfacing, to prevent inflation. Martin Jørgensen said that the constant interaction at the surface would negativly impact the mentality. If an new solution was to be made, it would have to not disctract from the activity while diving. This could eventually be done with some level of automation.

It should also be noted that very few of the users had actually heard about these products prior presenting them. However, users indicated that the idea of helping the diver to the surface was a good one. Some however still felt the solutions were inadequate, since they did not inform other nearby divers, nor do they help with emergency procedures. They still saw it as vital, that other divers were nearby and able to perform emergency procedures.

EVALUATION

This section confirmed a series of things for the project. For one, the idea behind combatting SWB is a very welcome one. However, current solutions create to much distraction during diving sessions. Combined with the known fact that a diver can't always act on or even register a blackout in time, means that there is a potential for creating a new solution. A solution that focuses on minimizing the amount of interaction from the user during a dive, while also creating awareness for nearby buddies and other divers. The current solutions do not help with emergency procedures either. This would mean a certain degree of automation. However, there is one major challenge with an automated solution that is supposed to help in the case of a blackout. A future solution needs to know when the user is having one. In order to solve this challenge, a potential solution needs measurable factors that change in the body, which indicate a blackout. With little to no knowledge about this, the group decided to conduct indepth research on what changes within the body during a blackout and what potentially could be measured, to use for an automated trigger system. Due to user feedback, it would be ideal if a solution included an option for manual triggering of the system.

- Potential for a solution with larger degree of automation than current solutions
- Option for manual triggering
- Potential to create awareness to facilitate the rescue of a blackout victim.

1.5 BLACKOUT PHYSIOLOGY

The objective of this section was to investigate if there are any clear physiological indicators of a blackout which could potentially be used as indicators for an automated solution. This was both in regards a proactive and/or reactive blackout situation. This section supports the initial research done in section 2.3. The research presented is supported by an interview with medical doctor and spearfisher Tom Helm Petersen. See worksheet 9 for interview with Tom Pedersen.

THE BREATHING INDICATOR:

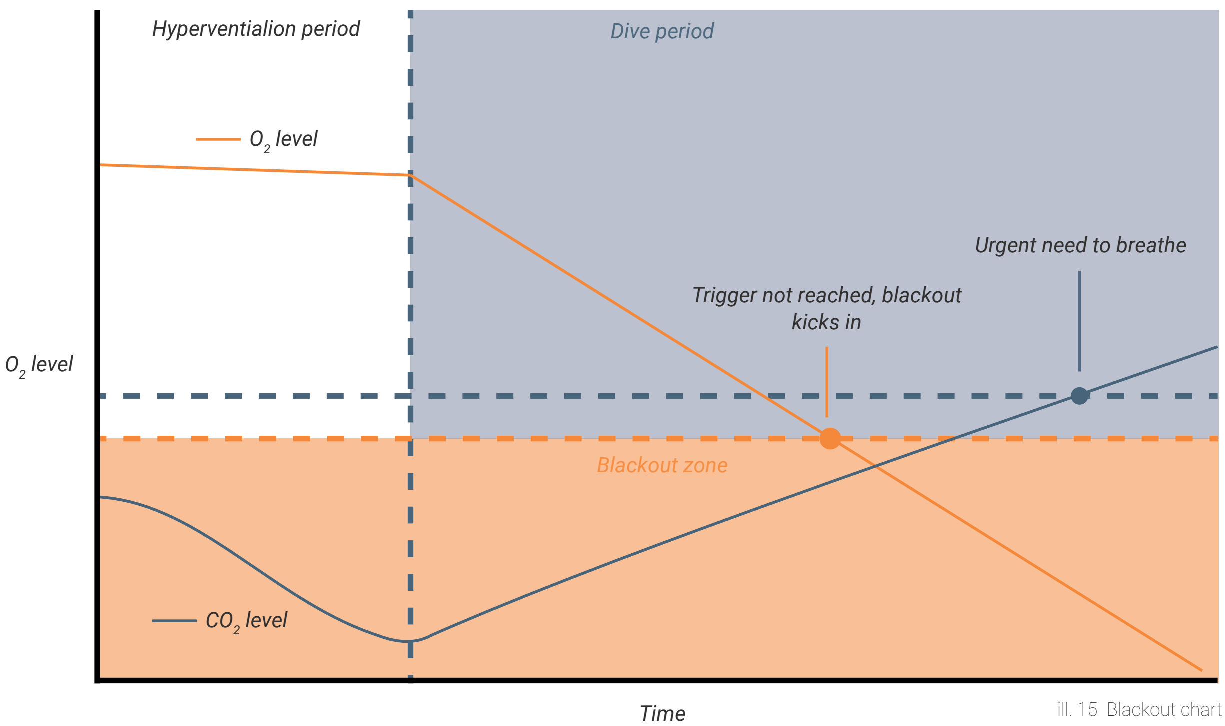
To understand what can be monitored within the body, it required understanding of why a blackout occours, on a much more technical level. Likewise, why divers are not always aware when they are in danger of a blackout.

The desire to take a breath as a result of breath-holding is dictated by the amount of CO_2 in the bloodstream and not the amount of oxygen (O_2). There are several ways that this indicator can be affected, one being hyperventilation. Hyperventilation causes a self-induced reduction of CO_2 in the blood and can ultimately result in a diver not being able to detect when the body runs out of O_2 (Culture of safety n.d.). A blackout due to hyperventilation happens because CO_2 has been scrubbed from the system, and the system now depletes O_2 faster than it takes to reach the natural urge to breathe. (ill. 15)

Hyperventilation has previously been very popular due to the fact that it makes you feel like you are able to breath-hold for longer periods of time. Likewise it removes other symptoms that arise due to high amounts of CO_2, like stomach cramps and burning throat sensations. Hyperventilation nowadays is highly discouraged when performing any underwater activity. Therefore freedivers are training to ignore and overcome the symptoms which is the body's natural way of telling you to breathe. Another way to affect the CO_2 indicator is by physical exorcise. New research upon the consequence of aerobic exercise states that exercise prior to a dive, can result in O_2 being used faster. This is because the muscle tissue requires more oxygen. (Lindholm & Gennser 2005)

It is discouraged to perform dynamic breath-holds following longer periods of time with physically exhausting work. Therefore it is important to take extra care when involved in any underwater activity with repetitive breath-holds within longer periods of time. Including freediving competition days or a long day of recreational spearfishing. It is in situations like this very important to pay attention to replenishment of the carbohydrate stores (glucose). If these are not restored properly, the body utilises fat as energy source which means oxygen is deprived from the blood more rapidly and less is produced. In this case oxygen is consumed up to 8% faster and the amount of CO_2 produced is up to 30% less (Lindholm & Gennser, 2005).

With this information on why a blackout can happen, it was necessary to know what the different stages of a blackout are. In addition, it was also needed to find out what the body's natural reactions to submersion in water are.



ill. 15 Blackout chart

THE STAGES OF A BLACKOUT:

Oxygen deficiency in relation to freediving can generally be described in 3 phases: Loss of Motor Control, Blackout and Drowning. The 3 phases are presented below.

1. Loss of Motor Control (LMC)
Due to low levels of oxygen in the blood at the end of a dive, a freediver might experience loss of motor control (LMC), which is basically the brain lossing controls of the motoric functions in the body. (ill. 16) While experiencing LMC, a person will still be in a state of consciousness, but will typically be unable to react purposefully. During the loss of the control over the body, one might experience muscle seizures. One might also experience difficulty breathing.

LMC will either subside by itself, within about 5-20 seconds, or will lead to loss of consciousness (Villadsen 2014). The subsequent effect depends on how severe the oxygen deficiency is and how well the LMC is handled during the episode. As this is the earliest indication of SWB, this could have potential as a measureable indicator for an automated solution.

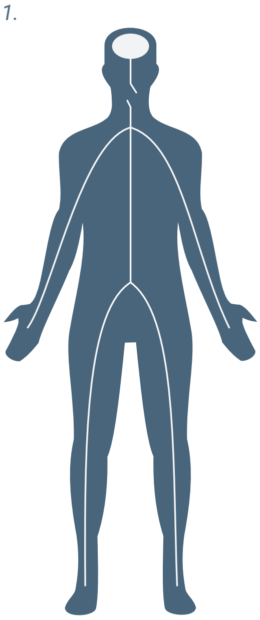
2. Blackout (syncope)
A blackout involves loss of consciousness and is medically described as a syncope. A syncope can be caused by different things, including the lack of a sufficient oxygen supply to the brain (Cerebral Hypoxia). In relation to freediving this is a result of deficient oxygen levels in the blood due to prolonged breath-holding. A hypoxic blackout is the body's natural response in order to prolong the opportunity for survival. Consciousness is shut off as the oxygen left in the blood flowing around is now used to preserve the brain and heart (ill. 17).

An unconscious freediver with the airways submerged in water will not automatically recover, like one potentially could above water. If the freediver does not receive help in time drowning will most likely follow. The most critical phase of oxygen deficiency takes effect when the deprivation of oxygen is either severe enough for water to start entering the lungs or a cardiac arrest to occur.

3. Drowning
The human body is equipped with a protective reflex that causes the throat to seal shut when blacking out underwater. This phenomenon is called "laryngospasm". This reflex fortunately prevents water from entering the lungs but unfortunately fresh oxygen too. As a result hypoxia will continue. This reflex usually releases after a short amount of time, typically after 30s, and result in involuntary exhalation followed by water filling the lungs (ill. 18). This phenomenon is called wet-drowning (Freedive Earth n.d.-a).

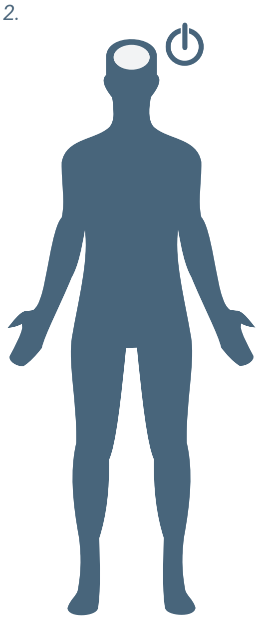
Laryngospasm in relation to freediving can potentially last up to 2 minutes before releasing. Cases of laryngospasm have even in some cases been reported to have lasted for up to 30 minutes, thanks to hypothermia, without the result of brain damage. Hypothermia plays a major role in slowing down the physiological system (Naslund 2008). In some cases the laryngospasm will persist until cardiac arrest. A cardiac arrest stops the heart from beating and thereby causing blood flow to stop. Thus it naturally prevents the flow of oxygen to the brain. This phenomenon is called dry-drowning.

1.



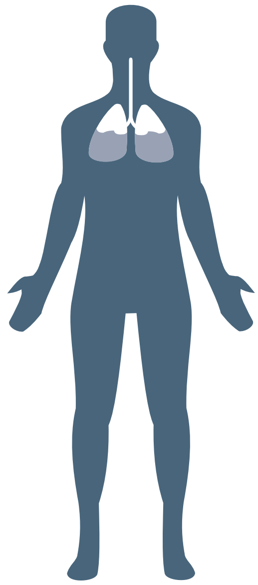
ill. 16 LMC

2.



ill. 17 Blackout

3.



ill. 18 Drowning

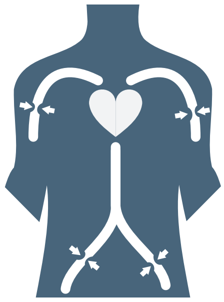
THE BODY'S RESPONSE:

With a deeper understanding of what the different stages of a blackout is, the next step was to understand what the body typical reaction to being submerged in water is. The human body is equipped with a mammal diving reflex. It is triggered when the face comes in contact with or is submerged in water. The reflex is amplified in colder water. It is a physiological phenomenon that automatically functions to conserve oxygen. The following four main effects comes into play (Ash 2017).

1: Reduction of heart-rate:
By lowering the heart-rate while not compensating with an increased stroke volume, the body conserves oxygen. A reduction by 20-30% in untrained people has been observed and 40-50% in trained athletes (Villadsen 2014) (ill. 19).

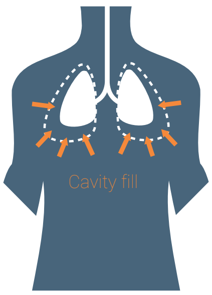
ill. 19 Heart rate reduction

2: Closing veins
By narrowing blood vessels in the extremities, the body directs an increased amount of oxygen towards vital organs. The body simply priorities tissue differently. Extremities such as fingers, toes, hands and feet demand significantly less oxygen than the brain does (ill. 20).



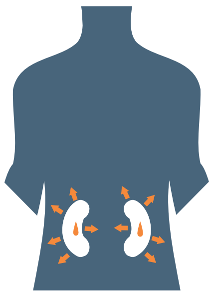
ill. 20 Vein narrowing

3: Cavity filling
Air inside the body will start to compress as the atmospheric pressure naturally increases with depth. The blood shift caused by the vein constriction will direct blood to air filled cavities inside vital organs. As blood is an incompressible fluid, it compensates for the compressed airspace. Thereby, among other things, it prevents the lungs from collapsing (ill. 21).



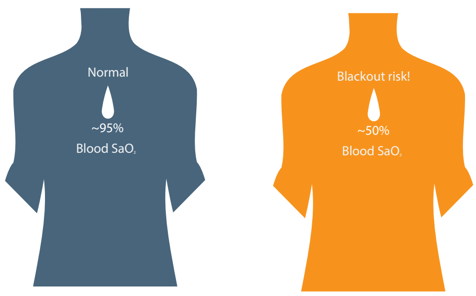
ill. 21 Cavity filling

4: Blood release
Large amounts of blood circulates through the spleen making it a reservoir of red blood cells. When the spleen starts to contract, as the diving reflex is triggered, blood is released. Blood released by the spleen act as a support to the blood shift by strengthening the oxygen supply to the vital organs (ill. 22).



ill. 22 Blood release

Oxygen saturation levels
Oxygen saturation (SaO_2) levels are the percentage of red blood cells saturated with oxygen. A normal arterial saturation is 95-100%. A hypoxic blackout might occur at an arterial oxygen saturation at approximately 50% in non-divers and lower than 50% in trained divers. A study explored restoration of oxygen levels after a dive (Schagatay & Åman 2019). The study showed full restoration (95-100%) after 45s in 8m depth breath-hold dives. This correlates with the previous understanding of hypoxia continuing for up to a minute after resurfacing (ill. 23).



ill. 23 oxygen saturation

Oxygen partial pressure
A sufficient partial pressure of the oxygen (PPO_2) in the lungs is required for consciousness. It is the driving pressure of the gas exchange between lungs and blood. During descent, the partial pressure of oxygen in the lungs increases and decreases again during ascent. In itself this partial pressure change is not a problem, but becomes important to take into consideration when a diver starts consuming oxygen at the bottom of the dive. The situation becomes critical if the decreasing partial pressure during the ascent is no longer high enough to compensate for the amount oxygen left. ill. 24 shows the relation between depth and oxygen partial pressure in the lungs. Note that the threshold for SWB is typically 0,10 PPO_2 (Freedive Earth n.d.-b).

In practice, the most critical part of a dive is the last 10 meters, during the ascent. This is because the pressure in the lungs that occours while under water, is no longer enough to supply enough oxygen to the body.

DEPTH [M]	BAR [ATM]	$PP0_2$	$PP0_2$ Ascent
0	1	0.21	0.09 = SWB
10	2	0.42	0.18
20	3	0.63	0.27
30	4	0.84	0.36
40	5	1.05	0.45

ill. 24 Partial pressure chart

EVALUATION:

Research has shown the importance in replenishment of carbohydrate stores during long days with exercise. It is better to metabolise carbohydrates rather that fat, for effective oxygen conservation and CO_2 build-up. A long day of exhausting physical work combined with diving deep increases the risk of having a blackout. Even though oxygen is only consumed 8% faster predominantly during fat metabolism, it might be a factor of high risk when you consider the rapid partial pressure change during the ascent. Especially the last 10 meters where the biggest change is seen. The partial pressure is at the surface half of what it is at 10 meters. Therefore blackouts are often seen at the last part of the ascent or at the surface. This could be a potential focus area for a solution.

As for possible monitoring solutions; Arterial oxygen saturation (SaO_2) seems to be a major indicator that might be useful to monitor during a dive. Even though trained freedivers have a higher tolerance towards low saturation levels, it is an important oxygen deficiency indication.

The second option could be looking at the first indicator of a blackout. When in a state of "loss of motor control" (LMC) it's harder to act in case of an emergency. Seizures and/or unpurposeful reactions during LMC is an interesting indicator prior to the blackout. The third indicator could measure if a diver has reestablished breathing within a certain time period. That could potentially be used as a very clear indicator, since lack of breahting over an unusually long period of time could be clear sign of an SWB. A potential solution could also be able to measure if the user is having a blackout, even if they have reached the surface. Some elements might turn out to require a deeper insight at a later stage in the process in order to achieve precision and feasibility in regards to a concept proposal.

MEASURABLE PARAMETRES

Blood oxygen levels and heart rate
The ability to measure these two factors already exists in watches. This could potentially be used in a wrist or chest mounted device.

Loss of motor control and panic movement
Since this is the first stage of a blackout, this could be a clear indicator, that can be measured through some sort of body mounted movement sensors.

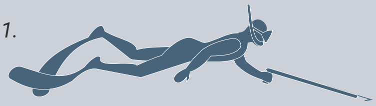
Breath monitoring
Since breathing is essential to reestablish the body's O_2 levels, it would be an ideal parametre to measure. This could possibly be done through a sensors able to measure breathing.

» Measurable parameters were found.
» Parameters can be measured non-invasivly
» The risk of blackouts are highest at the end of a dive (last 10 meters)

1.6 TIMELINE OF A BLACKOUT

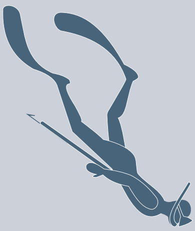
Below is a demonstration of the progression of a blackout over time, as well as the coping strategy in case the blackout is spotted in time. The timeline is buildt from knowledge from section 1.1, an interview with Tom Helm Petersen and videoes of blackout situations and rescues recorded by a variety of divers. The timeline is an example of a spearfisher dive, but is applicable to freediving as well. It provides the broadest understanding.

1.



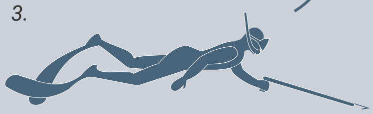
1. Diving down
Divers will usually float at the surface, breathing through the snorkel in order to relax, planning the next dive and look for potential prey. When they are ready, they will hold their breath and dive down to their destination. For this example, the diver will be going down to 15 meters depth. Divers usually dive seperate with between 50 to 100 meters in spacing.

2.



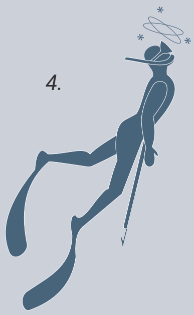
2. Lung compression
As the diver descends, the pressure of the water will compress the divers lungs, increasing the air pressure inside them. At 10 meters, the atmospheric pressure will have doubled. The mammal diving reflex will also kick in, reducing oxygen consumption.

3.



3. Air consumption
While the diver is at 15 meters depth looking for fish, the body will slowly use its stored oxygen over time. The divers also tend to ignore the breathing reflex, that comes from the CO_2 build up. Freedivers train themselves to push past this reflex and will often ignore warning signs from the body. This way, the diver can end up using to much oxygen, without realizing it. However, the diver does not feel this, since the increased air pressure in the lungs is enough to compensate for it.

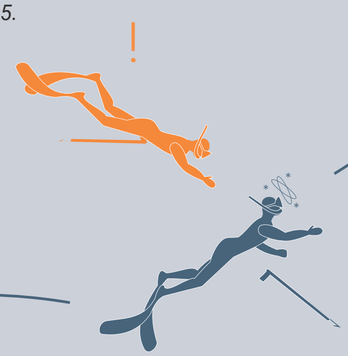
4.



4. Lung decompression
When the diver starts to head towards the surface, the partial pressure in the lungs starts to lessen, meaning that there is no longer enough air pressure to compensate for the lack of oxygen. As a result, the diver will suffer a Shallow Water Blackout. It will start with the diver feeling disorientated or “drunk”. The lack of oxygen after decompression can be so severe, that the diver can still be at risk of a blackout when they reach the water surface, and even after taking a few breaths.

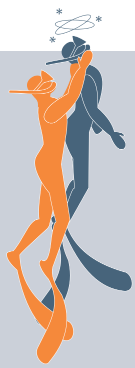
- Diving buddy is your best chance of survival
- Getting to the surface is vital for survival

5.



5. Passed out
The diver will quickly loose consciousness, often so fast that they do not register it themselves. This is were LMC will start to occour. Divers will also have irrational movements, like trying to tear of the mask and dropping the speargun. This is also a visual indication to other divers that something is very wrong, if they are close enough to see it.

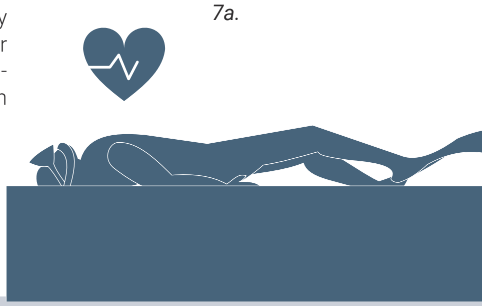
6a.



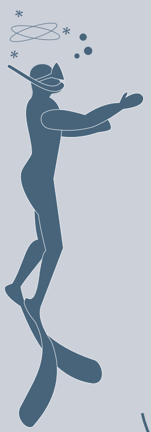
6a. Rescue
In this scenario, a dive buddy was close enough to notice something was wrong, and will start to try and carry the victim of SWB to the surface. They do this by holding both hands around the victim head, under the chin and back of the head. When they reach the surface, the dive buddy will initiate the blow-tap-talk procedure, to try and wake the passed out diver. Even if the diver resurfaces on their own, the head must be kept above water, as the body won't do this by itself.

7a. CPR
Depending on the divers condition, or if the diving buddy is unable to get the passed out diver to wake up, the diver will be taken to a boat or any hard surface and CPR will be attempted. From here, emergency services will be called, and the diver will be taken to the hospital by ambulance or helicopter, depending on the divers condition.

7a.



6b.



6b. No rescue
If the unfortunate thing should happen that nobody notices that a diver has passed out, the diver will start to lose complete consiousness. The body will attempt to prevent water from entering the lungs by sealing the throat. This also means the body will be unable to breathe unless this reflex is countered by blowing air in the divers face at the surface. Eventually this reflex will stop working in most cases, and the remaining air in the lungs will be released and water will enter. The body's oxygen reserves will last around 2 to 2,5 minutes before risk of brain damage.

7b. Death
The body will slowly start to shut down while being unable to breathe. The last reserve of oxygen will be depleted trying to keep the brain and vital organs alive. From here, the diver will technically be considered dead, but can still be revived if rescuers are fast enough. It will depend on the amount of damage the brain has taken, and the amount of acid that has buildt up in the body due to CO_2.

7b.

1.7 PROBLEM SLICING

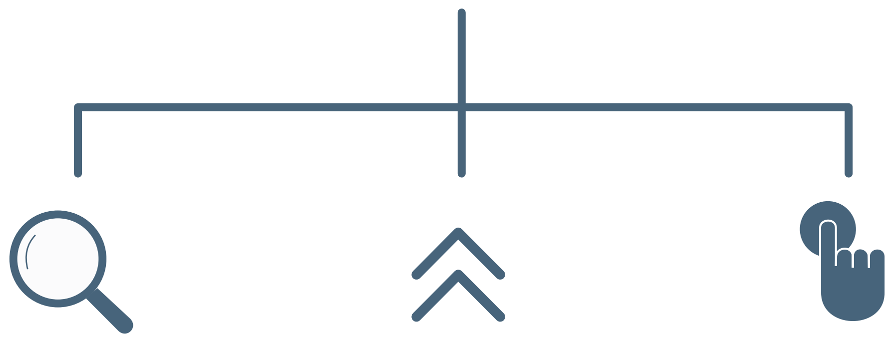
SEPERATING THE MAIN PROBLEM

The main problem of a diver that suffers from a Shallow Water Blackout, is a very complex problem. Since it is almost impossible conceptualize a solution that solves every aspect of such a problem at the same time, it was decided to split the core problem into smaller parameters. This way, different aspects of the problem can be tackled one at a time and independently from each other. Working with them independently allows for ideation and research on the individual problem parameters, without having to consider the entire problem at once.

It was decided to seperate the main problem into 3 different parameters. The first one is detecting whether or not the diver is having a blackout. The second parameter is getting the diver to the surface, in case a blackout occurs. The last one is figuring out the interaction concern the triggering of a potential solution, either manually or automaticly. Correspondingly, user needs will be split into the same 3 parameters, in order to clearify what issue they are aimed towards.

CORE PROBLEM

SHALLOW WATER BALCKOUT



MONITORING

This parameter consists of trying to determine a blackout when it happens. Initial research showed that there were potential in using certain indicators within the body to measure when a blackout occours. As previously stated, it was important that any measurement devices used were non-invasive. In order to solve this, the group proceeded to investigate potential sensors, technology and existing solutions that could provide inspiration or ways to measure one of the parametres previously addressed.

RESURFACING

If a diver has lost consiousness and is unable to get to the surface by themselves, they need help in some way to get back up. Another aspect of this issue is staying at the surface once you reach it. However, it was decided to focus on getting the diver to the surface, since this was of a higher priority. Therefore, the intial research stage consited of looking into exisiting solutions and technology, to get a better understanding of what is practically possible, and what is already in use.

INTERACTION

This issue can be seen as a link between two previous parameters, since it depends on the way the two other solutions are solved. The inital approach was to gather inspiration on both manual and automatic triggering. However automatic triggering is hard to sketch for, so the early focus was on looking at different existing solutions in equipment that already had manual releases in intense situations. The next was the to try and find a way to adapt these for a potential solution.

» Needs will now be split into 3 issues.

INITIAL RESEARCH

Below is some of the initial research done, seperated into the 3 problem parameters previously presented. This was a very basic investigation, aimed at trying to explore what options are available.

MONITORING

The research managed to find a series of different non-invasive sensors that could measure different parameters inside the body. Most of the relevant parameters could be measured noninvasively, but it should be mentioned that invasive methods were more accurate in some cases. It was found that sensors could be used to track both body movement and breathing. O_2 levels and heart rates could be measured by using an infrared sensor (ill. 25). See more on initial monitoring research on worksheet 7

ill. 25 Monitoring options

RESURFACING

The research for the resurfacing issue was getting a better understanding for what floatation equipment is commonly used, how they are categorized and different methods for creating buoyancy. The quick research showed that materials like kapok and cork would not be preferred, since these would provide a constant buoyancy, which would make it hard to dive (ill. 26). Ballast tanks or CO_2 cartridges, seemed more promising alternatives with variable buoyancy. See more on initial resurfacing research on worksheet 8

ill. 26 Resurfacing options

INTERACTION

The focus for the research for the triggering mechanism was to find manual releases or mechanical principles that could be used. The research did not show any solutions that were more ideal than the other, but it provided good inspiration from other products (ill. 27), that has manual release meant for intense and even panicked situtations. Other options were pull-straps or button mechanisms.

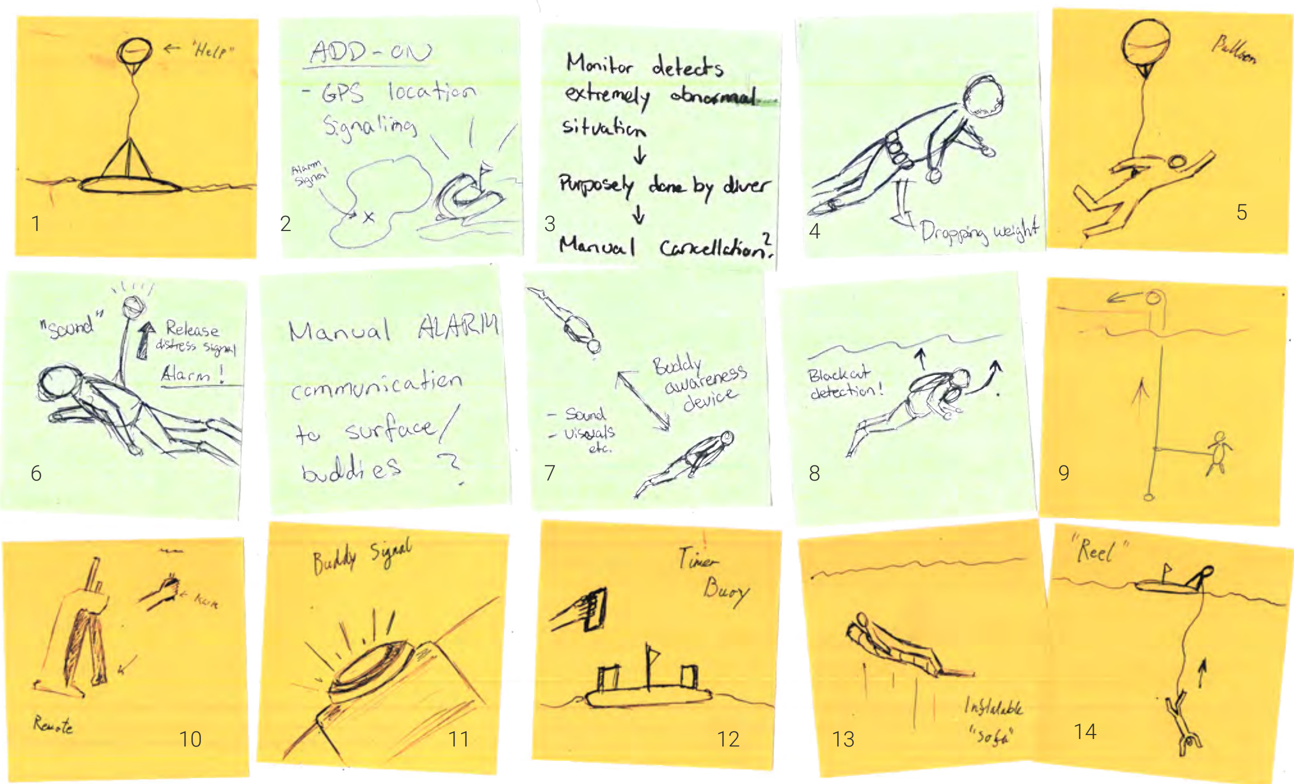
ill. 27 Triggering options

EVALUATION

The research presented in this section was not very in depth and does require further follow-up, but it provided a good insight into what was actually possible and gave an understanding of what might be a viable solution. For the monitoring issue, It showed that most of the SWB indicators could be measured noninvasively, but it should be mentioned that invasive methods were more accurate in some cases. For resurfacing, it showed that CO_2 cartridges were ideal, since they do not add buoyancy before it is needed. The research into the interaction issue only gave some ideas of the kind of release that could be used. After this initial research session, the next step was to attempt to formulate some inital ideas in order to identify possible concept directions.

1.8 INITIAL IDEATION

On the basis of information gathered from the inital research, a sketching session was held in order communicate some of the ideas that had appeared. The sketching session focused on trying to combine ideas and inspiration gained from the earlier reseach into monitoring, resurfacing and interaction.



ill. 28 Sketches

IDEATION EVALUATION

A series of different ideas emerged from the sketching session, some of them similar to each other. One of the more clear ideas, which can be seen on sketch 1,2 and 12, were using the buoy to create awareness at the surface with some kind of alarm.

Another idea was a communication system with a diving buddy to create awareness under water, which can be seen on sketch 7 and 1. A common idea was an inflatable ballon, that would inflate and bring the diver to the surface, as seen on sketch 5 and 6. A variation of this can be seen on sketch 13, which shows a kind of inflatable sofa, that could bring a diver to the surface.

There were also a few alternative ideas for getting a diver to the surface. Sketch 14 and 9 show a buoy or boat mounted reel, that would reel the diving line back in. There was also a single suggestion for a manual release on sketch 10.

The initial ideation was a very fast sketching round just to clear the head of ideas. Therefore ideas and thoughts are very rough. Key takeaways from the ideation might turn out to have great influence later in the ideation process, since the first ideas are often the hardest to move past.

It was realized after this session that the problem of a shallow water blackout can in itself be hard to comprehend and ideate upon. In order to move forward it is necessary to work with the problem in a more specific context. So far, the context has been freediving in general, however it was realized that in order to push the concept development in a more concrete direction, a more specific context was needed. The next step was therefore to pick a specific freediving context to focus on.

» Further ideation and concept development requires a more specific context.

1.9 PICKING A CONTEXT

THE TWO CONTEXTS SO FAR

Througout this research chapter, a range of different studies into the problem of shallow water blackouts have been presented. At the start of this process, the group was introduced to freediving and it was decided to differentiate between competitetive freediving and spearfishing. In this section, it will be explained which specific context was chosen to work with and how the previous research affected this choice. Recreational freediving have been excluded, since both competitve freediving and spearfishing proved more relevant, since they provided a more defined context and larger risks of blackout.

CONTEXT

FREEDIVING

COMPETETIVE FREEDIVING

The insight gained from the visit at Fridykning Aalborg, combined with later research into SWB, gave the group a good understanding of how freedivers combat the risk of SWB. In competetive freediving, the diver tend to push themselves much further towards a blackout and on a much more regular basis. However, since the occourence is more common, the divers are much more aware of it, and take extra precautions in order to medigate the consequences. Paradoxically, this means that while the risk of having a SWB during competetive freediving is much higher compared to spearfishing, the chances of being rescued from a blackout is much higher.

From interviews with Sigurd it was also learned that both scuba divers and other freedivers are present, and actively follow the divers, making some of the ideas that were presented in the earlier sketching session irrelevant. In addition, there are certain protocols and rules that must be followed, which have been put in place to prevent divers to push themselves too far.

All of this means that even though the risk of SWB is large here, it is less critical, since help and rescue is often nearby.

SPEARFISHING

After several interviews with spearfishers and freedivers, it was clear that there was divide in the mentality between spearfishing and competetive freediving. The focus of spearfishing is not getting the deepest or the furthest, but rather to catch fish. That means that the spearfishers don't typcially push themselves as far, but as mentioned before there are way more distracting factors. There are also very little security during a spearfishing. Spearfishers typically have a buddy with them, so are relying on the buddy in case anything happens to them. However, interviews with Martin, Sigurd and Tom clearified, that spearfisher are not very good at keeping an eye on each other. Therefore, they might not notice if anything happens.

Analysis of the equipment in section 1.3 showed that they generally do not use any equipment to reduce the risk and/or consequences of SWB. They typically only rely on the blow-tap-talk protocol after rescuing a victim of SWB. This means that even though the chances of a SWB occouring is much lower than in competetive freediving, the consequence is much higher, since there are a much lower chance of being rescued. With this in mind, the group decided that there was a larger potential for a solution in the spearfishing context.

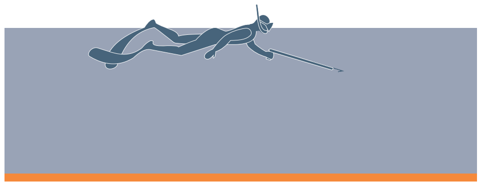
EVALUATION

Now that the context had been specified to focus on spearfishing, it allowed for a better framing of the project. After this directional decision, it was important to get a more detailed look into spearfishing. This includes the users habits and the context that it typically takes place in.

» New context: Spearfishing

1.10 SPEARFISHING IN DETAIL

From qualitative interviews with Tom Helm Petersen and a spearfishing trip to Frederiskhavn with spearfisher Martin Jørgensen, it was possible to establish a much better sense of the context. The first part of this chapter explores the diving methods and equipment customization of a spearfisher. This is followed by illustrations of the environment when spearfishing. Lastly is an user journey and an exploration of the differences between recreational and competetive spearfishing.



ill. 29 method 1

DIVING METHODS

There are three main diving methods. The first is hunting from the surface or just below it, shooting at fish that you can see while snorkling. This is only done in shallow waters (ill. 29). The second is freediving spearfishing, which involves starting at the surface, diving down and slowly moving through the water in order to spot fish (ill. 30). The third method is stationary hunting. This is practically ambush hunting, where the diver dives down from the surface, and then lies still at the ocean floor. Here they wait until fish swim close enough or they run out of air (ill. 31). This means that a potential solution should take into account contact with the seabed. This method is called aspetto. Diving near the seabed can also involve more dynamic hunting than aspetto.

ill. 30 method 2

ill. 31 method 3

EQUIPMENT CUSTOMIZATION

The equipment commonly used in spearfishing was introduced in section 1.3, but in the case of spearfishing, a lot of this equipment is actually customized on an individual basis. A very good example of this is the diver buoy. The buoy seen on ill. 32, has some customized elements, such as backpack straps, that in reality are aquarium hoses. Likewise, the handles have wooden sticks put hrough them, so that they are easier to grab onto with wetsuit gloves on.

The customization also extends to the wetsuits use. The wetsuit manufactureres usually provide wetsuits that are sewn to the users preferrences, with optional padding if the user wants it. These suits are usually used for many years, but neoprene can easily tear if not treated right. For this reason, it is very common for spearfishers, and divers in general, to fix their own wetsuit with patches of neoprene using neoprene glue, as seen on ill. 33.

ill. 32 Buoy customization

These Do-it-yourself (DIY) solutions seemed very common amongst spearfishers, which showed that they are willing to make modifications to their own equipment as they see fit.

- » Customization and DIY solutions are common within the user segment.

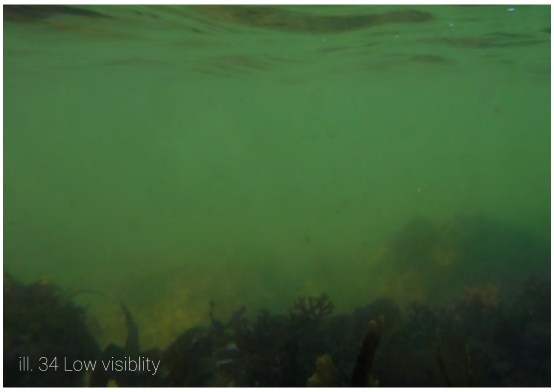
- » Movement during a speafishing dive can be very dynamic

ill. 33 Neoprene glue and patch

SPEARFISHING ENVIRONMENT

This page showns the difference between the diving environment in Denmark and examples from the more popular travel destinations for spearfishers. Spearfishers are willing to travel in order to try new areas to dive and catch fish in.

DENMARK



ill. 34 Low visiblity

ill. 35 Low visiblity 2

Diving in Denmark generally has very poor visibility in most waters and most of the year. The range is typically between 3 to 5 meters (ill. 34), with a maximum of 10 meters, but it happens very rarely. The water temperature can on average be around 2 to 18 C°.

The fish in danish waters are typcially camouflaged in the sand and can often be found in caves or hiding under rocks. As seen on ill. 35, the low visibility can make it quite hard to shoot fish at range. Luckily, some skilled divers are able to catch certain kinds of fish by hand or using a diving knife.

OUT OF COUNTRY

ill. 36 High visibility

ill. 37 high visibility 2

Places like Greece, Norway and France are popular destinations for european spearfishers. Norway is pictured above on ill. 36. Waters in Greece and France can be even clearer. The temperature in the water can also be more comfortable than cold danish waters. The second reason is that the water generally have better visibility, depending on the area. There are also more areas that allows divers to go much deeper. The clearer water allows divers to dive deeper without loosing their bearings.

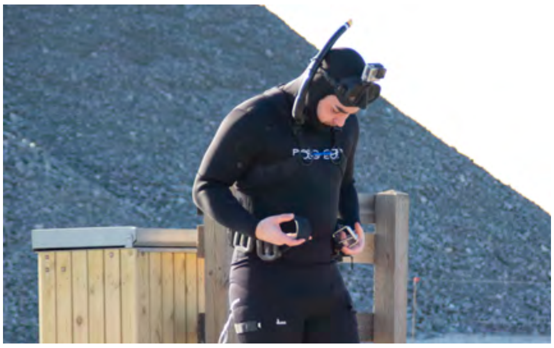
However, diving deeper natually carries a much larger risk of blackout. In southern waters spearfishers even hunt at up to 50 meters below the surface. During very deep diving being tied to a buoy is more uncommon.

?

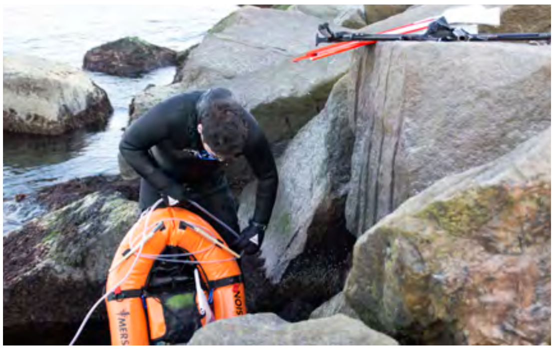
» Some spearfishers dive at up to 50 meters depth. This might prove relevant for future concepts.

USER JOURNEY - SPEARFISHING TRIP

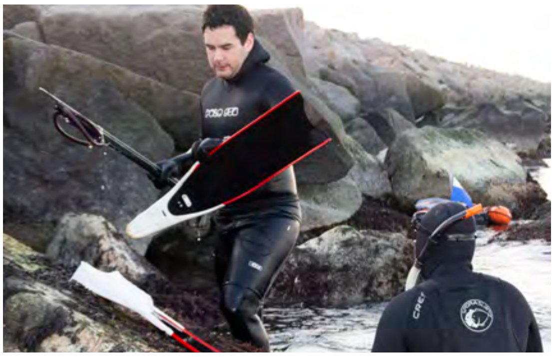
To gain a better understanding of how a spearfishing trip takes places, the group joined spearfisher Martin Jørgensen on a spearfishing trip to Frederiskhavn.



1: Equipment is carried by hand brought from the divers car to the spot where they start their dive from. The diver proceed to put on the wetsuit and other equipment first.

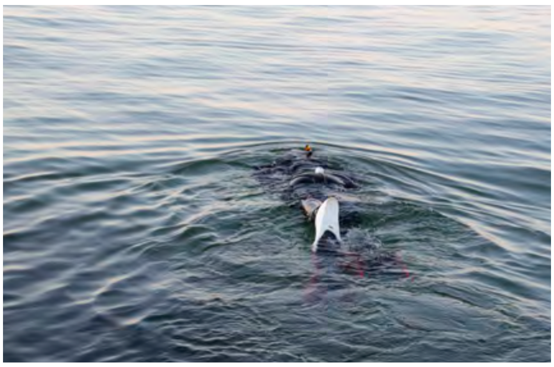


2: Diver readies the buoy and puts telephone, snacks or water in it. The float line that the diver should be attached to at all times, is also fixed here.

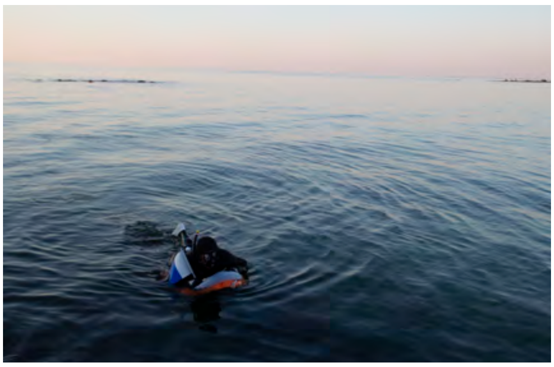


3: Lastly, flippers are put on and speargun readied. The speargun is considered a dangerous weapon and must not be loaded on land. They usually coordinate where they are going with the diving buddy, before going into the water.

4: The divers proceed to swim out to the desired fishing location. This is done either dragging the buoy via the connected float line or on top of the buoy.



5: The divers proceeds to look for fish, preferreably spending as much time at the bottom as possible. Here the diver will look for fish in caves, in the sand or swimming freely around. The buoy now acts as a base point. Any caught fish will also be hooked to the buoy.



6: When the divers gets tired or has caught enough to be satisfied, they return to land. The total time elapsed can be from 2 to 5 hours.

DIFFERENT KINDS OF SPEARFISHING

The insight given on the previous page clearified the user journey involved in recreational spearfishing. Besides recreational context, a competitive one also exists. There are some explicit differences between the two, that will be explained in the following section.

RECREATIONAL SPEARFISHING

This is the most common form of spearfishing. Its takes place during most months of the year, from around april to october. There are no specific goal but the ones that the individual diver sets for themselves. Frequency of diving trips varies from diver to diver, from once a month to several times a week. Divers often dive with a buddy, and usually spaced out with around 50 - 100 meters.

COMPETITIVE SPEARFISHING

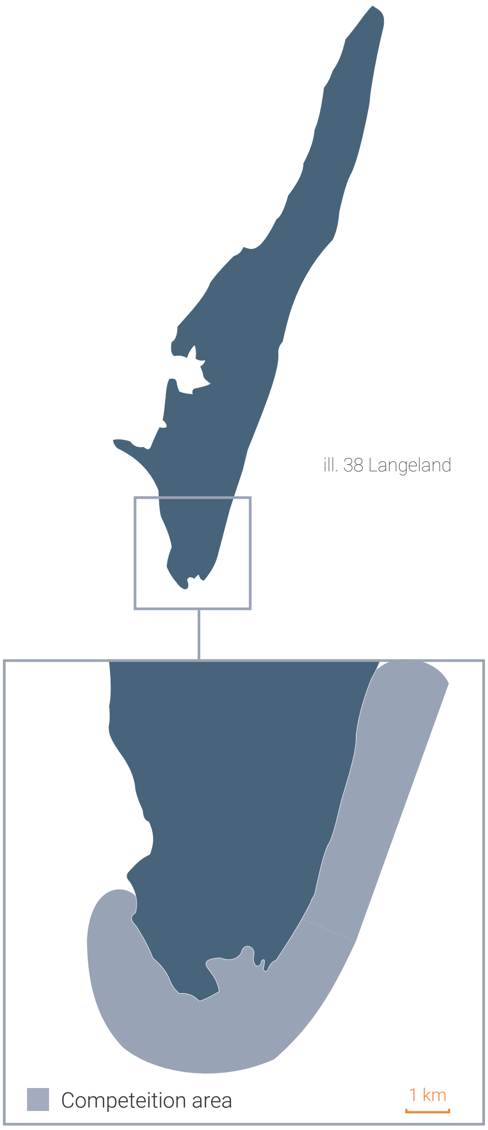
Competetive spearfishing takes place over a very large area up to 10 kilometers in length and as far off shore as 1.4 kilometers. For example, the 2019 euro-african championships in spearfishing were held here in Denmark, at Svendborg, organised by CMAS. Here, around 150 spearfishers took part, spread over the coast of Langeland and nearby areas (ill. 38) (see Appendix 1). During competitions there are set rules, such as you must have a buoy with you. There are also rescue boats in place, but they are far apart (Undervandsitetet 2019).

The tragic death during CMAS 2019

Unfortunatly, during this event one of the competitors, portuguese Matthias Sandeck tragically died. Matthias was not tied to his buoy and instead had it tied to a pylon. He was spearfishing down to 25 meters of depth, with 1 meter visibility and almost total blackness at the bottom. Tom Helm Petersen, who was a medical doctor and rescue diver on site, told during in interview that the body was found around 15 meters from his buoy and the pylon. Only after other nearby divers had noticed Matthias had not come up for air in a long time and eventually called for rescuers to look for him. However he was found to late and did not survive. Tom expressed that the event highlighted a lack of safety for the individual diver. Even if the competition officials do their best to medigate it, and have decided to make a refocused effort towards higher safety. (see interview with Tom on worksheet 9)

EVALUATION

The more indepth study into spearfishing gave some important insights into what kind of context a potential concept should fit into. Firstly, a concept should take into account the different diving techniques that the diver uses. It should also be taken into account that visibility sometimes can be low, down to 1 meter, depending on the location. A typical fishing trip can last up to 2 - 5 hours, which means a concept should ideally be able assist in case of a blackout in that entire duration. The research also showed that there could be a potential for making a solution targeted towards competitive spearfishing. Due to recent death and the renewed focused on safety, it would be ideal to design a concept that could assist in this.



ill. 38 Langeland

» Potential for a solution meant for competetive spearfishing

» A diving session can last up to 5 hours

1.11 DESIGN BRIEF

PROBLEM SUMMARY

Freediving is becoming an increasingly popular activity globally. Whether it involves competition, underwater sightseeing or spearfishing. Holding one's breath during a dive does not come without risk. The phenomenon, Shallow Water Blackout, is an underwater faint/sudden loss of consciousness due to limited oxygen supply to the brain. A blackout can occur very fast even when a diver thinks everything is seemingly fine. Divers that are low on oxygen often do not realise it, due to several factors.

Currently, there are very few solutions on the market that can help bring a diver aid in rescue in the case of a blackout, and the ones there are, are not in use. There are also few ways to actually signal that you are in trouble, given that you realize it. For perspective, you have around 2 - 2,5 minutes, before risk of permanent brain damage due to oxygen deprivation. Annually it is estimated that 28.000 people die from having a Shallow Water Blackout. Countries with deep and clear waters are the most dangerous to freedive in.

PROBLEM STATEMENT

"How can we develop a solution that is capable of assisting a spearfisher to the surface in the case of an underwater blackout and the recovery from it afterwards."

BUSINESS CASE

There appears to be potential for a new product that will differentiate itself by offering a more automated solution, that does not distract the diver while in use. The new solution could be sold as a business to consumer product, with a pricing around 5.000, since existing solutions are in that price range.

There was also found a potential in competitive spearfishing. A recent death has highlighted that diver safety is lacking and they are looking for ways to bolster that. This could be ideal for the new solution, aimed at creating more safety for competitive spearfishers.

TARGET GROUP

The primary target group are divers that spearfish regularly, either on a recreational or competitive level, both men and women of all ages. Based of the research conducted in this chapter however, the majority of user base appears to be male. It is divers that have an interest in pushing their limits, but still have a concern for their safety.

CONTEXT

The new solution needs to fit in an wet environment, under dynamic conditions which can have low visibility.

USER NEEDS AND DESIGN DILEMMAS:

The findings in each chapter have been seperated under the 3 different problem parameters. The number for where each finding came from is seen on the right.

Monitoring	Page nr.
» Must be able to detect a blackout, before or when it has occours	» 10
» Must be able to measure for either LMC, heart rate and oxygen levels or breathing	» 21
» Non - invasive measurement of blackout parameters	» 21
» Take into account the dynamic conditions while diving	» 29

Resurfacing	Page nr.
» Aid in the resurfacing of the diver	» 22
» Aid in holding the divers head above water	» 22
» Must create awareness for the blackout victim	» 17

Interaction	Page nr.
» Potential for a solution with larger degree of automation than current solutions	» 17
» Option for manual triggering	» 17

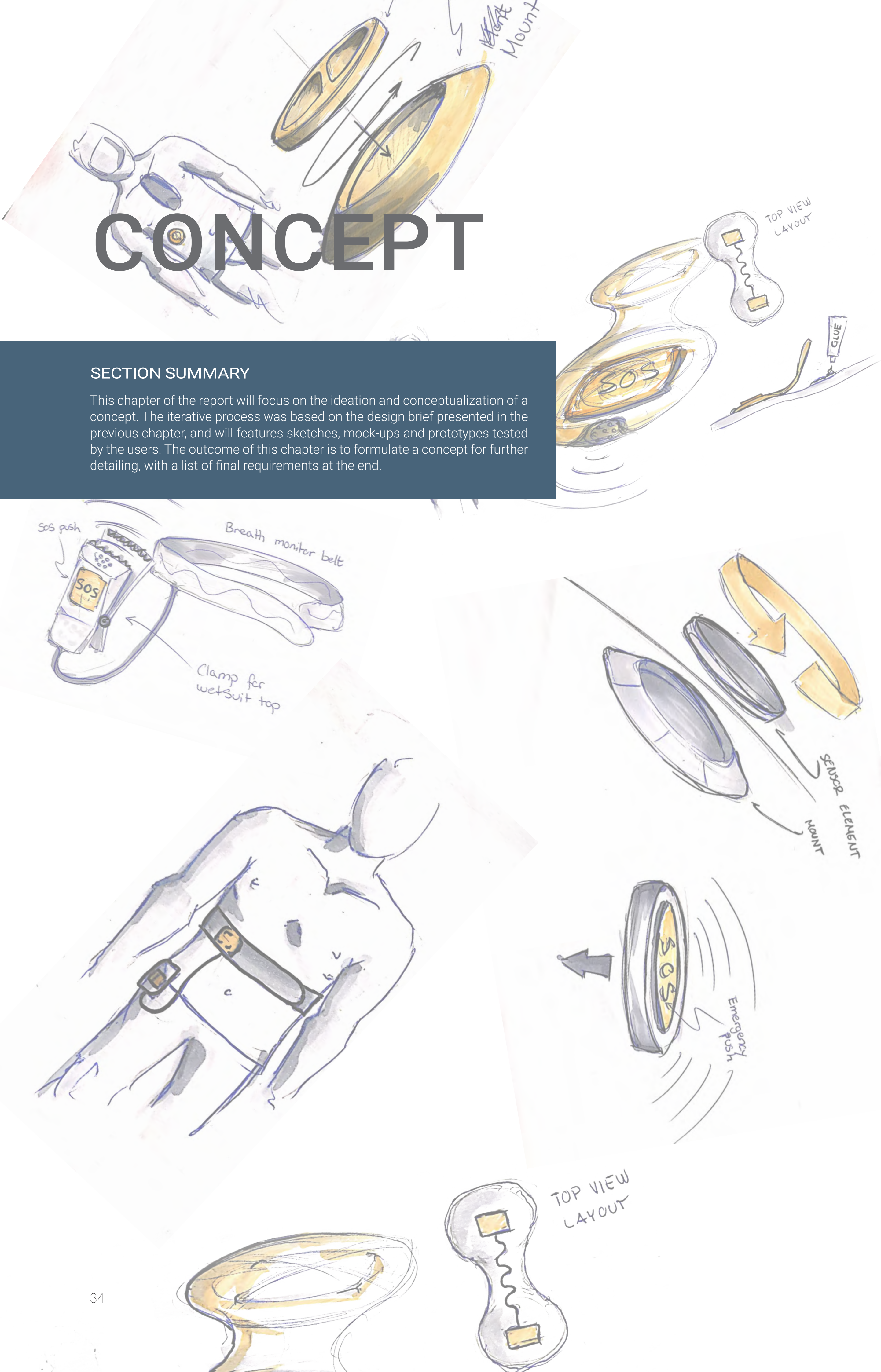
CORE DESIGN DILEMMAS

Throughout this framing section, two different design dillemmas emerged through the research and investigation done. These are paradoxical in nature and will be kept in mind throughout the design process.

Security vs Sense of freedom
The dilemma between creating a solution that is as safe as possible, but does not hinder the divers abilities underwater or creates a nuisance.

Instinct vs The right direction
This dilemma is about helping the diver make the right actions in order to save themselves, even though their instinct tells them to do elsewise.

CONCEPT



SECTION SUMMARY

This chapter of the report will focus on the ideation and conceptualization of a concept. The iterative process was based on the design brief presented in the previous chapter, and will features sketches, mock-ups and prototypes tested by the users. The outcome of this chapter is to formulate a concept for further detailing, with a list of final requirements at the end.

2.1 CONCEPT SYNTHESIS 1.0

Based on the knowledge gathered so far throughout the research chapter, three very different concepts were developed. The three concepts are heavily influenced by ideas from the initial ideation round and are each supposed to differentiate themselves in all three problem parameters; monitoring, resurfacing and interaction. These were all presented at milestone 1 and likewise presented for three users in order to gather feedback. The original gathered user feedback can be seen on worksheet 10.

USER FEEDBACK

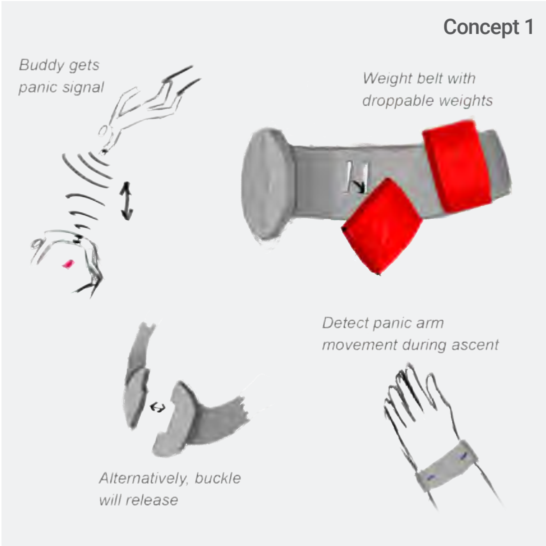
Concept 1
Detection of panic-like movements seems to concern all users as the nature of spearfishing involves several sudden movements all the time, which increases the risk of false positives. The idea of involving the buddy as part of the rescue was popular among the users as the victim might not be able to react themselves. There were concerns about the effect of dropping weight not being enough to resurface. If a diver is too deep, this will not cause enough positive buoyancy due to the high atmospheric pressure. A buddy will have to assist in this case. The belt might not fall of if the diver is in an aspetto position on the seabed.

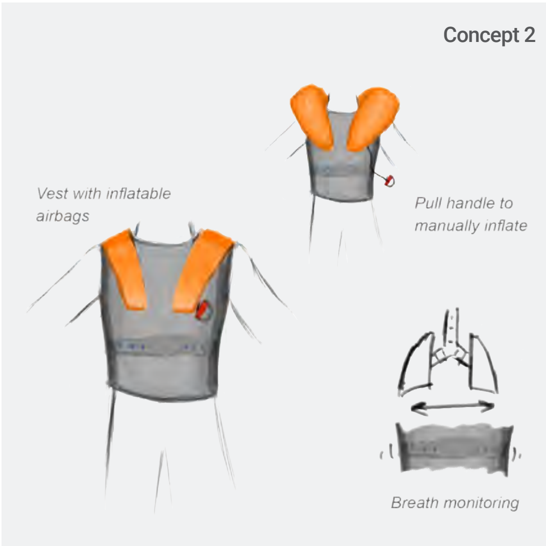
Concept 2
Detection of an attempt to breathe underwater might prove difficult as cramps in the diaphragm are very common during prolonged breathholds. In addition, an underwater exhale might not be clearly detectable as the air inside the lungs are heavily compressed at depths, resulting in limitied contraction. However, breathing at the surface following a dive is needed to re-establish the oxygen level. Inflating elements to create buoyancy is a nice feature but must not hinder the freedom of movement. This feature will neccisarily not rescue a blacked out victim as help might still be needed in terms of the blow, tap, talk procedure. The addition of a manual trigger was well recieved as it is a nice feature if you get yourself in trouble during a dive.

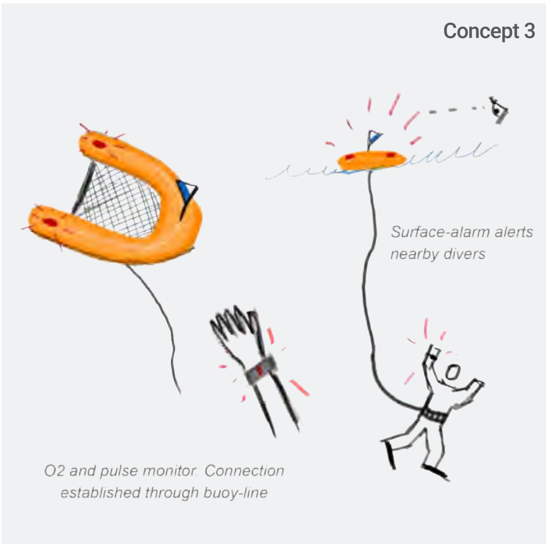
Concept 3
Detection of low oxygen levels measured on the wrist will most likely cause false numbers when close to a blackout. The diving reflex causes vasoconstriction in the extremeties and shifts blood away them (see chapter: Blackout physiology). Detection of sudden changes in heart rate could also be caused by a passing shark or a big fish. This results in high risk of uncertainties and false positives when monitoring for a blackout. The idea of using the buoy as an alarm platform recieved great feedback as you're supposed to use one anyways when spearfishing. Having others aid in your rescue ensures better recovery if action is taken in time.

EVALUATION

The feedback states that creating alarm and utilizing buddies in order to recieve help and secure better recovery were highly valued among the users. In order to be a solution to bother using, it must be simple and conserve the divers ability to move freely. In terms of monitoring, there were major concerns if a monitoring system would provide false positives. It could lead to an unwanted triggering of eg. an inflatable vest. It is potentially a dangerous situation, if one is looking inside a small cave.







2.2 KEY FUNCTIONALITIES

As stated in "2.1 Initial concepts" the expectation was to get useful feedback on all concepts in all three problem parameters. This was initially supposed to lead the way for future concepts in a more clear direction. Even though very useful feedback was recieved, it turned out not to be as directional as initially hoped for. This was most likely because the presented ideas were too unspecific and intangible making them difficult to give clear feedback on. As the users can only react on what they are presented with, it was important to reflect upon what can be done in order to get the desired kind of feedback the next time.

A NEW APPROACH

Going forward it was realized that it would be a beneficial strategy to think of the project as a system with functionalities in combinations and as possible add-ons instead of "one solution solves all." This strategy would hopefully ease conceptualisation and prototyping and likewise facilitate more concrete feedback to work with in the future. 7 different functionalities were defined, which allows for development in each separately, instead of trying to develop every aspect of an entire concept at once. This segmented approach allows for exploration of different sub-solutions without affecting an overall concept. The intention was that these sub-solutions, at a later stage in the process, could be combined into more complete concepts through sketching and prototyping. The next 5 sections will adress the different key functionalities. The face above water functionality was part of the increase buoyancy research.

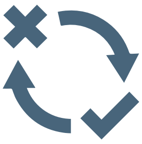
THE 7 KEY FUNCTIONALITIES

CONVEY INFORMATION
For whom is information adressed?
Where is it placed?
Which information?
How is it comminucated?

COLLECT DATA
Where is it placed?
What data is collected?
How is it collected?

TRIGGER MANUALLY
Where is it placed?
How is it triggered?
What does it trigger?

CREATE DISTRESS SIGNAL
Where is it placed?
Who is the alarm adressing?
How is alarm created?



TRIGGER AUTOMATICALLY
How is it triggering?
Why does it trigger?
When does it trigger?

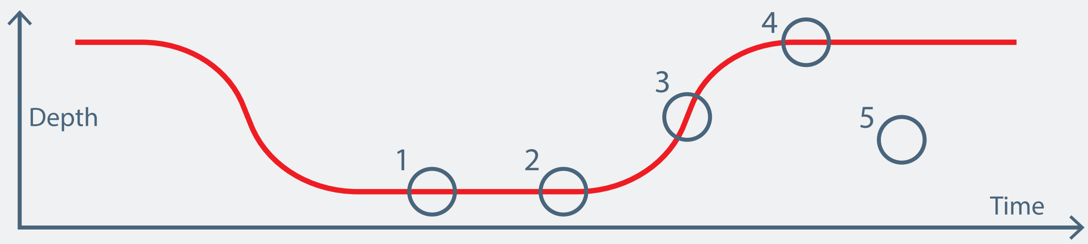
INCREASE BUOYANCY
Where is it placed?
How is buoyancy created?

SECURE AIRWAYS
How is the face kept above water?

2.3 COLLECT DATA

Following the user feedback on the three initial concepts presented, it was clear that the main concern was how to monitor for a blackout, without false positives and uncertainties. As an initial strategy to combat this concern it was neccisary to break down a simple standard dive into different stages (ill. 39). At each stage opportunities for different relevant monitoring parameters are proposed. This strategy helped provide an overview of opportunities within monitoring for a blackout and eased decision making and further project framing at a later stage in the process.

MONITORING CONSIDERATIONS



ill. 39 Monitoring stages

1. Proactive during dive
During a dive, different parameters could be monitored and given as information to the diver. A system could proactively warn or react on its own before a blackout occurs, based on information that indication of a blackout. Highly relevant monitoring parametes could be oxygen satuation level, heart rate, dive time, surface time and diver depth.

2. Reactive during buttom of dive
A system that reacts when a blakcout occurs. Valid parameters to measure are unusual paniced movements, and attempts to breathe while submerged. Although, given the previously adressed circumstances of spearfishing, those are hard to distinguish from other factors during a dive.

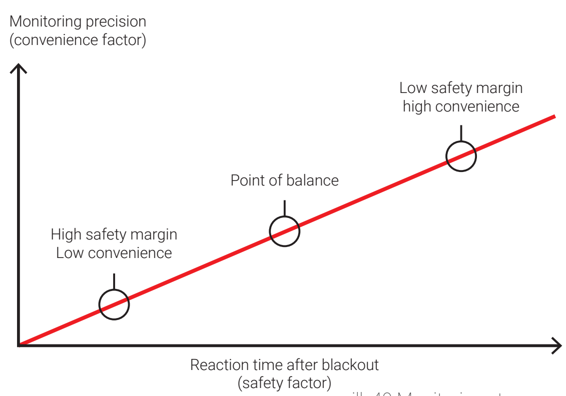
3. Reactive during ascent
Possibility of monitoring the ascent and to react if surface is not reached. To eliminate false positives the system would have to distinqush between a consequent ascent and fluctuations in depth, eg. diving over a cave or a large rock. Greater changes in depth over time and diver orientation are possible parameters to monitor during this stage.

4. Reactive at the surface
Following a prolonged breath-hold, the diver needs oxygen in order to not black out. Monitoring of re-established oxygen levels and breathing activity at the surface following a dive are both relevant parameters. If breathing is not re-established or oxygen levels not restored, a system could react on the basis hereof.

5. Reactive when exceeding limiting value
A spearfishers skill level and experience is highly related to the ability to dive longer and deeper. The parameters, time and depth might be indicators of a troublesome situation or a blackout. exceeding a limiting value could, as a backup safety-feature, initiating a reactive system.

Safety vs. freedom dilemma in automatic triggering
When dealing with a reactive solution both diver convenience and diver safety are vital elements of the monitoring consideration. It will always be a balance between the two (ill. 40).

The faster a system responds to a blackout, the greater the risks of false positives and uncertainties. Conversely, a longer response time means greater precision in the blackout monitoring and detection. A high level of diver convenience is conserved, but at the cost of less chance of survival as more time has passed.



ill. 40 Monitoring stages

INSPIRATION

When looking to collect data it is obvious to look at how current solutions do so. Collection of data was divided into two categories; External data and internal data.

External data
Data that is possible to measure directly on the context. This type of data is particularly prominent in dive computers and watches. Typically they collect time and depth related data. More advanced ones provide the option of navigation with compass features like the Shearwater Teric dive watch (ill. 41). Diving watches for freediving can generally be used in a proactive context as a means to prevent a blackout. They are also used for performance review by analysing dive logs.

Internal data
Data that is directly related to the human physiology. No current spearfishing equipment utilizes physiological data to directly combat the problem of a shallow water blackout. However, different solutions that measure physiological data are used in various other contexts and were used as inspiration. In the clinical setting abdominal and thoracic belts are used to measure breathing. The NeXus respiration sensor (ill. 42) collects data on respiration frequency and the corrosponding depth of breathing.

In order to possibly circumvent the previously mentioned disadvantages of measuring SpO_2 in the extremities, a chest mounted pulse oximetry device from ST&D served as inspiration (ill. 43). It measures changes in SaO_2 levels much quicker than a traditional finger probe (Healthcare in Europe 2007).

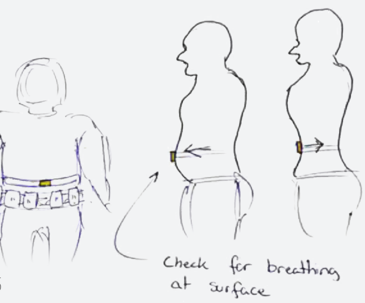
Heart rate monitors like the Garmin HRM-Run (ill. 44) provides pulse measurements in a chest mounted configuration using electrical pulses. These provide more reliable data compared to a wrist mounted solution which uses optical technology (The Heartbit 2018). This principle might be possible to transfer into the spearfishing context.

ill. 41 Shearwater Teric dive watch

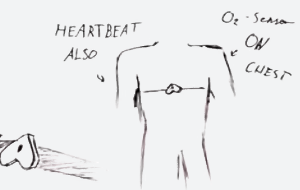
ill. 42 NeXus respiration sensor

ill. 43 ST&D chest mounted pulse oximetry

ill. 44 Garmin heart rate monitor



ill. 45



ill. 46

IDEATION

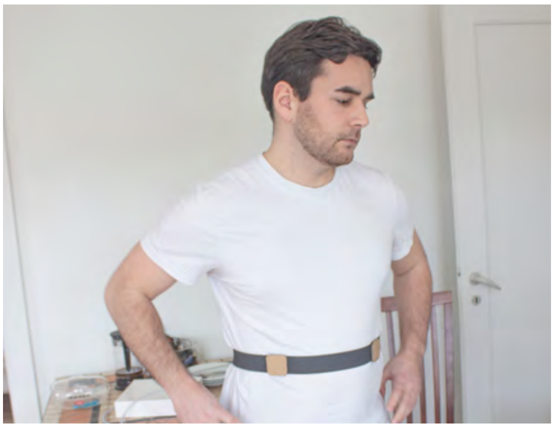
A quick ideation round led to a couple of ideas regarding the implementation of data collection in the context of spearfishing (see all on worksheet 12). (ill. 45) and (ill. 46). Both illustrate the idea of implementing both heartrate and oxygen saturation sensors on the chest and checking for breathing at the surface with an abdominal belt. A third idea includes the buoy to track active dive time and restarts when diver resurfaces (ill. 47). An idea focused towards a very simple external data collection. All three do not differ much from previous ideas or inspiration seen above.

ill. 47

USER INVOLVEMENT

Sensors that collect external data are not restricted to specific areas of the body. Comparatively, sensors which monitor physiological conditions are naturally more limited in terms of their placement. In order to get an understanding of where the latter have potential to be positioned, a quick prototype and test was necessary (worksheet 16). It was in this regard interesting to explore if any placements were a no-go or in any way limits the user during spearfishing.

ill. 48 Sensor belt prototype



ill. 49 Martin wearing the prototype

ill. 50 Chest reinforcement on inside of Martin's wetsuit

Sensor belt test and feedback session

Feedback from Martin showed no problem with sensor placements other than mid-section, as this is used for loading the speargun. Therefore, the test showed great potential in sensor placement on the sides of the chest and abdomen (ill. 49).

Simply having an elastic band around the wetsuit has the potential to get stuck, which spearfishers in general do not support. This proved that the sensors needed better integration than just a simple elastic band around the outside of the wetsuit. However, a belt around the body on the inside could potentially be a simple solution to collect data without potentially obstructing the diver or furthermore risk their lives.

Integrated elements like reinforcements to different areas on the suit and a pissette for easier urination, is already a common thing. Either mounted by the manufacturer when a freshly tailor-made wetsuit is ordered or retrofitted by spearfishers themselves. On ill. 50 Martin's wetsuit can be seen with a chest reinforcement. It is simply mounted with neoprene glue which basically welds the pieces together.

This new knowledge provided a whole new opportunity for sensor integration. According to Martin, some spearfishers are very religous about specific brands of equipment. Therefore it might be more profitable to integrate sensors as a retrofit to the suit or in a new undershirt to wear. Data could possibly also be collected via implemented sensors in the weighted vest which is regularly used by spearfishers. This provides an opportunity to collect data without interfering with the spearfisher motions during the activity.

EVALUATION

The prototype was solely made for a quick test to gather feedback from the user on placement of sensors and what limitations and possibilities it brings. It would be relevant to test the data collection in a better integrated prototype later in the process to acquire more direct and concrete feedback.

- Potential to integrate sensors into wetsuit or weighted vest
- Potential to wear sensor belt or undershirt beneath wetsuit
- Sensor must accomodate the speargun loading area

2.4 TRIGGER MANUALLY

Feedback from the three initial concepts speaks in favor of including the functionality of a manual trigger in the system. If a diver suddenly has problems under the surface, it is necessary to be able to quickly respond to it.

ill. 51 Survitec Halo Lifejacket

INSPIRATION

When considering a manual trigger it is obvious to be inspired by parachute pull releases. The initial assumption is that the type of trigger will heavily depend on what the system triggers. However pull releases is seemingly the most common type of manual trigger that comes to mind.

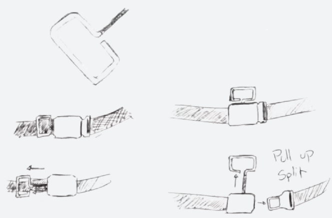
The Halo life jacket (ill. 51) is designed for helicoptor pilots. It is equipped with handles which have tactile pearls meant to be quickly loacted på feel in case of an emergency.

(ill. 52) shows a paraglide deployment handle. A fairly large red handle meant to be easy to hold onto and pull.

ill. 52 Paraglide deployment handle

IDEATION

Based on the information gathered, a series of quick sketches formed ideas on different manual triggers (see all on worksheet 12). Placement and type of trigger mechanism varies a lot from sketch to sketch (ill. 53). It was necessary to test variations with tangible elements as a next step.



ill. 53

USER INVOLVEMENT

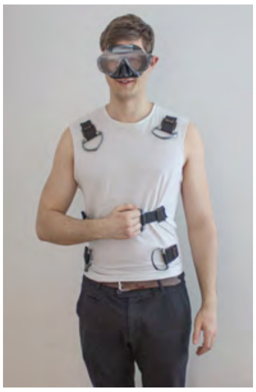
In order to get an understanding of how to manually trigger a system it was necessary to create physical prototypes. These prototypes will be used for tests, which gave indications towards what works and what did not. A test like this be executed on non-users as it is a key functionality everyone must be able to use in case of emergency.

Two seperate prototypes have been made, one to test trigger position and another to test handle types. The full test can be viewed on worksheet 14. It was important to separate the test to achieve one input at a time so the results do not affect one another.

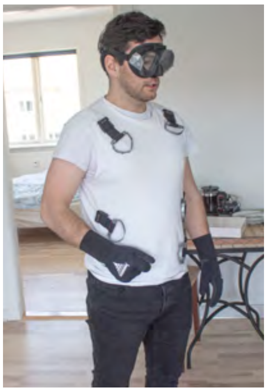
It is important that this function is designed to accommodate cases of reduced motor control and consciousness. It is not an option to put the lives of the test subjects at risk for a 100% realistic scenario. Therefore, googles modified with a blurred film was used during the tests to imitate the situation to a certain degree.

All prototypes are of the pull releases type. This would hopefully provide useful feedback and sub-principles that would be transferable to other types of triggers dependant on the what the system triggers.

Position of manual trigger
This test was carried out on two different people. One non-spearfisher, Jonas (ill. 54) and a spearfisher, Martin (ill. 55). The test suggested that the feel of a strong and secure pull is important, therefore the test proved it would make most sense to pull from opposite side in order to achieve this. Martin did not see a problem with dropping the speargun in order to trigger a system. To quickly locate the release it is important to position it at a direct reference point and not just a larger area on the middle of the stomach. As an example the mid left handle was the go-to in Jonas' case as the position is similar to his inside pocket in his jacket. The left and right top handles was just outside the area of vision with goggles on and therefore only possible to locate by feel. The mid-chest and mid-stomach is used to load the speargun, so this area must be kept clear of any release, hence the side mounted ones was all well recieved.



ill. 54 Jonas



ill. 55 Martin

Handle prototype
This test was carried out with 6 different release handles on the same people (ill. 56). There was positive response on releases that fingers/hand could get into and thereby securely pull (handle 2, 3 & 4). Releases that should be grabbed around were harder to quickly pull. It would require a greater level of fine motor skills and finger strength during an emergency situation. Tactility on the release proved to be important for a more secure pull as well. The addition of the pearls (handle 4) was easy for the test persons to locate, put could certainly be improved in size, weight and material. Especially the rubber material (handle 6) delivered a great tactile feedback from its surface with resistance, feeling like non-slip. Feedback from the test also proved that any release should be secured more closely fittet to the body. They should not be able to catch something under water during a dive.

ill. 56 Six different release handles

EVALUATION

The test in general suggested that the type of handle should be weighted higher than its overall placement. To locate a release by feel it must be heavily dependant on both shape and material tactility.

The use of 5mm gloves would also have been preferable to use on every test person, as it seemed they made a huge difference during the last test on Martin (ill. 57).

Most of the manual release principles found for inspiration within this key functionality involved pull triggering mechanisms. Therefore this test worked exclusively with pull as the interaction. Different interaction principles for manually releasing a system might prove to be of relevance but will be considered later in the process if need be.

ill. 57 Martin testing the handles with blurred goggles and 5mm neoprene glove

!

- Must be able to be located by feel only
- Shape and material tactility is important to easier locate trigger
- Must accomodate use of 5mm neoprene glove
- Preferably placed at a known reference point

2.5 INCREASE BUOYANCY

ill. 58 Quicksilver highline airlift vest

ill. 59 Onyx A/M-24 inflatable life jacket

ill. 60 Kingii inflatble bracelet

Principles of increasing buoyancy have previously briefly been adressed in initial reseach in section 1.7. The objective was to investigate further principles of affecting buoyancy to aid in resurfacing and conduct a test with a tangible prototype. In order to initiate any ideation or creation of prototype relevant inspiration on buyancy increase was gathered as a starting point (worksheet 11).

INSPIRATION

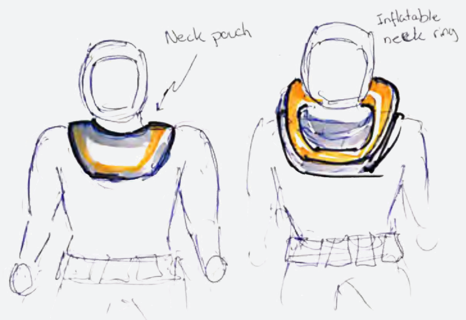
Especially the use of CO_2 as inflation gas is commonly used in a variaty of products suitable for water activities. The Quicksilver airlift vest (ill. 58) is a product used by big wave surfers in case natural resurfacing is not possible due to the extreme conditions. It is a great example of a well executed integration of inflatable elements as opposed to the Freedivers Recovery Vest or Sens07vest which is basically just inflatable life jackets. An inflatable life jacket like the Onyx A/M-24 (ill. 59) works well on boats, which it is designed for. Using this during spearfishing would be too inconvenient.

The Kingii inflatable bracelet (ill. 60) also uses CO_2 to inflate an element. This is a much smaller product which is used in shallow water and as a floatation aid. It is a very unobtrusive product and a great way of providing extra buoyancy, also useful for surfers.

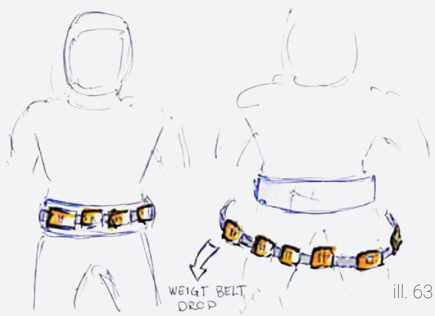
IDEATION

A quick ideation led to series of rouch ideas on how to implement buoyancy increase (see all on worksheet 12). This was used to lead the way into prototyping and testing with the user.

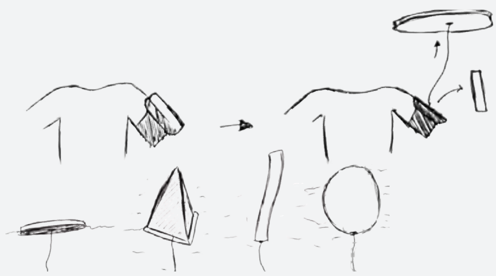
The idea seen on ill. 61 is a relatively small inflatable neck pouch providing buoyancy around the neck. On ill. 62 a inflatable element is located on the upper arm and also thought to provide a better visual mark on the surface. A removable weight belt could consist of two belts so the diver does not disconnect from the buoy. (ill. 63).



ill. 61



ill. 63



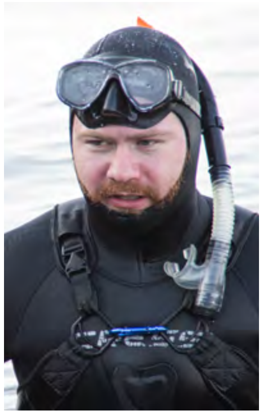
ill. 62

USER INVOLVEMENT

One principle of increasing buoyancy works by adding negative weight by inflating an element and one simply works by removing weight (se test on worksheet 17).

An inflatable prototype were used to test on the user in order to obtain feedback on comfort and opportunities to better design for the context. The inflation prototype took inspiration from compact inflatable life jackets, but intended to be smaller and more focused towards increasing buoyancy around the neck. No small inflatable element is tested as the nature of a shallow water blackout still requires the element of securing airways of the victim. Therefore this test would consider the key functionality of securing the airways to a small degree. Testing the principle of removing weight was carried out with a simple test with spearfishing equipment in the context.

ill. 64 Inflatable neck ring prototype on Martin



ill. 65 Mads wearing Martin's weight vest

Inflation prototype test

The test and feedback from Martin indicated a great potential in combining an inflatable buoyancy element like the tested neck ring with the weighted vest that some spearfishers already use (ill. 64 & ill. 65). Combined or not it must be adjustable to fit a variety of different body types. It is very important that a wearable like this does not get in the way of any upper arm movement or when loading the speargun when uninflated (ill. 66). When inflated, improved head support could aid in securing the airways.

ill. 66 Martin showcasing speargun loading

Dropping weight test

The weight drop test provided good insight into the effect of dumping the weight belt (ill. 67 & ill. 68). Dumping weight is very effective and quickly affects buoyancy positively, thereby aiding in resurfacing. The weight drop technique is also an integral part of any dive course as it is proven to work in case of emergency. There is certainly a great potential in a concept that revolves around dropping weight. Potentially either integrating the principle into an innovative spearfishers weight vest or belt.

ill. 68 Floating after dropping weight

ill. 67 Weight removal principle tested

EVALUATION

The test of inflation was simply carried out by manually inflating the neck ring through a connected tube. This inflation method will naturally not be the case out in the real context as it must operate independently. The prototype and test involved no CO_2 cartridge size reference to test for comfort and potential placement of such. This would be necessary for future development if any inflatable elements were to be mounted on the user. The fabric bag and associated inflatable element was simply mounted on a GoPro chest harness for the quick test. However, this would require better integration, so things like comfort would become easier to acquire direct feedback upon.

The weight drop test was only done at approx. 2 meters depth. This was however with an almost full exhalation at the bottom to provide a starting point with much greater negative buoyancy for the test.

» Potential to integrate inflatable elements in weight vest
» Potential to drop weight without disconnecting from buoy line
» Must not obstruct when loading the speargun

2.6 CONVEY INFORMATION

In order to make a spearfisher aware and able to proactively react to the data being collected, it needs to be communicated properly. First, existing ways to communicate information was explored (worksheet 11) to form a basis for a quick ideation (worksheet 12) and later user involvement session (worksheet 15).

ill. 69 PDW Expedition watch band compass kit

INSPIRATION

The aforementioned dive watch is basically the sole thing currently used by spearfishers to recieve information from. Dive watches typically provide options of information in the shape of visuals, sound or vibrations based on time and depth as mentioned in section "2.3 Collect data".

A visual information principle like the colour illuminated ring add-on seen on (ill. 69) is very simple in its communication. A principle like this could possibly give information in conjuction with physiological data. Another interesting solution is the goggle add-on by Scubapro for scuba divers (ill. 70). Information is within visual range at all times.

ill. 70 Scubapro Galileo HUD dive computer

ill. 72

ill. 71

IDEATION

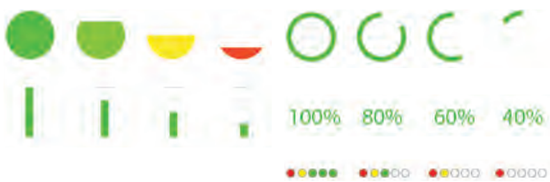
Based on the aquired inspiration a couple of ideas on this key functionality were made in which two are presented here. ill. 71 takes much inspiration from the watch add-on. A simple indication that informs the diver when the situation turns dangerous. Another idea consist of a chestmounted information display able to be seen when looking down (ill. 72). The ideas from this quick ideation did not provide much new input prior to the user input session.

USER INVOLVEMENT

To get useful input on the inspiration and ideas, it was necissary to provide the user with a couple of ideas on simple information displays (ill. 73). The display ideas are kept simplistic in their communication as previous conducted interviews suggest only very simple information is desired. Feedback from Martin Jørgensen suggest that colours would work great in a simple display as these are not to be mistaken. The same with the the ring being gradually emptied, which would be a great symbolic for eg. gradual oxygen deprivation. Numbers or text would be too much in a situation where you push yourself. You should not have to think.

Concerning how dive watches convey information it turns out that spearfishers generally do not support sound and vibration. You simply risk scaring away the fish which goes directly against the intention of the activity according to Martin. Vibration or sound should only be used in case of an emergency.

The goggle attachment by Scubapro would in a spearfishing context be too distracting and take away focus from the activity itself. A chestmounted display would too be inconvenient because of limited range of head movement with goggles and wetsuit hood.



ill. 73 simplistic information displays

EVALUATION

Usefull information and insights was gathered providing a much better foundation for further work into this key functionality. Tangible prototypes wouuld be necessary as a next step to test regarding conveyment of information to achieve even more directionary feedback.

- Must not take focus away from activity
- Must be very simple, preferbly no text or numbers

2.7 CREATE DISTRESS SIGNAL

ill. 74 Handheld smoke flare

ill. 75 Handheld LED flare

ill. 76 Seareq ENOS rescue system

ill. 77 DiveAlertPLUS signaling device

Previous findings and feedback on the three initial concepts clearly highligts the importance in a distress signal in case of a shallow water blackout. It will greatly increase the chances of receiving the necessary help and thereby the chances of survival. As of yet no specific way of signaling distress has been adressed. Therefore, current solutions was be explored to inspire and gain a better understanding.

INSPIRATION

Typical methods of signaling distress involves audible, visual and satellite solutions. A signal could both be relevant at the surface aswell as underwater. Smoke flares are commonly associated with distress and are also used for that purpose as they generate highly visible orange smoke (ill. 74). However they only burn for a very short time, whereas LED flare solutions signals for much longer time periods (ill. 75).

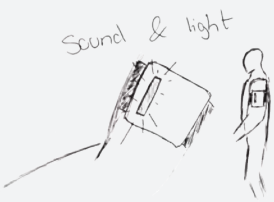
The ENOS rescue system designed to scuba divers by the german company Seareq a satellite based solution (ill. 76). With its recieving range up to 10 km it is a GPS based system to prevent divers from getting lost at sea (Seareq 2019). A solution like this would be highly relevant in a competitive spearfishing context, with medical boats ready to respond. To put this into perspective, the largest competitive area was 11x2 km during the 2019 championship in Denmark, where the Portuguese spearfisher died. (Appendix 1).

An audible solution is the DiveAlertPLUS by DiveAlert. It is a sound distress signalling device for scuba divers. It utilizes the compressed air inside the divers tank to sound a loud horn (ill. 77). People have reported hearing the signal from an around 1,6 km distance when used at the surface (DiveAlert 2020). When used underwater the horn emits a buzzing noise.

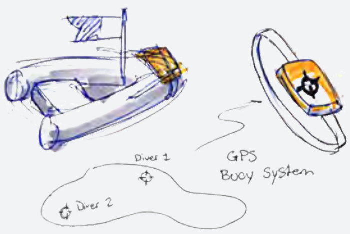
IDEATION

Some ideas were produced based on all gathered knowledge and inspiration so far. A couple of highlighted ideas can be seen in this section. ill. 78 & ill. 79 involves creating an alarm locally on the diver, for nearby divers to hear and see. Other ideas revolve around alarm solutions on the buoy. Both satellite, visual and audible mounted alarm devices (ill. 80 - ill. 82).

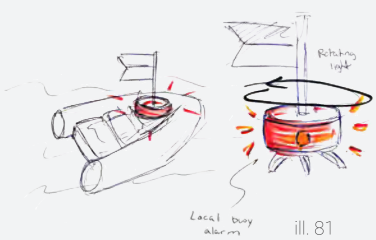
ill. 78



ill. 79



ill. 80



ill. 81

ill. 82

SPEARFISHING BUOY MAPPING

During the the ideation on creating a distress signal it was clear that there was a potential in installing a solution on the buoy and not just the diver. A better understanding of the buoy was required in order to start prototyping on any mounted signalling device (worksheet 13). What areas are ideal for creating visibility for other divers? What are the mounting options? What areas are considered restricted? For this mapping, a buoy provided by the user, Martin Jørgensen was used (ill. 83). This buoy is very similar to the official Scorpena buoy provided for the 2019 Euro-African Spearfishing Championships in Denmark (Appendix 2).

ill. 83 Buoy provided by Martin

Mounting points
Several points throughout the buoy were identified as great potential for mounting options (ill. 84 - ill. 88).

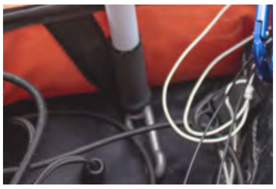
- Front handles: There are two front handles which is used to grab and manipulate the buoy both in water and on land.
- Rubber ring mounts: A total of four are located on top of the side panels. Often used for fastening the speargun during transportation. Each ring is equipped with a red strap for easier manipulation with glove.
- Carabiners: Several carabiners are located around the buoy. They are used to fasten the floatline in front, a net for caught fish and additional other things brought along.
- Lower loops: Six lower loops around the bottom edge. The one in front is used for the float line carabiner.
- Elastic flag straps: Two straps which are placed in the mid-compartment. Used to keep the flag fastened and upright.


ill. 84 Front handles


ill. 85 Ring mounts


ill. 86 Carabiners


ill. 87 Lower loops


ill. 88 Flag mount


ill. 89 Restricted area

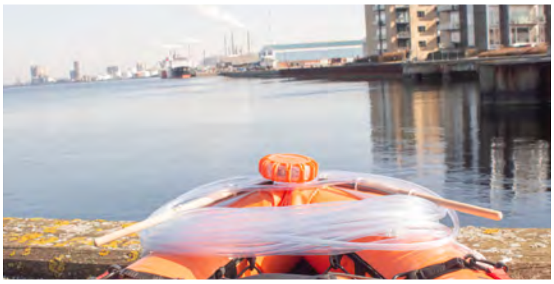
Visibility
The analysis of the buoy suggested that the best mounting option is on top of the front and side panels. This provides highest level of visibility for others. The buoy itself is bright orange and in high contrast to the water making it easier to spot.


ill. 90 Prototyping on flexible mounting of distress signaling device

Restricted area
The buoy is not only used as both a base for caught fish and rest during spearfishing but also a vehicle. As a result there is a considerable space in the middle of the buoy, and towards the back, that should be considered as less ideal for mounting. (ill. 89)

Mounting prototyping
After analysing the different opportunities for mounting on the buoy, it was determined to build a quick prototype that could be mounted on a series of different locations. The prototype consisted of a simple case made out of cardboard, with holes for straps and pole mounts. It was determined that there were a series of viable places that a potential signalling device could be placed (ill. 90). However, after reflecting on how the user liked to customise the buoy, it was found more ideal to try and make a flexible mounting solution. This meant that the future goal for a concept mounted to the buoy, should enable the user to move it around as the user preferred, and not necessarily tied to one spot.

Part evaluation
The analysis and prototyping on relevant mounting solutions was excellent for providing better knowledge. This knowledge would be usefull for later conceptualization and prototyping hereof. It should be considered however, that it was done without the user. Involving the user could have led to changes in exactly which mounting options were available, based on user preferences in the proper context. The buoy mapping did not provide any indications towards specific types of distress signalling but rather physical possibilites related to the buoy. This was required to understand the full width of the key functionality; creating a distress signal.


ill. 91 LED warning device


ill. 92 Smoke alarm

BUOY DISTRESS SIGNAL TEST

To establish a benchmark for a potential Distress signaling system a test was performed to determine the range of both light and sound (worksheet 18). The test was done using two seperate devices. A visibility LED warning device which divers already use to mark their position on the water at night (ill. 91). The other device was a standard smoke alarm, capable of producing a 80-90 dB piercing sound (ill. 92). Both were placed on top of the buoy, and another person was placed along a stretch of water in the intervals of 150, 200, 300 and 500 meters (ill. 93). it was then observed whether or not the light was visible, as well as if the sound of the smoke alarm could be heard.

The test showed that the maximum perceivable and locatable range was at 300-400 meters for the smoke alarm, and 200-300 meters for the LED device. The test made it clear that in the case of the two devices, that are around the same size, sound had a longer range. It was also easier to locate, as you had to know the light was there in order to see it. This means that sound could be more useful in situations where the users wouldn't have direct line of sight on the alarm. Situations such as diving in rough conditions with waves in the ocean.

Part evaluation
According to the test sound should be prioritized over light when it comes to alarming nearby divers, which opens up for more possibilities when it comes to placing it on the buoy. However, there exist several other visual alarm types that could potentially create a visual distress signal.

There are a lot of potential sources for errors in this test. The weather and the wind direction could have played a major role in how far the sound and light was perceived. It was, however, very still weather on the day of the test. The test was also not done on the water, but rather with water inbetween the signal source and the receiver. In addition, the user knew the test was going to happen, and did not wear a neoprene hood, like normally in cold-water spearfishing.

ill. 93 Distance map. Buoy location at KMD, Aalborg

EVALUATION

Different ways of creating a distress signal have been ivestigated. Various mounting options was analysed and explored and a test regarding range of an audible and visible alarm was conducted. This was all a good benchmark for further development in terms of this functionality and has shown several promising potentials along the way.

!

- Potential in creating satellite, audible and visual based distress signals
- An audible signal is preffered over a visual
- A diver mounted underwater alarm has potential

?

- A 9V smoke alarm producing 80-90 DB can be heard and located up to about 300-400 meters away (benchmark)

2.8 CONCEPT SYNTHESIS 2.0

The exploratory, divergent and segmented approach in the previous five sections have provided a deeper insight into the key functionalities. New knowledge was gained through this and several development potentials for sub-solutions proved relevant to the project. The objective for this section was to composite concepts for milestone 2. In order to do this, it was first necessary to look at where it makes sense to delimitate the project in regards to monitoring of blackout and the data this requires to collect.

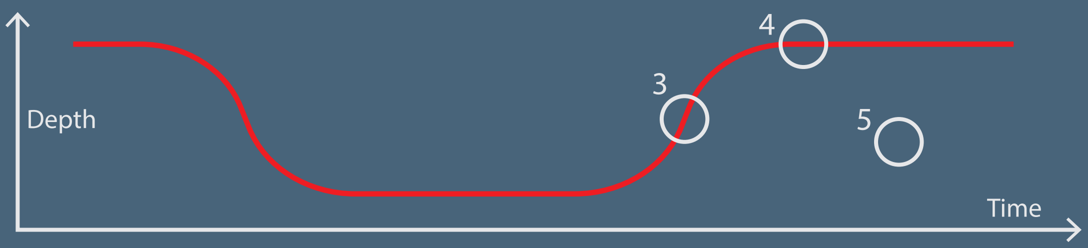
MONITORING DELIMITATION

As previously mentioned in in the chapter "Research", there are three clear factors that can come as a surprise to the diver and eventually cause a shallow water blackout:

1. Exhaustion: Depleted carbohydrate stores result in a more rapid oxygen consumption and slower CO2 build up. More energy is also required to fight tough diving conditions.
2. Partial pressure: During the ascent the Partial presurre decreases. The pressure is halved the last 10 meters making it a significant zone of risk if too much oxygen have been consumed during the bottom of the dive.
3. Inconvenient decision making: The activity of actively hunting fish below the surface occationally entails getting caught in the moment.

With this in mind, it is considered that the greatest potential for this project lies within a reactive solution in order to combat the risk of dying from a shallow water blackout.

In section 2.3, it was adressed how a dive can be split into 5 monitoring stages. Naturally the final part of a dive entails the greates risk. Physiological indicators like oxygen saturation and heart rate are largely individual. Even with a personal benchmarking system, values within these parameters are considered difficult to distinguish between a blackout or not. Therefore the greatest potential is considered to lie within monitoring the ascent and establishment of breath at the surface. Therefore monitoring will be focused towards the three last monitoring stages of the dive (ill. 94).



ill. 94 Monitoring stages focus area

Ascent monitoring

The initiation of an ascent is purposefully done to reach the surface in order to breathe. As a dive includes fluctioations in depth it is neccisary to determine if a change in depth is associated with the ascent or not. As an example, half of the maximum depth of each dive could realistically be considered the limiting value. The limit in which the monitoring system determines the relative change as an ascent. if the ascent is abruptly interrupted it would be considered a blackout.

Surface monitoring

The establishment of breathing at the surface following a breath-hold dive is a human physiological need. Therefore post dive breath monitoring is considered as a requirement. Replenishment of oxygen is equally important, but requires the skin to be in direct in contact with a sensor. Therefore it is not chosen for further development. A value for how long a diver must stay at the surface will have to be determined in order for the monitoring system to acknowledge consciousness of the diver. As an example, half of the dive time could realistically be considered the surface monitoring time value, as mentioned by Martin Jørgensen.

Threshold monitoring

A maximum diving time would have to be adjustable as it depends directly on a divers individual skill and experience. A preset user defined time value will have to be determined. As a time threshold would be highly relevant in all situations, a depth threshold would only be in some cases. As an example, it would be relevant when wreck diving. The time treshold is considered the most important and will currently be the only one considered going forward.

Programming delemitation

The limiting values of depth and time in ascent and surface monitoring will be considered flexible variables. It is observed as a problem of adjusting variables rather than a problem in product design. These variables will require implementation tests in regards to creating the perfect balance previously adressed in section 2.3.

User involvement

Feedback from Tom Helm Petersen and Martin Jørgensen verified the importance and eligibility in the chosen three monitoring stages. A combination of the three will be a step towards increasing safety for spearfishers.

» Time, detph and breath hold will be monitored, via breath sensor, depth sensor and timer

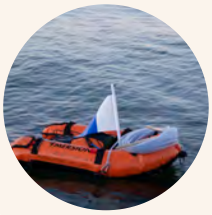
TWO DIRECTIONS

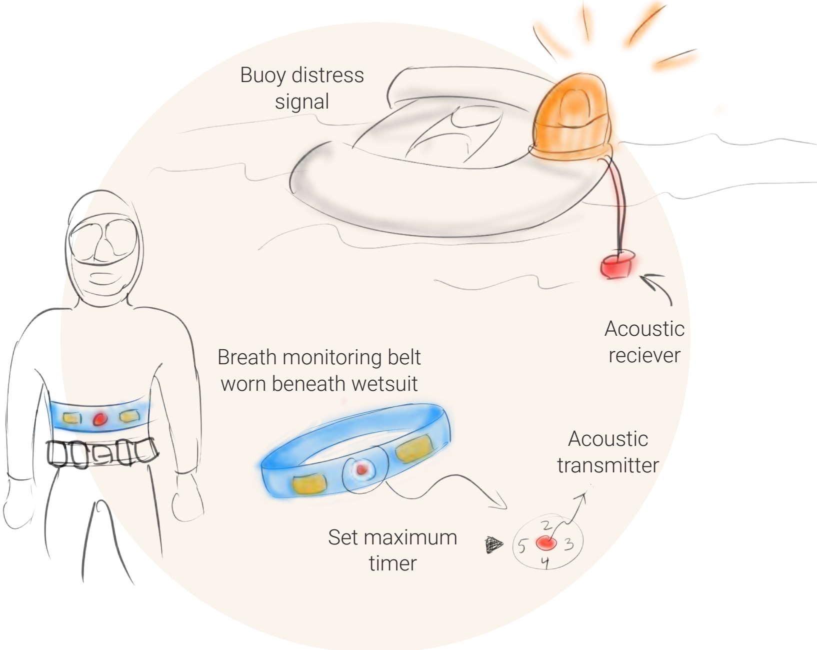
Contemplating previous findings it is clear to see how much emphaisis should be put towards creating a distress signal. Therefore two directions with regards to a distress signal have been created, combined with the monitoring delimitation.

1. Utilize the buoy as platform to create a distress signal.
2. Create a distress signal locally on the spearfisher.

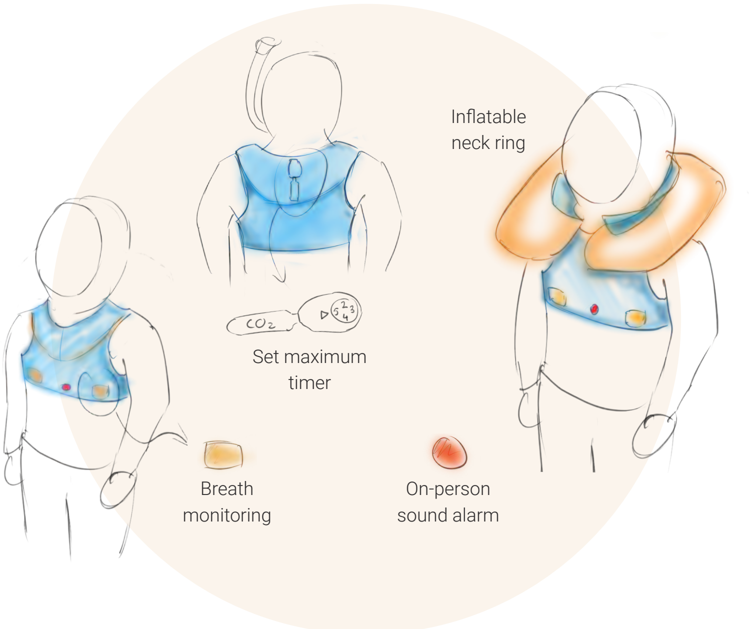
Based on this and previous findings, two concepts have been presented for the second milestone seminar. Concept 1 and 2 can be seen below

CONCEPT 1
Buoy distress signal





CONCEPT 2
On-person distress signal

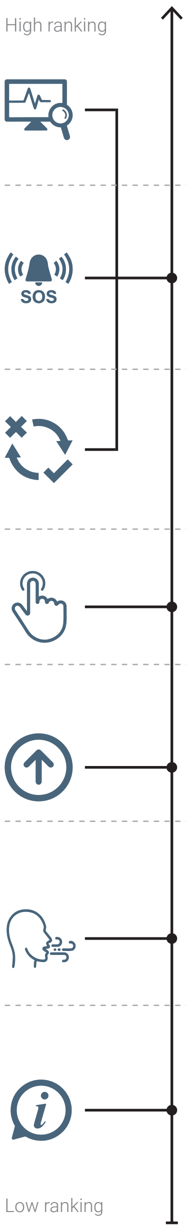


2.9 THE MINIMUM VIABLE PRODUCT

The two concepts presented at milestone 2 did differ much from the initial concepts presented at milestone 1. However since then, great knowledge has been gathered towards the key functionalities involved in the project and what to consider when designing a solution.

A NEW APPROACH

Through feedback from milestone 2 and a reflection upon the process so far, it was recognized that the two concepts are merely one basic concept with variations. This led to a change in approach. It was decided to narrow down focus and establish a minimum viable product (MVP) with functionalities considered most central to the project. A reflection upon each of the 7 key functionalities were deemed essential to make it clear which are required for the MVP. In this context they are ranked according to their importance for the project based on all knowledge gathered through research, test and feedback.



Collect data
Data collection is an indispensable feature in order to monitor for any parameters possibly related to a blackout. It is what forms the basis for and enables the reactive system. Previous delimitation, towards the final part of a dive in connection with monitoring of a blackout, proves the significant importance of data collection. Great responsibility and dependancy is placed towards this key function.

Create distress signal
More than anything, users heavily valued signalling distress in order for others to come to the rescue. This is perfectly consistent with the fact that secondary aid is the only way to ensure a full recovery. The blow, tap, talk procedure proved crucial following an underwater blackout. If the lungs has taken on water or suffocation has occoured, chances of survival also heavily depends on other divers ability to react. As a result this key functionality achieves highest rating.

Trigger automatically
Due to the nature of a shallow water blackout, automatc triggering has proven to be an important functionality. When it happens , it happens without the diver realizing it. The inability to respond when unconscious places great demand on a system being able to automatically provide the victim with the necessary help.

Trigger manually
The ability to manually trigger a system provides the spearfisher with more control and proved valuable to the users. It is very relevant in other dangerous situations as well. However since it is considered a proactive strategy it does not recieve equal rating as the automatically reactive triggering.

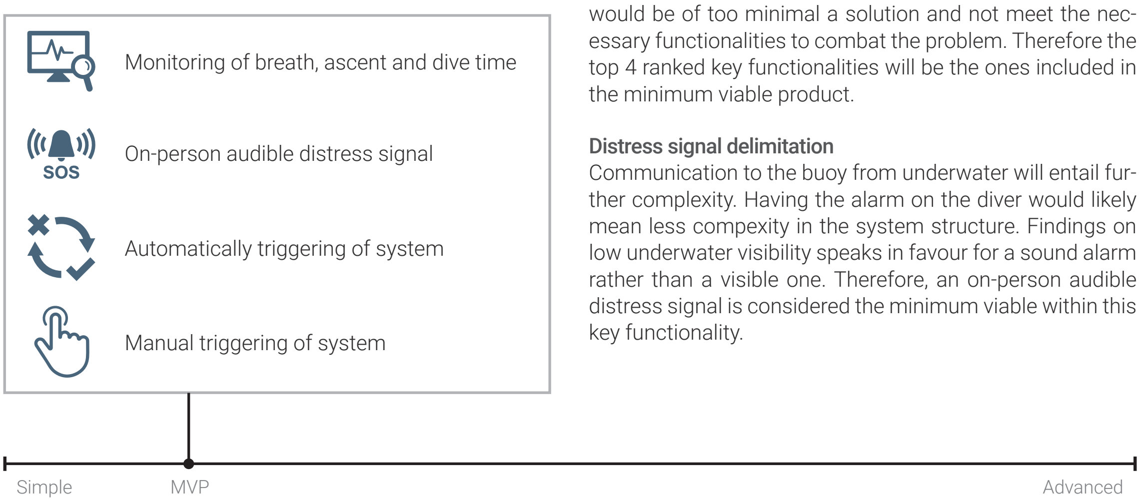
Create buoyancy
Positively increasing the buoyancy on the diver aids in resurfacing. However, in itself this feature does not provide ensurement that a blackout victim will necessarily wake up and recover. Therefore, it is considered more important to rely on others to lift and assist the victim to the surface. Considering this, a distress signal is more crutial than this feature.

Secure airways
The feature of securing airways to prevent face submersion and risk of water intake depends on resurfacing of the victim. Therefore heavily dependent on the principle of creating buoyancy. However securing airways do not ensure waking up and risk of suffocation and cardiac arrest is still highly present. A blackout victim is still dependant on secondary aid from the buddy. This feature is viewed as an assistance towards combating the problem rather than a solution to it.

Convey information
Spearfishers are already pushing the body beyond its limits and what human physiology allows. Previous interviews found that users find value in having almost no distractions other than those directly from the activity. It is debatable to what extent they will be willing to act on any information other than depth and time already conveyed on dive watches. If so, this information must be very precise which is not the case with eg. previously mentioned pulse oximetry and heart rate indicators. As a result, display of information achieves lowest priority.

MINIMUM VIABLE FUNCTIONALITIES

Not all functionalities can be considered as minimum viable when considering the development of a MVP. The previous ranking of the functionalities serves as a foundation for this selection process. Functionalities within a "simple" solution and an "advanced" one is defined as a benchmark to rightfully position the MVP.



Simple strategy
The "simple" functionality combination serves as the bare minimum. This would consist of eg. an on-person alarm automatically triggered by only a timer.

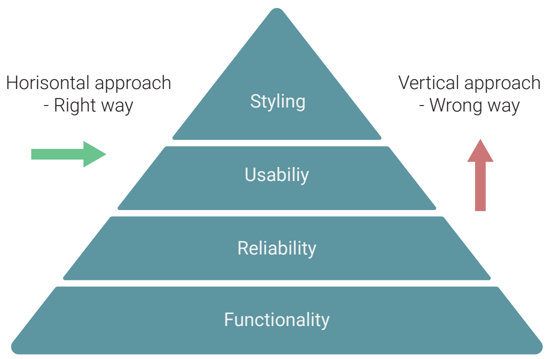
Advanced strategy
The "advanced" functionality combination serves as a highly complex solution. This would consist of a combination of all 7 key functionalies.

MVP positioning
It is considered that the "simple" functionality solution would be of too minimal a solution and not meet the necessary functionalities to combat the problem. Therefore the top 4 ranked key functionalities will be the ones included in the minimum viable product.

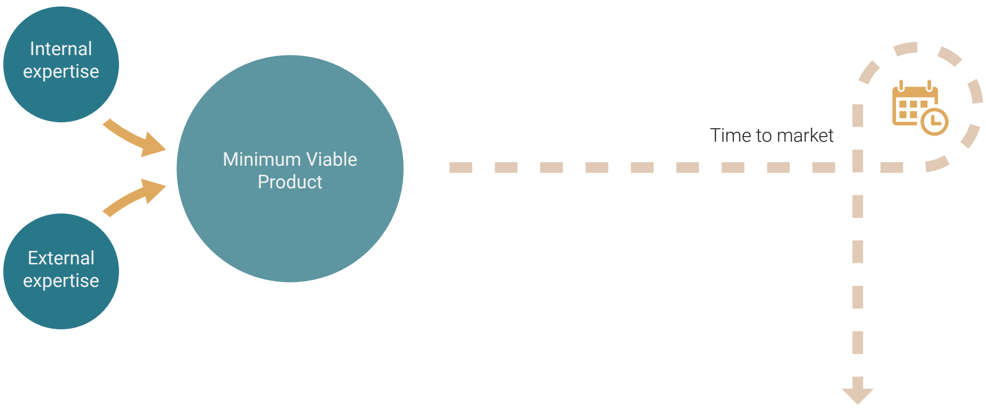
Distress signal delimitation
Communication to the buoy from underwater will entail further complexity. Having the alarm on the diver would likely mean less compexity in the system structure. Findings on low underwater visibility speaks in favour for a sound alarm rather than a visible one. Therefore, an on-person audible distress signal is considered the minimum viable within this key functionality.

MVP BUSINESS APPROACH

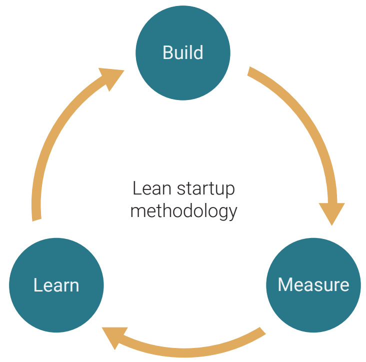
Development of a minimum viable product must not only entail focus on the functional aspects of the product, but be a complete package that can fit within a certain market. Therefore several other parameters have to be considered during the development of the product. As the key functionalities for the MVP have been chosen it was time to start considering the parameters further up the pyramid illustrated on ill. 95.



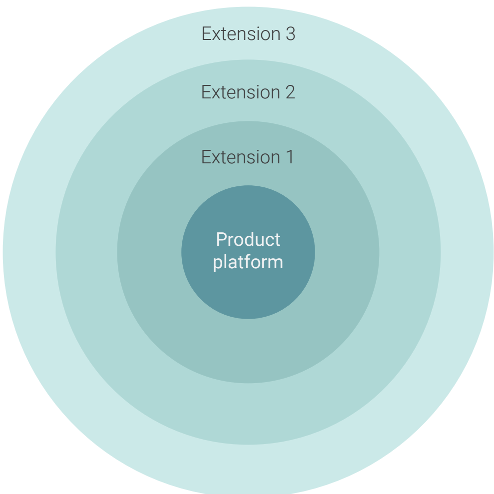
ill. 95 Approach for development of MVP



Development of the MVP requires external expertise in order to launch (ill. 96). The two-man group behind this project do not house all the necessary expertise for all development up until first launch. Especially investment in external firmware and software engineering will be needed. Even though it will take some time to reach the first launch, it is extremely advisable to launch on the market as early as the development of the MVP allows for. This is consistent with the lean start-up methodology (The Lean Startup n.d.). This methodology excels in utilizing a feedback loop to accomplish new knowledge for further development with short time to market. Thereby improving the product which leads to improved chances of surving a shallow water blackout with least possible investment upfront. Not only will this strategy push the product development, but will also serve as a foundation for experience and knowledge towards running a business.



ill. 96 MVP business approach



ill. 97 MVP product platform

Poduct platform
Even though several functionalities have been scrapped to accomodate the minimum viable product strategy they are still highly relevant for future development. The key functionalities chosen for the MVP allows for extensions to the product system. The MVP will therefore also function as a platform to extend and add upon later on (ill. 97). As an example, an inflatable neck ring or a buoy distress signal. By introducing extensions to the system it is possible to accomodate other scenarios than those targeted by the MVP. The buoy distress signal could as previously mentiod fit well into the competive context of spearfishing by communicating position to the organizers and medical staff. Therefore, it makes perfectly sense to align the product architectural interfaces with the vision of future extensions.

Market expansion
The MVP will initially be designed to meet the need for safety during spearfishing. However, it is observed that the MVP has great potential to serve other purposes and markets in the future. Some of these could even be performance realted. Possibly this might support additional sales due to the added product value.

USER NEED AND REQUIREMENT REVISION

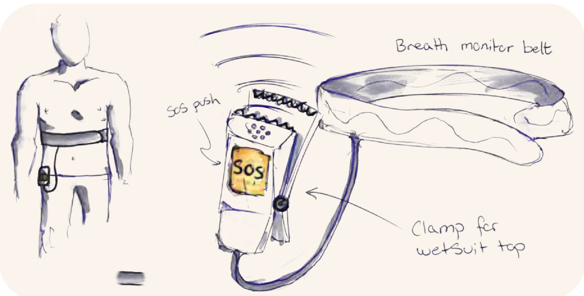
Throughout the previous sections of the research and concept chapter, various user needs have been found. These user needs have been translated into concept requirements seen in the table below. Due to the the new MVP approach, these requirements have been revised into a new set of requirements which can be seen in the table on the right.

USER NEEDS	MVP REQUIREMENTS
LMC, heart-rate, O_2 or breath monitoring (p. 21)	Breath, Ascent and time monitoring (p. 48)
Detection before or after blackout (p. 10)	
Non - invasive measurement (p. 17)	Integrate sensors in/on wetsuit, weighted vest, monitor belt or undershirt beneath wetsuit (p. 39)
Account for dynamic conditions underwater (p. 29)	Not obstruct speargun loading (p. 43)
Aid in holding head above water (p. 22)	Opportunity for product extensions • Buoy satellite, audible and/or visual distress signal (p. 47) • Inflatable neck ring integrated in weight vest (p. 43) • Automatic weight belt drop (p. 43)
Aid in the surfacing of the diver (p .22)	
Create awareness (p. 21)	Diver mounted sound alarm (p. 47 & 51)
Automated solution (p. 17)	User set threshold of dive duration (p. 48)
	Automatic and manual triggering of alarm (p. 51)
Option for manuel triggering (p. 17)	Placed at reference point (p. 41)
	Tactility to ease locate trigger by feel (p. 41)
	Usable with 5mm neoprene glove (p. 41)

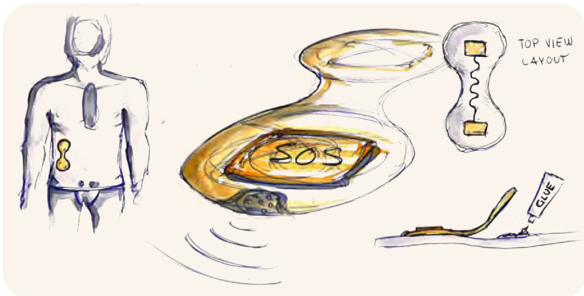
CONCEPTUALIZATION

After considering the MVP approach and the new requerements, it was necessary to create concepts based on the new direction. Here, three concepts were formed.

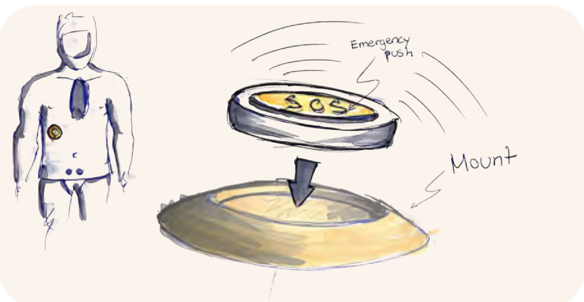
Concept 1



Concept 3



Concept 2



Looking at the 3 concepts it was clear to see that they differ in various parameters. These parameters were all necessary to investigate further.

» Investigate: Wearability, User interaction, Product architecture and breath monitoring technology of MVP concept

In order to start investigating wearability and use of the concept a more detailed study into non-invasive breath monitoring technology was needed.

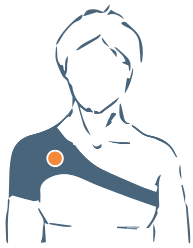
2.10 BREATH MONITORING

Breath monitoring was previously in the process briefly addressed as a cheap non-invasive alternative to complex medical respiratory monitoring solutions. Different non-invasive sensors might be of relevance in a wearable system for breath monitoring. Different types of sensors might necessitate different requirements for quantity, wearability or integration so this was investigated.

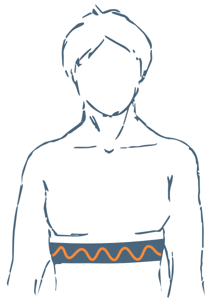
SENSOR TECHNOLOGY

A rather comprehensive 2019 study compares different contact based methods for monitoring the respiratory rate (Massaroni et al. 2019). Several of the contact points involves sensors around the facial region due to direct monitoring of different parameters within the airflow such as temperature, humidity and CO_2. These are disregarded in relation to this project due to the nature of the spearfishing activity. Instead, the focus will solely revolve around different monitoring possibilities on the torso region.

Acoustic sensors
The airflow generated from breathing can be monitored through the different sounds it creates. An acoustic sensor based approach to picking up these sounds happens through a microphone placed on either the suprasternal notch or the chest wall (ill. 98). An microphone monitoring system is however sensitive towards environmental related sounds generating noise and unrelated sounds from a subjects own movement or speaking. Therefore, these types of monitoring approaches tend only to perform well in clinical settings.

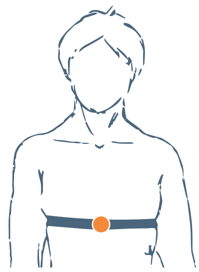

ill. 98 Acoustic technology

Strain sensors
When the chest and abdomen expands and contracts due to breathing, it is possible to measure strain with different type of sensors; resistive, capacitive and inductive sensors (worksheet 19 for more detailed info on types). These sensors measure changes due to mechanical strain internally within the sensor setup (ill. 99). A measuring setup like this therefore naturally require a certain degree of mechanical flexibility in order to measure changes.


ill. 99 Strain technology

Movement sensors
Changes in movement of chest and abdomen due to expansion and contraction can also directly be measured with different movement sensors (ill. 100); accelerometers, gyroscopes and magnetometers (worksheet 19 for more detailed info on types). These technologies relies on acceleration, angular velocity and/or magnetical changes provoked by the mechanical forces from breathing. Movement sensors, unlike strain sensors, are themselves independent of an internal sensor setup. It is an extremely discrete technology and allows for flexible mounting options.

A 2014 research paper (Yoon et al. 2014) studies the combination of both an accelerometer and gyroscope signal for high quality respiration signals in a dynamic setting. Furthermore the paper proposes an algorithm for increased accuracy in respect to dynamic exercise. The study confirmed an improved respiratory signal and determined possible real-time monitoring during dynamic exercise.

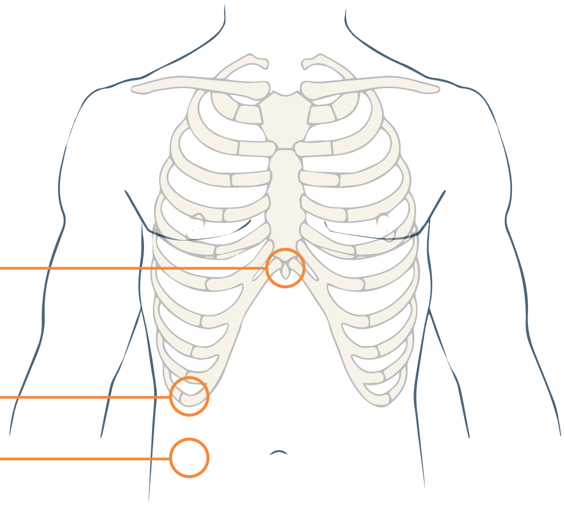

ill. 100 Movement technology

Part evaluation
The accoustic sensor technology is highly sensitive to noise in an unstructured environment. The microphone sensor is therefore likely to perform inadequately in monitoring breathing or lack of the same during spearfishing. Both strain and movement based sensors indicate great potential when considered for respiratory monitoring. Both sensor categories share main disadvantages of being susceptible to signal noise from breath-unrelated movement. The inductive strain did however, indicate good performance in a dynamic setting. When concerning movement sensors, this signal noise can partially be bypassed by combining several sensors. The fusion of both an accelerometer and a gyroscope (Inertial Measurement Unit / IMU) show great potential for real-time monitoring in a dynamic setting. Strain sensors embedded into flexible textiles raise significant concerns regarding durability compared to the integration of movement based sensors. Likewise, they provide less flexibility in terms of the mounting and integration itself.

Going forward, the choice fell upon using an IMU to monitor for breathing. Thereby detecting the absence of breathing at the surface due to a shallow water blackout. It was considered that this type of sensor possesses the necessary properties to measure breathing in this context. The next step was to figure out the specific placement and amount of IMU's considered necessary for the monitoring system.

SENSOR PLACEMENT AND QUANTITY

Besides the decision of choosing an IMU as the sensor to monitor for breathing, it was required to consider which sensor placement on the torso provided the most accurate input. Furthermore, the sensor quantity was important to address as this would most likely impact the signal accuracy and the whole product structure.



ill. 101 The 3 most promising sensor locations

Placement
A recent study (Siqueira et al. 2019) investigates the use of several accelerometers and their placement in 10 different locations on the torso. The study analyses optimal sensor position and sensor quantity in three different body postures; standing, sitting, lying. Although these do not match the exact postures and dynamic movements during spearfishing, this study is still considered highly relevant regarding sensor placement and quantity. The study reports more accurate monitoring results with accelerometers placed on the right side compared to left side of the torso. This matches well with human anatomy stating that the right lung bigger than the left. A bigger lung will therefore expose the sensor to greater movement, resulting in a more prominent signal. More precisely the study finds that the right costal arch on the chest, in most of the cases studied, appears as the optimal sensor location. This location appeared as the most accurate in most of the test cases.

Quantity
As more than one sensor is used to monitor the respiration the monitoring accuracy increases. However, when more than four sensors are used at one time, accuracy changes become more and more minimal as sensor quantity increases. When utilizing more than one the study finds that the right side of the abdomen appears to perform great as sensor location. Also, the xiphoid process loaction can give good results when used in conjunction with one or more sensors.

Part evaluation
The right costal arch on the chest is considered the best location for sensor placement out the 10 different placements addressed. The right side of the abdomen and the xiphoid process looks promising as both secondary or tertiary placements (see ill. 101)

EVALUATION

The study on sensor quantity and optimal sensor placement only studies respiratory monitoring using a tri-axial accelerometer in static postures (Siqueira et al. 2019). The study on fusing an accelerometer and a gyroscope does however only monitor on the xiphoid process but does so in dynamic settings too (Yoon et al. 2014). When considering the results of both studies it clearly indicates that an IMU placed at the right costal arch would provide a relatively precise measurement. By supplementing with another IMU at the right side of the abdomen or the xiphoid process even more precise measurements can be obtained.

The data acquisition required in this project only concerns a present or absent breathing activity at the surface after a dive and not a respiratory waveform analysis. A single IMU at the right costal arch is therefore considered more than adequate for the job.

!

- Measure breathing activity with an Inertial Measurement Unit (IMU)
- Place IMU on the right costal arch

2.11 PRODUCT ARCHITECTURE

This section is an investigation into main components, how to structure them and how to communicate with future product extensions. Pros and cons about different ways to structure and communicate are discussed. The full product architecture study can be seen on worksheet 21.

MAIN COMPONENTS

In order to consider the structural architecture an insight into the main component was needed at first.

Sound alarm
It was previously found that the MVP would require to signal distress through an underwater sound alarm. Dive watches already have the ability to provide significant beeping noise to a level where it annoys the spearfishers and even scare fish away. Hence they tend to turn the feature off, user Martin Jørgensen previously told. Through quick research it was found that the one component generating alarm noise in these watches, is a peizoelectric buzzer (ill. 102). It creates sound through high-frequency vibrations. These buzzers comes in a wide variety of different sizes and configurations. The same component is used to sound high pitched noise in smoke alarms.

Breathing sensor
In previous section one Inertial Measurement Unit (IMU) was found as the applicable sensor to monitor for breathing at the water surface. It was also found that it should be placed at the right costal arch. These findings were of great importance to understand limitations within flexibility of the product structure. Through quick research it was found that IMU's comes in a wide variety of types and brands dependant on intended use. For low-powered wearables they typically come in sizes about 5x5x1mm.

Depth sensor
In order to read the given depth of a dive a depth sensor is required within the system. Depth is related to the pressure of the atmosphere which is why an atmospheric pressure sensor is used to determine water depths. Pressure sensors used in divewatches are very small, only about Ø3x3mm

Micro controller unit
To process readings from the IMU, depth sensor and to sound the alarm, a micro controller unit (MCU) is needed in the system. The breath monitoring algorithm will be processed on this unit. The MCU will also natually be responsible for tracking duration of a dive. Through quick research it was found that MCU's suitable for low-powered wearables typically come in sizes about 10x10x1mm.

Battery
Due to the fact that electronical components are a part of the system a battery is required to supply it with suffecient power. A 200 mAh battery was quickly found applicable for the MVP. It was roughly estimated it would provide 35 hours of battery life. The rough estimate can be seen in worksheet 21. A typical 200 mAh battery size for low-power wearables is about 30x20x4mm.

ill. 102 piezoelectric buzzer in Salvimar One dive watch

PRODUCT STRUCTURE

The IMU is limited to its position on the right costal arch. Other components do not have the same limitations which opens up for structual flexibility in the system.

De-centralized
The idea behind this structure is to mount components other than the IMU away from the right costal arch and increase potential for comfort. Eg. other components could be placed at the bottom of the wetsuit top (ill. 103).

Centralized
Components are placed together, either in the same housing or closely connected. This means that there is a minimum of wires connecting the different parts together. The downside is that it could potentially cause discomfort, since all components are now positioned around the right costal arch (ill. 104).


ill. 103 De-centralized unit


ill. 104 Centralized unit

Why a centralized solution?
It was considered that a user test would be unnecessary in order to evaluate upon the best product structure for the MVP as it is mainly a matter of safety. Due to safety concerns and a relatively small package of main component, it is considered that a centralized unit will be the best. This means less extended risk of bending and breaking wires and getting stuck underwater.

PRODUCT PLATFORM INTERFACE

In order to allign with the vision of future extensions to the system, two interfaces for communication is needed. Communication on-diver and communication to surface were investigated.

Wireless communication on-diver

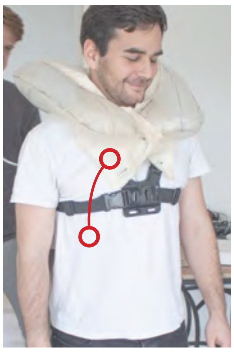
Even though radio frequency communication in general perform poorly underwater the technology is still used. In SCUBA diving, wireless tank transmitters can be used to send information about remaining tank pressure to the connected dive watch (ill. 105). By utilizing very low frequent signals, 38 kHz, they allows for underwater wireless transmission within 1 meter to the dive watch (appendix 3).

Wired communication on-diver

Compared to wireless underwater communication, a wired connection is way more stable and secure. However, not as convenient in terms of direct use if connection stability is disregarded. This would mean connecting an extension to the MVP with a wire. A wired solution would therefore require an interface on the MVP with a waterproof connection.

Why a wired solution?

The MVP is meant to provide spearfishers with an increased chance of recovering from a shallow water blackout. Signalling wirelessly is considered too unreliable a solution. A wired connection also provides the user with a directly visible perception of safety (ill. 106).



ill. 106 Wired connection on-diver to product extension

EVALUATION

The investigation into the MVP product architecture provided great insight into main components, how to structure them and how to communicate with future product extensions. It turned out that the various considerations were highly compatible with various factors of safety. As the safety aspect is a high priority, wired connections and centralized, closely fitted configurations serve as the best suggestions. This will be used in the later construction of the concept.

ill. 105 Shearwater wireless tank transmitter and watch

Communication to surface

Even though radio frequency communication can be used underwater in very low frequency configurations, it does not allow for communicating several meters to the surface. Therefore it was necessary find alternative ways to do so.

As the system already produce underwater sounds to alarm the diving buddy it would naturally be convenient to utilize this to extended communication. Therefore, it was explored if any existing equipment would fit this purpose and a hydrophone was found applicable. A hydrophone is as an acoustic reciever which was part of concept 1 on the buoy in "concept synthesis 2.0". It is a microphone used to pick up underwater sounds. To pick up sounds it uses a piezoelectric element similar to the component used to produce the audible alarm. It can both pick up vibrations and produce them itself. Hydrophones comes in many sizes, price classes and configurations. They are used to detect sounds far away and generally they have a wide pick-up frequency range (ill. 107).

ill. 107 Aquarian low-cost hydrophone

- Use piezoelectric buzzer to create loud underwater alarm
- Use wired solution for communication with product extension on-diver
- Keep components within product centralized

- Use hydrophone at surface to detect when sound alarm goes off in a product extension
- IMU, pressure sensor, MCU, piezobuzzer and battery is combined a relatively small package

2.12 WEARABILITY

After determining that the concept should be a centralized unit, the next step was to determine how to mount the product either on the diver themselves or the suit. 3 different concepts were made, a belt solution, a solution permanently fixed to the suit and solution that was attachable via a mount. The white block seen on the different illustrations is a prototype of the approxiate size of the concept, based on size of the components presented in section 2.11. For full prototyping session see worksheet 25. The goal was to synthesize and gather feedback on the prototypes, in order to produce a final concept prior to the presentation. Due to unfortunate events, the main user had to suddenly cancel the feedback session, and was unable to meet until after milestone 3. This meant that the team would have to do the tests without the user and then hopefully test and verify the result with the user on a later date, after the milestone.

MOUNTING/INTEGRATION

The belt solution

This solution was mounted on an elastic belt that is strapped around the user's stomach. This meant that the concept was easily removable, but it also meant that the user had to take it on and off every time. As a result, it would create the problem of the user having to know exactly where to place the concept every time they wear it. It generally also made it harder to interact with the product., since it was now very hard to feel the button. Since it also had to fit underneath the suit, it meant that it was somewhat challenging to keep the concept in the right place while trying to get the wetsuit on. The long term comfort was also in question with this solution.

ill. 108 Belt solution

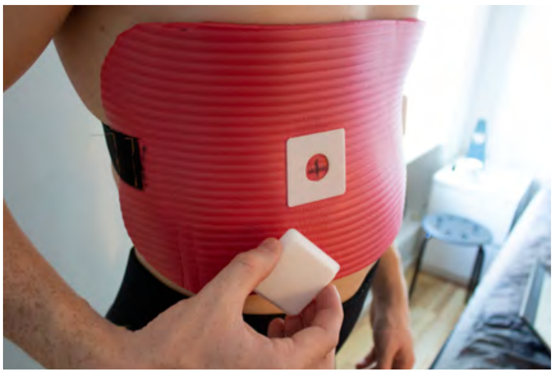
ill. 109 The permanent solution

The permanent solution:

This solution was meant to be permanently placed on the outside of the diving suit, via neoprene glue. The comfort levels were acceptable, as the concept was hard to feel through the material of the suit. The main difference to the permanent solution and the mounted one, was the fact that the permanent solution would not be able to be removed by accident or any other means. This does raise some problems regarding maintenance and charging the concept, since it is fixed to the suit.

The mount solution:

This solution was mounted on the outside to the suit. It consisted of two components; a mount and the concept itself. The mount was placed on the outside of the suit, with the concept on top. This was more comfortable than the belt solution, as the diving suit acted as padding. The placement on the outside also eased interaction with the concept. The mount is also permanently attached to the suit, which meant that the user only had to place it correctly once. The concept itself could then be taken off in case the user needs to remove it. Like the permanent solution, the comfort level was deemed acceptable, as it was hard to feel the concept through the suit. After evalutation, it was decided to proceed and iterate on the mount solution.



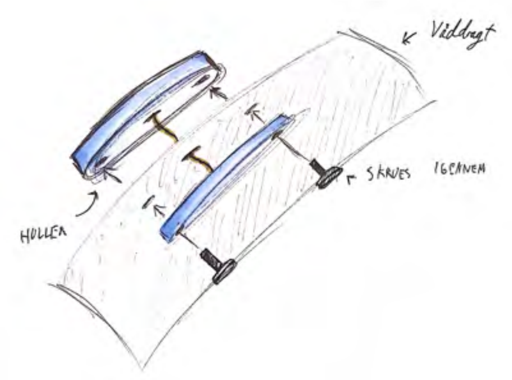
ill. 110 mount solution

» The concept is mounted non-permanently on the outside of the suit.

DIFFERENT MOUNTING SOLUTIONS

After the decision was made to further develop the mounting solution, a sketching session was started. The initial idea was to create a male and a female part of plastic, with one of the parts being permanently fixed to the suit.

There were some intial variations for this. The first idea was was to screw together to parts of a plastic shell, as seen on ill. 111. This raised some questions on how it would damage the suits ability to be watertight, so further options were explored. This led to investigating a pair of neoprene shorts, which had attached pockets meant for extra lead weights. The pocket is glued onto the shorts, and then sewn, see ill. 112 & ill. 113. After building a prototype based on the principles of the pocket, it was found that the pocket could easily be adapted to the concept, while avoiding damaging the suit in any way (ill. 114).



ill. 111 Mounting sketch

ill. 112 Shorts

ill. 113 Pocket

EVALUATION

3 different mounting solutions were evaluated during this prototyping session. The belt solution would move when taking the diving suit on and off, and could potentially move around. This is not ideal since it could potentially affect sensor readings. It was also hard to interact with the concept through the suit. The permanent solution made it easier to interact with and ensured that the concept stayed in place. However, it would prove problematic when the concept would eventually have to be charged. It also meant that the concept could not be moved from suit to suit. The mounting solution was judged the most ideal, since it ensured proper sensor placement every time. The mounted solution was then sketched and prototyped on, and a fitting solution was found by adapting the principles from a lead weight pocket.

At this point in the process, the team unfortunately had to make some assumptions regarding the mounting of the concept. This means that some elements of the proposal were based on assumptions and not actual feedback from the user. The findings would need verifaction and test with the user.

ill. 114 Pocket prototype

» A neoprene pocket is used as mounting solution

» Findings must be tested and evaluated with user

2.13 USER INTERACTION

After a mounting solution was found, the next step was to start development of an interface. The first step was to clearfiy which functionalities needed to be interacted with, based of the functionalities defined by the MVP. Following this, inspiration was gathered and sketching on interaction principles was done. There were some constraints that had to be taken into account. For example, the user has limited vision due to the diving goggles. In addition to this, the diver also has limited feel and finger dexterity, due to wearing neoprene gloves. For the full investigation, see worksheet 22 and worksheets 25. Unfortunatly, as this was just after the mounting tests, the team was unable to get user feedback in time. The tests presented in this section would be re-evaluated with a user in order to confirm the assumptions made.

ESSENTIAL FUNCTIONALITIES

Based of the MVP, the following functionalities were set.

On / Off
The user needs to be able to power the concept on/off

Timer setting
As the concept features a timer which triggers the alarm, the user needs to be able to set when they want the alarm to go off.

Battery indicator
The user needs to be able know the current battery status of the product.

Cancelling the timer
If the alarm goes off by mistake, the user needs to cancel the alarm.

TRIGGERING / CANCELLING ALARM

The first step was testing how the user should be able to trigger or cancel the alarm when needed. Even though the triggering of the alarm is supposed to be automatic, it was deemed important that the user was able to turn the alarm on or off in case of an emergency. The intention was to keep the concept as small as possible, so the initial test was done with one button. This was the best way to keep the concept as compact as possible.

As spearfishers often wear gloves, the test was done with a 5mm thick neoprene glove (ill. 115 & ill. 116). The test showed that it was possible to feel the concept itself through the glove, but it was hard to know if you were pressing down on the button or not. Based of this, it was decided that more work was needed in order to make it easier for the user to locate the button without using sight. If was however found that 25mm in diameter was minimal requrement for its size in order to accomodate for the neoprene glove.

A remote control for GoPro cameras was used as reference for the alarm button (ill. 117). The bump on the buttons and the more tactile feel of the material made it better for interaction with a neoprene glove on.

ill. 115 Manual trigger

ill. 116 Manual trigger 2

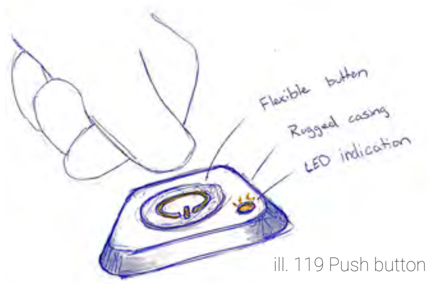
ill. 117 GoPro remote

ON / OFF SWITCH AND INDICATOR

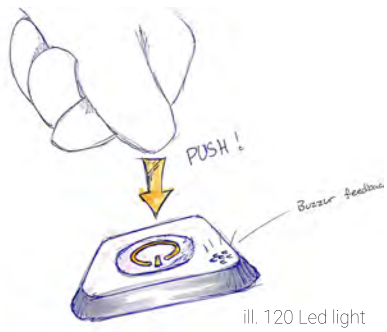
A sketch session was started in order to generate ideas on how the on/off switch should work as well as how battery status could be indicated. The Go Pro camera seen on ill. 118, was used as a reference since this a familiar product for spearfishers. Feedback from turning the concept on and off could be done through sound or light, but the decision was made to adapt the LED indicator from the Go pro on the of top the concept (ill. 119).

The initial intention was to incorporate as many functionalities as possible into one button, so the first iteration on the on/off switch was incorporated into the alarm switch (ill. 120). However, because of the placement of the concept, this raised concerns on the risk of turning the product off by accident when lying prone on the seabed. The solution was moving the switch and the LED to the back of the product. However, It does need further testing later on.

ill. 118 Go pro reference



ill. 119 Push button

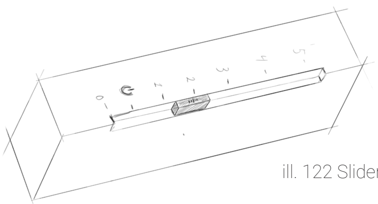


ill. 120 Led light

SETTING OF MAXIMUM DIVE TIME

Another sketching session was stared on how to incorporate a way to set the maximum dive time into the product. The sketching was on a basic level and focused on principles, with a dial (ill. 121) and a slider (ill. 122). Since the concept was so compact , it proved to challenging to incorporate. It was also brought into question whether or not the user actually needed to be able to set the timer while diving. It was decided to leave the functionailty out of the concept temporarily and then conduct an interview with a user, to determine whether or not it was neccessary to include the timer functionality on the concept itself. Instead it could be done through a computer or application.

ill. 121 Dial


ill. 122 Slider

EVALUATION

The initial prototyping and sketching session were usefull for creating an initial itteration of how the user should interact with the concept. It was concluded that the alarm button needed easier to locate by feel alone. The on/off switch should be placed on the back of the concept, so that it does not get turned off by accident when the diver is prone on the seabed.

Unfortunatly, because the user was unavailable to give feedback, the group had to make assumptions regarding these functionalities. Assumptions was also made on which functionalies should be included in the concept. For example, excluding the timer setting function would have to be re-evaluated with the user.

!

» One button interaction with alarm
» Alarm button min. size must be Ø25mm
» Great tactility on alarm button
» Maximum dive time is set on application and not on concept
» On / off switch must not be hit by accident

?

» Time setting must be verified with the user

2.14 CONCEPT SYNTHESIS 3.0

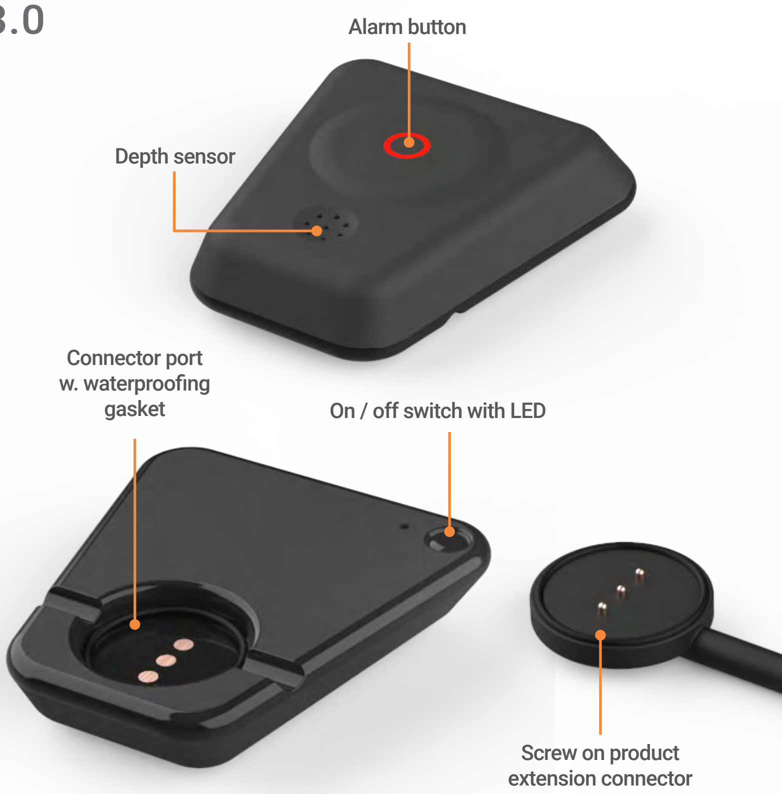
Using what was learned from the previous wearability and interaction tests an early concept was created. This concept was based of the new MVP approach and featured a limited set of functionalities listed below.

CONCEPT FUNCTIONALITIES

- A personal alarm system for spearfishers.
- Alerts nearby dive buddies if:
    - Max time is exeeded
    - Incomplete ascent
    - No established breathing at surface
- Designed as a platform for further add-ons

EVALUATION

The concept was intended to be presented at milestone 3 in order to gather feedback. It was made rather quickly however and based off of several assumptions that was made in the previous tests. This meant that the concept was largely unverified. It was decided to present this concept to the user, in order to verify the different assumptions made and find out which parts needed further iteration.



2.15 REQUIREMENTS 2.0

Requirements found in the previous sections of the chapter is presented. Previously presented MVP requirements have been updated and several now include a specification which can also be seen in the table below. The specifactions not given a page number are an interpretation based on the user need. The requirements serve as basis for future testing and are specified with metrics were applicable.

MVP REQUIREMENTS 1.0	REQUIREMENTS 2.0	SPECIFICATIONS
Monitor for breathing at surface after a dive (p.48)	Monitor with an accelerometer and gyroscope on right costal arch (p.55)	1 Inertial measurement Unit (IMU) (p.55)
Monitor change in depth to determine ascent (p.48)		1 Atmospheric pressure sensor, depth determined by ATM value (p.57)
Monitor dive duration (p.48)		1 MCU for timer functionality (p.57)
Integrate sensors in/on suit, monitor belt or undershirt (p.39)	Mounted on outside of the suit. (p.58)	Neoprene pocket mount. (p.59)
Opportunity for add-ons (p.53)	Wired connection for communication with product extensions (p.57)	
Diver mounted sound alarm (p.53)	Piezoelectric element to create audible underwater alarm (p.57)	Audible from a distance up to 100 meters, measured in Decibel
User set threshold of dive duration (p.48)	Threshold of dive duration is set on application and not on concept (p.61)	
Automatic triggering of alarm (p.53)		Triggered if: • Set threshold of dive duration is exceeded • Ascent is incomplete • Breathing is not established at surface following a dive
Manual triggering of alarm (p.53)	One button to manually trigger alarm (p.61)	
Tactility to ease locate manual trigger by feel (p.41) Usable with 5mm neoprene glove (p.41)	Great tactility and size on alarm button (p.61)	Material with high friction coefficient Size of alarm button must be min. 25mm in diameter. (p.61)
Manual trigger placed at reference point (p.41) Not obstruct speargun loading (p.43)	Small centralized package placed on the right costal arch (p.57)	
	On/off switch must not be hit by accident (p.61)	Placed on the bottom of the concept (p.62)
	Waterproof up to depths of 50 meters	IP classification 68 (depth is specified with pressure test)

DETAILING

SECTION SUMMARY

This chapter of the report presents the detailing of different elements of the concept presented in the previous phase. Here, it will be highlighted which parts were selected for further development, through feedback and testing. It will also present the considerations towards the construction, identity and styling of the product.

3.1 CONCEPT FEEDBACK

Assumptions made prior to milestone 3 presentation were important to test with the user and gather feedback on. A feedback session with Martin Jørgensen were set up as fast as possible following the milestone. See worksheet 24 for full test and feedback session with Martin.

FEEDBACK SESSION WITH MARTIN

Martin confirmed the general direction of the concept and the importance of creating an alarm device. The pocket based mounting option was perceived as a good solution, both because of convenience and comfort reasons. He also would not mind installing the mount on the suit himself, as long as the pocket was already provided as part of the package when buying the device. It was clarified by Martin that the location of the unit on the right costal arch would not obstruct or hinder spearfishing. However further development of the integration would greatly benefit from an underwater test with proper installation on a real wetsuit.

Interaction wise, the simplified interface was perceived as minimizing confusion and doubt on what to do. However, the tactility of the button could be better. While wearing the gloves, Martin noted that the button could be hard to locate only by feel (see ill. 123 & ill. 124). The power button on the back of the product was also confirmed as a good idea, since it negated the risk of turning the product off by accident. The power button was however too small (ill. 125). It was also expressed that the setting of the maximum timer was prefered set via a smartphone app, as to keep the product simple. This was ideal since they usually brought their smartphones with them on the buoy or in the car, just in case. Martin also commented on the add-on connection, noting that it was troublesome not being able to quickly reconnect or disconnect a product extension due to the waterproofing gasket. Being able to do so would improve the user experience with eventual extensions to the MVP.

The feedback session clarified a lot of the assumptions made prior to the test and milestone 3. It confirmed the general direction of the concept, but also confirmed interaction problems which still needed to be adressed.

ill. 123 Interaction test

ill. 124 Interaction test 2

ill. 125 Power button test

» Verified time set on computer or application
» Verified mounting solution on outside of wetsuit with neoprene pocket

EVALUATION - NEW FOCUS AREAS

Based of off feedback and own evaulation, the team was able to determine which elements of the concept needed further development.

1. Buttons
- More defined and easier to use alarm button by feel
- Size of the on/off switch

2. Electrical components
- Size and power of piezo buzzer
- Specification and size of eletrical components
- Revision of add on connection and charging

3. Construction
- Waterproofing and layout of components

4. Styling
- Adapting outer shell to body shape
- Product identity and style

3.2 BUTTON PROTOTYPING

Previous feedback showed that the alarm button was hard to locate only by feel. The On/off switch was also too small to use. The group created a series of prototypes focused on increasing tactility for the alarm button and making the on/off switch easier to use without increasing the risk of accidently turning it off.


ill. 126 Glove on button

ALARM BUTTON TESTING

Two prototypes were created that focused on different surface patterns and edges. Testing of the different prototypes were done with a diving suit glove, as shown on ill. 126. The first protoype was focused on creating a clear, elevated edge around the button, while sinking the button itself lower than the edge (ill. 127). A circular pattern of bumps were also added. The second prototype featured a “ramp” that was supposed to lead the users finger down into the button (ill. 128). It also featured a pattern of bumps in a row.
After testing, it was clear that the product was not big enough to create a ramp that made a noticeable difference. The elevated edge from prototype 1 was much easier to feel through the diving glove. Additionally, the bumps helped to create more definition when touching the button. It was decided to use the principles in prototype 1 further on in the design process.


ill. 127 Prototype 1


ill. 128 Prototype 2

ON / OFF BUTTON TESTING

Three different models were created to test different sizes and shapes of the On/Off switch. This was an evaulation between how easy the button should be to push and not being at risk of turning the alarm of by accident.


ill. 129 Larger button


ill. 130 Wide button


ill. 131 Switch button

Circular button
The first suggestion was to create a circular button that was big enough to press down, so that it could stay down while the product is turned on. This would minize risk of the button being pressed again by accident, while it is in the mount. This was evaluated as being the best solution.

Wider button
This button was an attempt to make a button that was as wide as possible. The idea was to make it easier for the user to see if the button was pressed down. However, this resulted in the button being so wide that it had a high risk of being pressed by accident.

Switch
The idea for this prototype, was to incorporate a switch, so that when one side was pressed down, the other would be pressed up. This would give the user a good analogue indicator of on/off status, but it would result in one of the switches sticking out. Alternativly, it could be put deeper into the product, but this could take up to much internal space.

EVALUATION

The prototypes created for these test were very basic. This was fine for the alarm button test, but the test for the on/off button could have used a functional model. The test could have then provided better feedback on the amount of travel the buttons should have. Nevertheless, the test gave good principles to incorporate into the final concept.

!

» On / Off should stay depressed when on
» LED as an on/off indicator

3.3 ALARM TESTING

It was important to investigate how far the range of an underwater alarm was and how audible it was at different ranges. See worksheet 23 for test and worksheet 20 for research into underwater sound range.

ill. 132 Alarm test 1

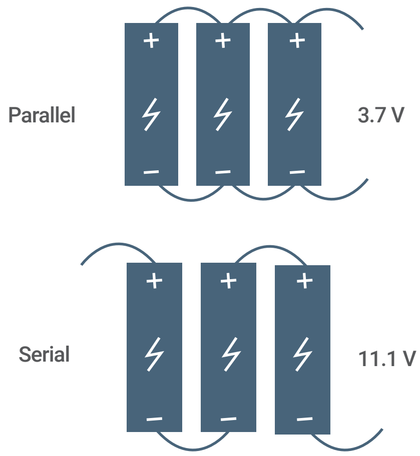
BUZZER TEST

The test was done by submerging a 85 dB smoke alarm under water and then having a person listen after the sound with their head under water as to simulate diving conditions. Initially, the test was done with only around 5 meters of distance between the person and the alarm (ill. 132 & ill. 133).Unfortunately, the sound of the alarm appeared muffled already at 5 meters. This was unexpected as sound in theory should travel faster and therefore further underwater, the sound should be just as clear underwater as above water. The test showed that this unfortunately was not the case. It was speculated that the way the test was done was the issue. The alarm was packed inside two layers of plastic, with air in the space between. It was speculated that the layers of plastic and air worked to isolate the alarm from the water, which then worked to dampen the sound, instead of carrying it. Another reason could be that the alarm itself was built to transmit sound through air, and not water. If the alarm is not built to transmit underwater it will not reach far. This alarm would have to be constructed so that it does not move air, instead using a material to transfer the vibrations directly into the water.

ill. 133 Alarm test 2

CONSEQUENCES FOR CONSTRUCTION

Because the of the results of the test, the strenght of a piezo buzzer was still uncertain. It was decided to try and accomedate this uncertainty by using the smoke alarm as a reference. This means that the concept would be equipped with a similar piezo buzzer used in the buoy alarm test in section 2.7, since this piezo buzzer had a known range of around 300-400 meters above water. However The piezo buzzer in the smoke alarm runs on 9 volts, while most small batteries for low-powered devices only output 3,7 V. The solution to this was to mount three batteries in a serial connection. Compared to a parallel connection where the voltage is constant, the voltage in the serial connection is additive, so the output of voltage can get much higher (ill. 134). However, a higher voltage in a serial connection is at the expense of an unchanged mAh capacity. Other components will also have to be protected from the higher voltage by a voltage regulator.



ill. 134 Battery connections

EVALUATION

As a result of the test, the layout of the batteries had to be changed to accomdate the use of a 9V piezo buzzer. Additionally, the placement of the piezo buzzer seemed to be vital to the effect of the speaker. The buzzer test showed that no air could be allowed in between the piezo buzzer or the water, otherwise the noise will be absorbed. This meant that the piezo element would have to be placed directly against the outside of the procudct, so the vibrations can be transferred directly to the water. These findings was taken into account during the constrcution of the concept, which will be detailed later on.

!

- Batteries mounted in serial connection (3 cells)
- Piezo element placed against transmitting material.

?

- The range of the underwater alarm will have to be tested.

3.4 PRODUCT IDENTITY AND STYLE

A styleboard, see ill. 136, was created in order to determine the desired expression along with details that could be translated into the design. References was found in diving equipment alongside rugged products like handheld GPS's and tools. The intention was to create a expression that both communicted ruggedness, while also presenting itself as a safety product cabable of being in the water. See worksheet 26 for full study of product identity and style.

1 **Screws and Phased edges**
Phased edges and screws can be incorporated into the look to create a more rugged expression.

2 **Material changes**
Shifts between plastic material and rubber can help create indicators for interaction areas.

3 **Creating dynamics**
Making use of dynamic curves can help indicate that this is also a product that is meant to fit on the body.

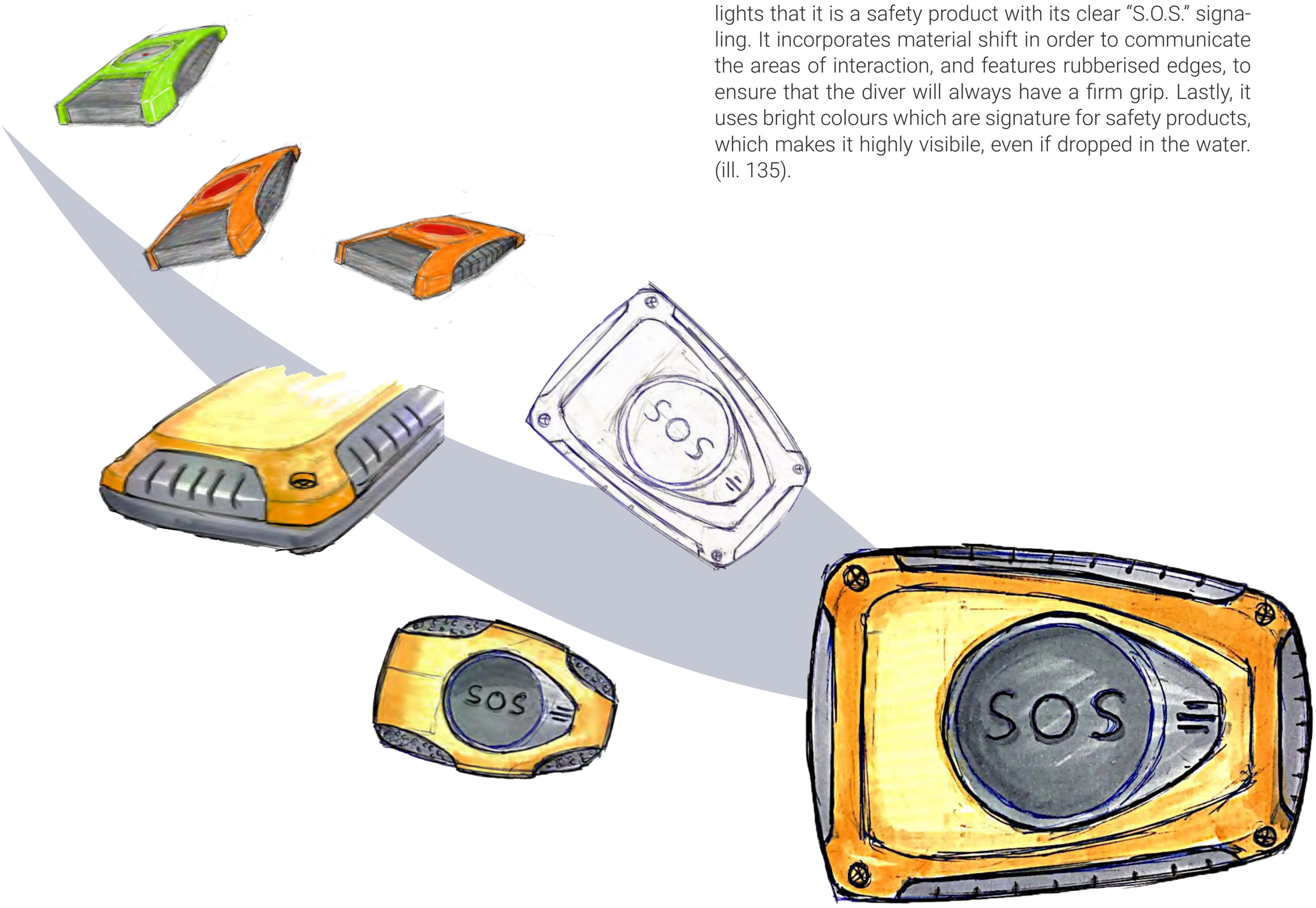
4 **Clear Indicators**
Using clear colours and graphics to clearly indicate what each button does and how to interact with it.

5 **Contrasting shells**
Using shells to create contrast between the different areas of the product, while still ensuring they compliment each other.

6 **Rubberised edges**
Helps reinforce the rugged look, while giving the giving the user a good grib surface as well, so that the product doesnt slip through the fingers.

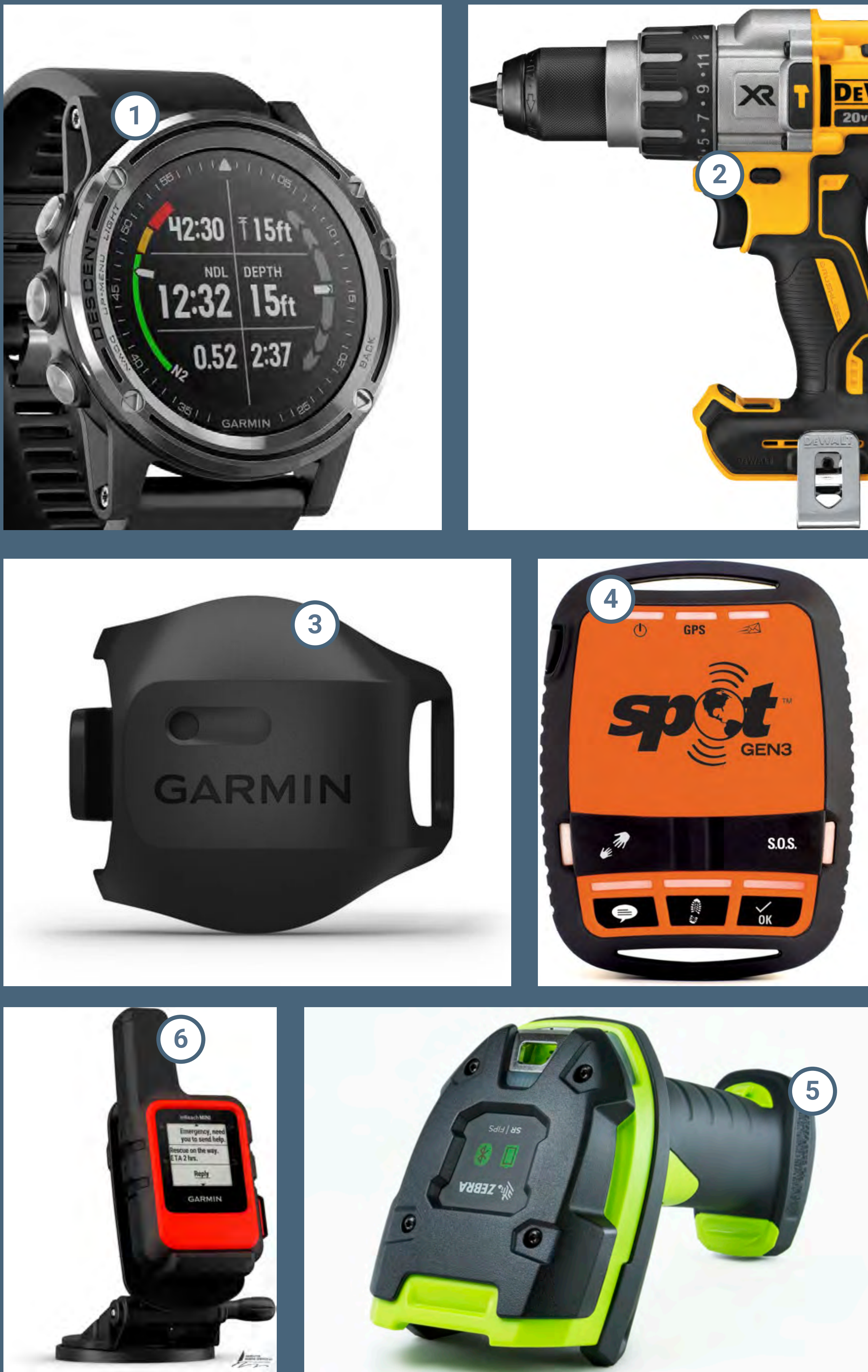
FINAL IDENTITY

The final product identity is shown below. It is a result of trying to combine the different elements into one expression, that both communicates ruggedness, but still highlights that it is a safety product with its clear "S.O.S." signaling. It incorporates material shift in order to communicate the areas of interaction, and features rubberised edges, to ensure that the diver will always have a firm grip. Lastly, it uses bright colours which are signature for safety products, which makes it highly visibile, even if dropped in the water. (ill. 135).



ill. 135 Final styling and identity

ill. 136 Style board



3.5 CONSTRUCTION DEVELOPMENT

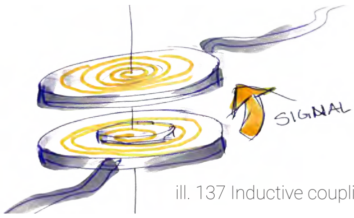
The construction of the product was a combination of including considerations about styling, functionalities, manufacturing and materials. Firstly, the wired connection used for product extensions and charging, needed to be revised. Thereafter this led to a basic construction principle which evolved into more advanced construction considerations.

REVISED WIRED CONNECTON

Based on feedback from Martin Jørgensen on the concept a new wired connection was needed for external communication. One that would enable a less permanent external connection. By using magnetic transmission through an inductive coupling it would be possible to accomodate an easy on/off connection (ill. 137). It is the same technology used for wireless charging in newer smartphones. An inductive coupling possesses great environmental advantages. It performs well in both high-pressure and wet environements (Jacobs n.d.).

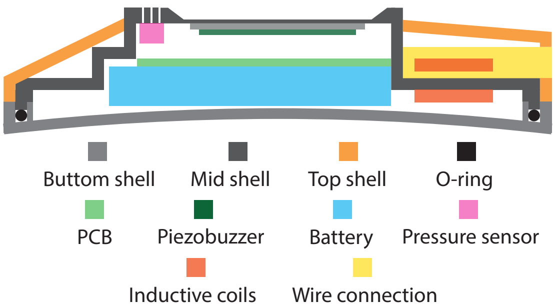
As this product interface is responsible for communicating the alarm signal it is critical to ensure a secure and stable connection. Therefore both coils must be the same diameter and alligned over the smallest possible airgap. This ensures a tight coupling factor rather than a loose and less effecient one (Frumusanu 2015).

To fasten the external wire inspiration was found in the GoPro remote previously mentioned. A keyring is mechanically fixed with a spring loaded slider to the remote (ill. 138). This locking feature in combination with an inductive coupling, enables a flexible but securily mounted wire connection.

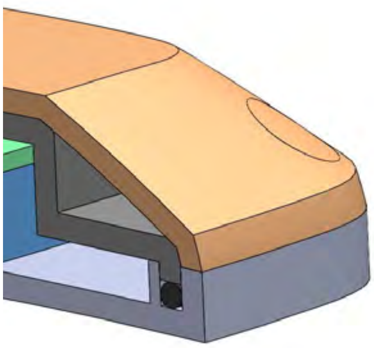


ill. 137 Inductive coupling


ill. 138 GoPro remote keyring locking feature



ill. 139 Construction overview - section cut

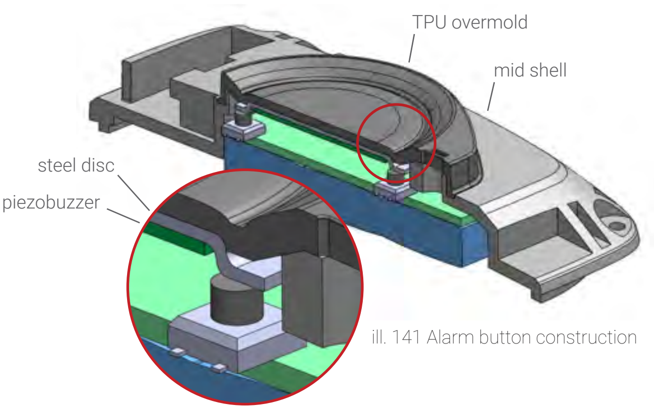

ill. 140 Waterproofing with o-ring - section cut

BASE CONSTRUCTION

Before initiating the construction in CAD software, it was necessary to start out with a construction overview (ill. 139). Finding and determining the exact size of the main electronic components was one of the very first steps in getting started with the overview. The size of the battery, which is the biggest component, is impacted by its capacity. Therefore it was essential to figure out its size and capacity based on components' current draw in the system. The process was back and forth trying out different sized batteries to finetune the overall dimensions. Implementation of the dynamic styling, the alarm button size and an overall size minimization was a large focus during this process. Different sized 200mAh batteries all counteracted the intention of size minimization and overall dynamics. Therefore a 150mAh battery was found to better comply with this. This battery capacity is estimated to deliver suffecient power for a duration of 24 hours with a 2 hours alarm buffer. Battery calculation and dimensions on electronic components can be seen on worksheet 27.

Waterproofing

In order to waterproof the device, a o-ring is clamped inbetween the bottom and mid shell (ill. 140). It is clamped by a total of four screws, one in each corner. This allows for maintenance and easier separation of materials when disposing of the product. Finetuned engineering is required for proper tolerences regarding optimization of the shells in order to achieve a reliable gasket. Furthermore an IP-rating test is required to rate the device to a certain depth.



ill. 141 Alarm button construction

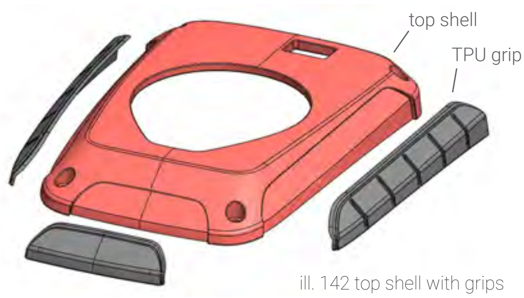
ALARM BUTTON

The feature of the alarm button is an essential one. Due to the placement of the piezobuzzer it was required to utilize the rim around it to active the alarm to not damage the piezo buzzer. The construction proposal for the button includes 4 micro switches pushed down by a steel disc. The buzzer is surface mounted onto this disc (ill. 141). Finally a large overmodled button allows for pushing down the disc.

The overmold is made from TPU, which is part of the thermoplastic rubber family (TPE) with flexible properties. It allows for tactile travel in the button construction, while retaining a waterproof exterior when bonded with the shell. A polyether based TPU is specifically suited for underwater applications which serves the purpose well. It possesses high strength and great tactile properties (Treatstock 2020). The TPU is injection molded onto the shell in a secondary manufacturing process.

TOP SHELL

Both to accommodate for a rugged look and easier handling of the device, TPU grips have been added to the sides and front on the top shell (ill. 142). The side grips have added grooves to further improve tactility. Like with the overmolded button these grips are molded into the shell in a seconday process. For the shells Polyoxymethylene (POM) has been chosen. POM possess high stifness and strenght and a weak water absorbtion ability (Rias n.d.). All three shells are suited for injection molding with POM.



ill. 142 top shell with grips


ill. 143 Wired connection

WIRED CONNECTION

The proposed combination of the connection mechanism and an inductive coupling is placed in the rear end of the device (ill. 143). The wired connection cointains an integrated inductive coil which is coupled with a coil inside the enclosure between the bottom and mid shells. The wired connection is securely locked in place with a spring loaded slider similar to the one in the GoPro remote.

EVALUATION

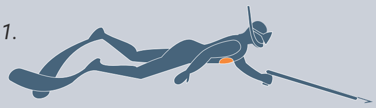
During the process of constructional development. The construction has evolved from more simple considerations to advanged proposals. However several features needs future work for further optimization. The gasket needs competent knowledge on tolerences in order to design a proper seal. The alarm button could also be optimized to utilize one central button in the future.

- Optimization of shells for proper watertight seal
- Optimization of alarm button to use one central button
- Better waterproofing is required before IP-rating

3.6 NEW BLACKOUT TIMELINE

The timeline below illustrates how the proposed concept functions in the context. The timeline describes the different parameters involved in monitoring, and what causes the alarm to trigger.

1.

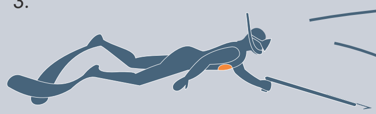


1. Surface tracking
The Inertial Measurement Unit (IMU) will track the divers breathing and as soon as the diver starts the dive, a timer starts. This all happens automatically, and the only thing the diver needs to do beforehand, is set the maximum time limit

2.

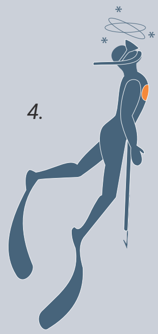
2. Depth tracking
The depth sensor tracks the depth of the dive. Meanwhile, the timer will keep counting down.

3.



3. Normal diving
The diver simply dives like they always would, except that in this example, the diver spends a little to long on the bottom and starts to ascend.

4.



4a. Ascent tracking
The diver unfortunatly is experiencing the onset of blackout. Meanwhile, the product is tracking whether not the diver is still going towards the surface via the depth sensor.

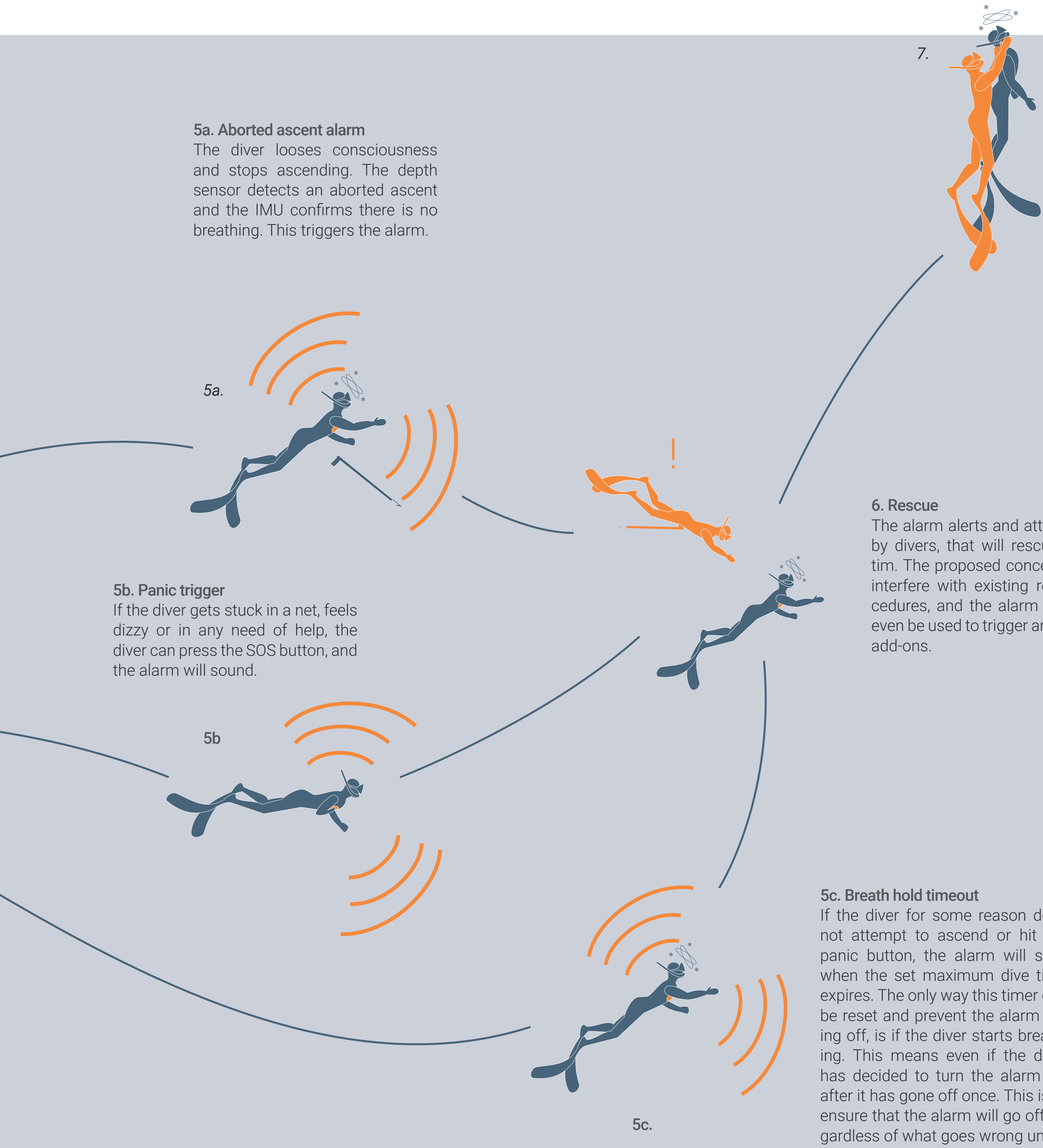
4b. Surface blackout alarm
The diver makes it to the surface, but blacks out shortly after. The depth sensor knows that the diver is at the surface, but the IMU is not detecting breathing. The alarm is triggered, alerting nearby divers.

7. Rescue
When the diver is at the surface, the rescue diver can procced with emergency protocols. The alarm will only stop if the diver starts breathing, or the alarm button is pressed by a rescue diver.

5a. Aborted ascent alarm
The diver looses consciousness and stops ascending. The depth sensor detects an aborted ascent and the IMU confirms there is no breathing. This triggers the alarm.

6. Rescue
The alarm alerts and attracts nearby divers, that will rescue the victim. The proposed concept will not interfere with existing rescue procedures, and the alarm signal can even be used to trigger any eventual add-ons.

5b. Panic trigger
If the diver gets stuck in a net, feels dizzy or in any need of help, the diver can press the SOS button, and the alarm will sound.



5c. Breath hold timeout
If the diver for some reason does not attempt to ascend or hit the panic button, the alarm will start when the set maximum dive time expires. The only way this timer can be reset and prevent the alarm going off, is if the diver starts breathing. This means even if the diver has decided to turn the alarm off after it has gone off once. This is to ensure that the alarm will go off regardless of what goes wrong under the water.

3.7 BUSINESS PLAN

This section explores the overall strategy, operational value chain, estimated production costs and an eventual product portfolio for the current concept. In the following section, a business plan is proposed. The assumption is, that a new company will be responsible for selling the product, and explore the opportunities for this start-up company to bring the concept into reality. The considerations have been supported by a "Breakeven analysis" that describes the initial investments required and when the product will actually start turning a profit. The intent of this business plan is to produce a suggestion on how to launch a brand new product into a market with brands familiar to the target group.

B2B

User Martin Jørgensen has expressed that spearfishers have a tendency to be very loyal to specifics brands. This means it can be hard for a new brand to enter the market, but the established brand can also be used as an entryway for a new product.

The product itself or parts of it, could be sold as an OEM product to brands that already have an existing user base. For example, if the product gains enough traction, it could be possible for diving suit manufacturers (ill. 144) to pay a licensing fee for the pocket itself, so that they can manufacture it in whatever colour or camouflage pattern the buyer desires.

Another positive is that the familiar companies have access to sales channel that the start-up will not. These sales channels can be used to quickly gain access to a wider market, without making large investments into marketing and sales.

The downside is of course that there is an extra middleman which means that the start-up will get a smaller percentage of the final sales price.

ill. 144 Wetsuit manufacturers

B2C

Another approach would be to sell the entire product directly to the customer. Because the users are brand loyal, it could be a good option to use the channels they buy their known brands from. This means selling through local diving stores or rental shops, or through some of the more popular websites that sell a wide variety of spearfishing equipment, such as Kingfish.dk (ill. 145).

The product itself will have to come with one or several neoprene pockets which the user can attach to their diving suits themselves, since this is necessary for the product to work properly. Earlier investigation has proven that the users were not shy of modifying their own equipment, but the product has to come with a through guide, that ensures that the product is placed correctly on the diving suit.

The advantage of selling the product B2C, would be that the start-up company would recieve a larger percentage of the final sales price, but it could be harder to reach good sales numbers initially.

ill. 145 Wetsuit retailers

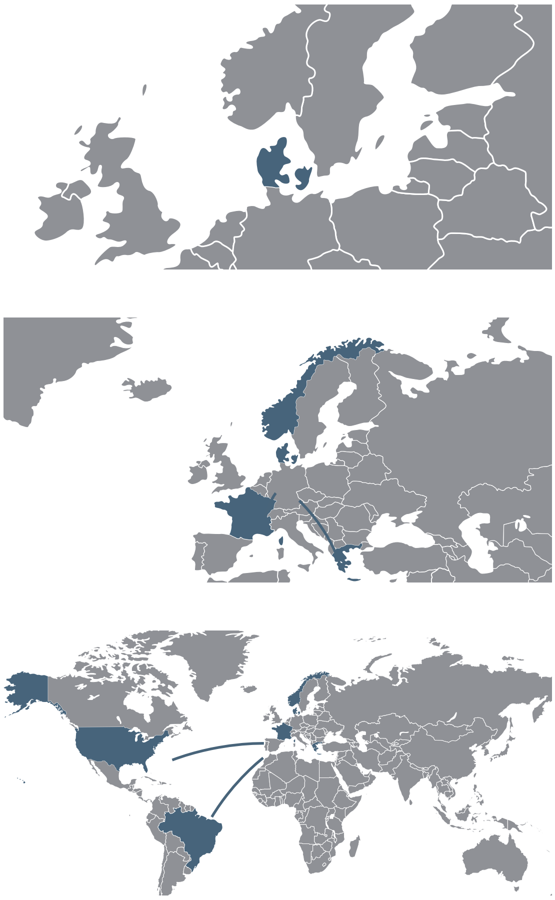
EVALUATION

There is potential in using both B2B and B2C channels to sell this product. The neoprene patch could easily be outsourced or licensed out to diving suit manufacturers. However, the alarm device itself should ideally be kept so that the start-up company sells them directly to customers themselves. This way, the company doesn't sacrifice revenue by having an extra middleman, but allows users to have the customization they want. However, until the product is recognized, it could be sold as a complete kit through diving stores.

OVERALL STRATEGY

The primary strategy behind selling the product would be selling it in areas where spearfishing is popular. As for market strategy, the first step would of course be to sell the product very localized. Local stores could be used to validate the product, which could help gather investors with capital to eventually sell the product in other countries in Europe. For instance contries like Norway, Greece and France, where spearfishing is popular and divers have a tendency to dive deep.

Eventually, the product could be moved overseas to the American markets, and especially states like Florida, where diving and spearfishing is very popular (ill. 146).



ill. 146 Businessstrategy

SALES AND EXPENSES

Based of the pricing of competing products and user interveiws, the pricing of this product is estimated to be around 3.000 DKK. The product is placed in this price range alongside similar diving electronics, like diving watches, while being cheaper than competitors like the Sens07vest. The product should not be sold too cheap however, since users might percieve the product as ineffective or not capable of providing safety.

The largest initial expenses for launching the MVP concept would be the programmering and testing of the breathing algorithm. Quite a lot of work will have to go into making sure the algorithm works properly and doesnt give false positives, which in turn will take a substancial amount of time and money. Additionally, the moulds for the plastic part will also have to be invested into. The electric components themselves are all standard, and can thus be bought in bulk from suppliers. All in all, it is not the product itself that will be expensive, but rather the software and testing that goes into it.

PRICING

It is estimated that it would take around 2 years to bring the market. The desire would then be to make the initial investment back within the next 2-3 years. With a unit price around 3.000 DKK, it will requires 525 units sold. This can be seen in the breakeven analysis below, which is based on sales in the danish market (ill. 147). See worksheet 28 for more information.

Denmark		2.5% increase	2.5% increase	2.5% increase	2.5% increase	
Budget:	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total:**
Parts sold:	500	513	525	538	552	2,628
Sales price (Factory):	1,582.68	1,582.68	1,582.68	1,582.68	1,582.68	
Product cost:	239.80	239.80	239.80	239.80	239.80	
Turnover:	791,340.00	811,123.50	831,401.59	852,186.63	873,491.29	4,159,543.01
Variable cost:	119,900.00	122,897.50	125,969.94	129,119.19	132,347.17	630,233.79
Contribution margin:	671,440.00	688,226.00	705,431.65	723,067.44	741,144.13	3,529,309.22
Investment:	-1,780,000.00	-1,108,560.00	-420,334.00	285,097.65	1,008,165.09	
Contribution:	671,440.00	688,226.00	705,431.65	723,067.44	741,144.13	
Remaining:	-1,108,560.00	-420,334.00	285,097.65	1,008,165.09	1,749,309.22	

ill. 147 Break even analysis

3.8 OPERATIONAL VALUE CHAIN

Below is a suggestion on an operational value chain, that would provide a certain degree of flexibility for expansion and allow for customization for the user. The graph illustrates what a structure might look like.

START-UP COMPANY

The company will be responsible for the programming, development and support of the product. Prototyping and assembly of low numbers could initally be handled internally. The company would initially have to rely on external suppliers and manufacturers, but as the product expands, it would be critical to internalize some processes.

ELECTRONICS

The electronics will be ordered in bulk, from different suppliers that has the required parts. Finding the right parts and suppliers will be a part of a larger task, since this involves a lot of lobbying.

START-UP COMPANY

ASSEMBLY

PLASTIC COMPONENTS

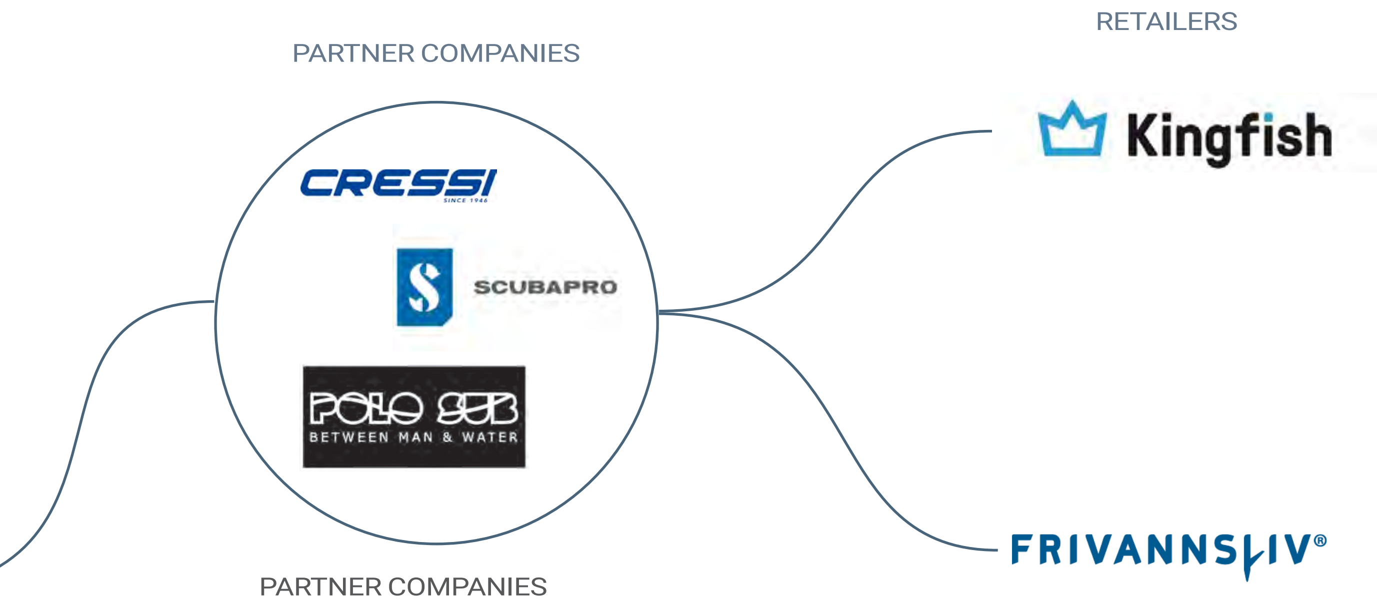
The plastic components will be supplied by a plastic mouldings company, here Stephens Plastic Mouldnings. This company was chosen as an example since they have the capability to do TPU moulding. These Plastic parts will be shipped from the manufacturer to assembly. in some cases, the manufacturer can also handle the production of moulds.

ASSEMBLY

The assembly and testing could initially be handled by the start-up company, as long as it is early product versions in very small numbers. Eventually, the assembly and testing will have to be handled by either an assembly company with the required tools, or one of the suppliers, since this is sometimes a service they offer. The assembly site will also handle packaging. From here, the product will be shipped off either directly to retailers, or partner companies.

NEOPRENE PATCHES

The neoprene can be supplied by neoprene manufactures such as Voll Will, which can cut the finished patches, ready to be attached. If the partner companies are willing to make their own patches, it wont be necessary.



PARTNER COMPANIES

The partner companies would buy the license for producing the patches themselves. This way, the customer could get a customized patch for their diving suit.

The product could eventually be produced as an OEM product for these companies, but the initial plan is to sell the alarm device itself, and let the neoprene patch be outsourced.

PRODUCT - PROCESS INTERFACE

The main objective of this was to construct an infrastructure that was flexible and used external suppliers, but still retained control over the most important parts of the product, which is the programming.

There is a downside to the current way the product is designed. There is no way to change the exterior of the product, without having to change the the pocket that it is placed in. However, the programming is more flexible, which means the products intended user context can be changed, without having to change the physcial shape of the product and the production line with it. Meaning, that the solution easily could be adjusted to fit a performance context.

The product architecture also allows for add-ons, which is a good way to introduce the product into new markets and user contexts, without having to change the core product. Designing these add-ons will be a large investment though, and will also take time to develop.

REFLECTIONS

The advantages of this system, is that it enables the start-up company to lobby between subsuppliers, while still retaining the most important part of the product; The algorithm and programming for the alarm system. For partner companies, it also allows them to offer something that their competitors might not, which is a customized pocket for the product.

The downside is that the brand behind this new alarm system will be unknown, so it could be hard to break through on the market initially. This could be avoided by producing the alarm as an OEM product, for either the diving suit companies, or companies like GARMIN, that has a large focus on wearable tech.

3.9 PRODUCT PORTOFOLIO AND ADD-ONS

The MVP described will be the first edition of the product. There is potential for expanding the product into new markets, by using add-ons and adding additional features.

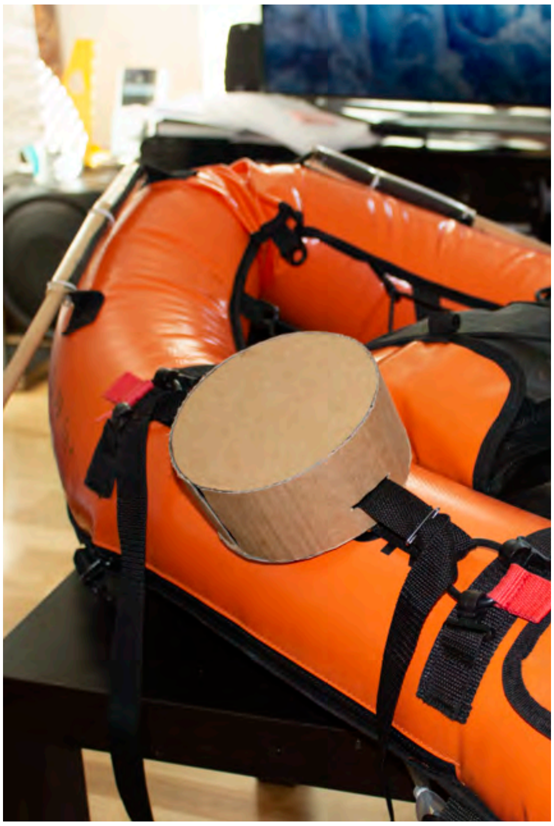
BUOY ALARM

There is potential to expand into the competitive market, by designing an add-on built for long range communication and alarm. Using concepts from earlier in the process, the group formulated a concept for an add-on that consisted of an alarm device that is mounted to the buoy. The add-on will sit tied to the buoy while the diver dives. Here it will float on the surface and will listen out for any alarms using a hydrophone. As soon as an alarm is triggered, the add-on will record it, and signal distress through visual, audible and/or sattelite alarm. The buoy alarms also have a potential to be used in a mesh network, sending signals to other nearby buoy alarms, rescue boats or competition officials.

The new solution is intended to work over large distances, such as those at spearfishing competitions. It allows the rescuers to know if there is a blackout, and quickly get information on the divers position. It helps the competition ensure the safety of its participants and could potentially be considered a requirement for participation.

FLOTATION VEST

This wearable inflatable diving vest will explore the potential for a product that is much more focused on active resurfacing. The vest will use the already existing connector port on the product, so that the two will always be physically connected with a wire. Through the inductive coupling the inflatable vest will recieve a triggering signal. The vest will contain elements that will inflate using a CO_2 cartridge, when the alarm device detects a blackout. When the vest inflates, it will increase the buoyancy of the diver and automatically bring them to the surface. The vest enables much more immediate rescue and thereby increases the chances of survival. It also has the potential to help keep the divers head above water when they reach the surface. This could be appealing to more novice divers that might not be sure of their abilities, and feel like sacrificing more freedom for safety. It could also be incorporated into the wieght vest, to increase the appeal for the new solution as previously found.



ill. 148

ill. 149

TRAINING EQUIPMENT

The programming for the MVP is only meant to encompass the basic functionalities of the product. However, the software has the potential to be used to expand the functionalities of the product.

With the right programming, the existing motion sensors could provide detailed information about the users breathing. This means that the product could be expanded to be used for breathing exercises, to help the user improve their diving time.

This also means that the product could be adapted to other sports, such as freediving, with minimal changes to the physical product. Similarly, the product could be programmed to provide feedback for SCUBA divers. The product could be issued to teachers and students, where the product would be monitoring the breathing of the students and starting an alarm if the student starts panicked breathing patterns.

ill. 150

3.10 CONCLUSION

The initial drive for the project was to create a new product to help mitigate the risk and dangers of diving. Early on it was clear that one issue in particular, shallow water blackout, was a recognized and constant risk. Furthermore, none of the solutions that were currently available were widely used; they were simply too troublesome and distracting. Creating a solution that did not distract from the activity and would insure the freedom of the diver, while still ensuring their safety, became a cornerstone of the project and was kept in mind throughout the process.

Both freediving and spearfishing were considered as potential target groups, but it was determined to focus on spearfishing. They are exposed to more distracting factors and freedivers are typically very aware of the risk and take more countermeasures. Through research it was discovered that the body had certain indicators that could be used to identify the early onset of blackouts though sensors mounted on the body.

Through sketching, mock-ups and prototyping, several suggestions were created on how to bring a diver back to the surface. However, after reevaluating the concepts with a lean start-up mindset, a new concept was found. This concept held the most essential functions which the solution required and left room for potential add-ons to the system.

Through additional testing and prototyping, the solution became the blackout rescue device "SENTINEL". Through breath, ascent and time monitoring, it is capable of automatically detecting a blackout in the most critical parts of the dive. When a blackout is detected, SENTINEL will alert nearby diver through a loud sound alarm. It is a safety extension to the current buddy system and provides a greater chance of recoving from and surviving a Shallow Water Blackout.

In addition, the product is designed as a platform for future expansion, and can serve as a triggering unit for buoy alarms and inflatable vests.

The initial investment of time and money into the software will be quite large, but will provide opportunity to expand the product into other sectors with minimal change in the physical parts. It provides an opportunity to establish partnerships with other companies without risk of losing control over the product.

3.11 REFLECTION

PROCESS REFLECTION

Unfortunately, this project was running concurrently with the outbreak of the Covid-19 which has had large consequences for certain aspects. Firstly, it limited user interaction and testing since social distancing was in effect. Luckily, user Martin Jørgensen was still willing to meet and test various prototypes throughout the project. It meant that the user group was small, but the team made the decision to focus on the quality of feedback instead of quantity. More tests could have been done online or through email, but the team chose to focus on getting feedback from physical tests, rather than illustrations or renderings. This could have give the wrong impression because many of the concepts were wearables. Broader user involvement could have given different feedback which could have affected the process with more nuanced input.

Secondly, the team had an appointment with Fridykning Aalborg for using their indoor pool for testing under a more controlled environment. Unfortunately, circumstances meant that the pool had to close and remained closed for the rest of the project. A controlled water environment could have been useful through the development process and might have facilitated better feedback from tests.

The decision to change into a MVP approach also had drastic influence on what the final concept looked like. It was a change in mindset from creating the best possible solution, to a more realistic launch approach. It will ensure a much faster time to market and much quicker initiation of feedback from the target group. It had a drastic effect on what functionalities and features were included into the concept. In general, the concept was scaled back to its essentials but with potential for expansion later. If the team hadn't decided to make the change of approach, the final concept would likely have looked very differently.

PRODUCT REFLECTION

Range of alarm
Due to the result from testing an alarm under water, the team had to make assumptions on the range of a piezo buzzer, based on earlier tests on the surface. It set certain requirements for the placement and powering of the piezo buzzer inside the concept, which the group has tried to accommodate. Testing the actual range of the alarm buzzer has still yet to be done, but requires the actual materials and construction in order to create valid results. This test would have to be done if the product is to be developed further.

Waterproofing
Waterproofing the product is essential considering the environment that it will operate in. The group has made efforts to include water tightening measures and principles into the construction of the product, but it will require further detailing, engineering work and testing in order to make sure the product fulfills the requirements.

REFERENCE LIST

Ash, S (2017) The Mammalian Diving Reflex: 4 Fascinating Things Happening to Your Body When You're In Water - The Inertia. Available at: https://www.theinertia.com/health/the-mammalian-diving-reflex-4-fascinating-things-happening-to-your-body-when-youre-in-water/ (Accessed: 13 February 2020)

Culture of safety (n.d.) Shallow Water Blackout. Available at: https://cultureofsafety.thesilverlining.com/aquatics/shallow-water-blackout (Accessed: 13 February 2020)

DAN Annual Diving Report 2017 Edition. Buzzacott, P (editor). - A report on 2015 diving fatalities, injuries, and incidents. Durham, NC: Divers Alert Network, 2017

Deeper Blue (2020) New Sens07vest Freediving Vest Unveiled. Available at: https://www.deeperblue.com/new-sens07vest-freediving-vest-unveiled/ (Accessed: 13 Marts 2020)

Deeper Blue (2013) What Is The Most Popular Freediving Certification Agency? Available at: https://www.deeperblue.com/what-is-the-most-popular-freediving-certification-agency/ (Accessed: 06 February 2020)

DiveAlert (2020) DiveAlertPLUS. Available at: https://www.divealert.com/index.php/divealert-plus (Accessed: 13 March 2020)

Dr. Brothers, Alex (2020) Shallow Water Blackout (SWB). Available at: https://www.swimming.ca/en/safe-sport/education/mental-and-physical-health/shallow-water-blackout-swb/ (Accessed: 06 February 2020)

Emotions Blue (2020) Seven Types of Freediving. Available at: https://www.emotions.blue/blog/item/seven-types-of-freediving (Accessed: 06 February 2020)

Frumusanu, A. (2015) 'Magnetic Resonance and Magnetic Induction', pp. 1–6. Available at: https://www.wirelesspowerconsortium.com/data/downloadables/1/2/4/6/magnetic-resonance-or-magnetic-induction.pdf. (Accessed: 18 May 2020)

Freedive Earth (n.d.-a) Freediving Hypoxia And Approaches To Safety. Available at: http://www.freedive-earth.com/learn-freedive/freediving-hypoxia-and-approaches-safety (Accessed: 13 February 2020)

Freedive Earth (n.d.-b) Blacking Out While Freediving. Available at: http://www.freedive-earth.com/learn-freedive/blacking-out-while-freediving (Accessed: 13 February 2020)

Gilliam, B (n.d.) The hazards of freediving - DiverMag. Available at: http://www.bretgilliam.com/assets/the-hazards-of-freediving.pdf (Accessed: 06 February 2020)

Healthcare in Europe (2007) Chest mounted pulse oximetry. Available at: https://healthcare-in-europe.com/en/news/chest-mounted-pulse-oximetry.html (Accessed: 13 March 2020)

Jacobs, J (n.d.) Power and signal over an air gap – TR Electronic Available at: https://isa100wci.org/Documents/PDF/Power-and-Signal-Over-An-Air-Gap.aspx (Accessed: 18 May 2020)

Kelley, M (2019) Shallow Water Blackout: Don't risk it spearfishing. Available at: https://maxspearfishing.com/spearfishing-safety/shallow-water-blackout (Accessed: 06 February 2020)

Lindholm, P. and Gennser, M. (2005) 'Aggravated hypoxia during breath-holds after prolonged exercise', European Journal of Applied Physiology, 93(5–6), pp. 701–707. doi: 10.1007/s00421-004-1242-y.

Lindholm P, Pollock NW, Lundgren CEG, eds. Breath-hold diving. Proceedings of the Undersea and Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006.

Massaroni, C., Nicolò, A., Lo Presti, D., Sacchetti, M., Silvestri, S. and Schena, E., 2019. Contact-Based Methods for Measuring Respiratory Rate. Sensors, 19(4), pp.1-47.

Naslund, S (2008) How to handle a freediver suffering blackout due to hypoxia - Freediving.Biz. Available at: http://www.freediving.biz/education/laryngospasm.html (Accessed: 13 February 2020)

Retsinformation (2000) Bekendtgørelse om regler for sejlads m.m. i visse danske farvande. Available at: https://www.retsinformation.dk/eli/lta/2000/779 (accessed: 1 March 2020)

Rias (n.d.) POM (Polyoxymethylen). Available at: https://www.rias.dk/industri-visuel-kommunikation/plasttyper/pom.aspx (Accessed: 18 May 2020)

Schagatay, E. and Åman, P. A. (2019) 'Repeated freediving – An efficient and safe method to rescue subjects trapped in cars underwater', Safety Science, 118(May), pp. 752–756. doi: 10.1016/j.ssci.2019.05.023.

Scuba Diving International (n.d.) Marketing Available at: https://www.tdisdi.com/wp-content/uploads/files/marketing/iti_prospectus.pdf (Accessed: 06 February 2020)

Seareq (2019) ENOS-System. Available at: https://www.seareq.de/en/products/enos (Accessed: 13 March 2020)

Siqueira, A., Spirandeli, A., Moraes, R. and Zarzoso, V., 2019. Respiratory Waveform Estimation From Multiple Accelerometers: An Optimal Sensor Number and Placement Analysis. IEEE Journal of Biomedical and Health Informatics, 23(4), pp.1507-1515.

The Active Times (2018) It Takes Only 60 Seconds to Drown & Other Water Safety Facts. Available at: https://www.theactivetimes.com/water/it-takes-only-60-seconds-drown-other-water-safety-facts/slide-7 (Accessed: 06 February 2020)

The Heartbit (2018) Heart Rate Monitor: Chest Strap or Watch? Available at: https://theheartbit.com/media/press-releases/heart-rate-monitor-chest-strap-or-watch/ (Accessed: 13 March 2020)

The Lean Startup (n.d.) The Lean Startup Methodology. Available at: http://theleanstartup.com/principles (Accessed: 27 March 2020)

Treatstock (2020) About TPU. Available at: https://www.treatstock.com/material/tpu (Accessed: 18 May 2020)

Undervandsitetet (2019) CMAS Euro-African Spearfishing 2019. Available at: https://undervandsitetet.dk/euro-african-spearfishing-2019/?fbclid=IwAR0k4yLNuvBJksxZ-hFTOoWSPCHXURj_VTFxt5XgGpNqDMNcI17tv5HOSm4 (Accessed: 21 February 2020)

Villadsen, M. (2014) Hold vejret - en bog om fridykning: 1st edition. Kromans, Danmark

White, P (2017) New Hypoxia Research Has Potential to Reduce Drowning Deaths - The Inertia. Available at: https://www.theinertia.com/surf/new-hypoxia-research-has-potential-to-reduce-drowning-deaths/ (Accessed: 06 February 2020)

Yoon, J., Noh, Y., Kwon, Y., Kim, W. and Yoon, H., 2014. Improvement of Dynamic Respiration Monitoring Through Sensor Fusion of Accelerometer and Gyro-sensor. Journal of Electrical Engineering and Technology, 9(1), pp.334-343.

ILLUSTRATION LIST

Illustrations listed below are only from external sources, non listed are the project groups own illustrations

ill. 1 https://www.deeperblue.com/avoiding-black-outs-hypoxic-fits/
ill. 7 Provided by Sigurd Van Hauen
ill. 11 https://www.youtube.com/watch?v=fNCxV0B2iyc
ill. 12 https://www.youtube.com/watch?v=fNCxV0B2iyc
ill. 13 https://www.provitatec.com/
ill. 14 https://www.provitatec.com/
ill. 25 https://www.biofeedback-tech.com/biofeedback-shop/nexus-respiration-sensor
https://www.medtronic.com/covidien/en-us/products/pulse-oximetry/nellcor-portable-spo2-patient-monitoring-system.html#carousel-example-generic
ill. 26 https://www.amazon.com/Evike-Gram-CO2-Cartridge-Airsoft/dp/B07TDTFF4Q
https://www.pngfuel.com/free-png/reoed
ill. 27 http://www.hardmotorsport.com/hard-motorsport-rs-door-latches-pull-strap-conversion-kit-bmw-e46-coupe/
https://www.deviantart.com/minimillart/art/C4-Remote-Detonator-Battlefield-4-522866153
ill. 34 Provided by Martin Jørgensen
ill. 36 Provided by Martin Jørgensen
ill. 35 Provided by Martin Jørgensen
ill. 37 Provided by Martin Jørgensen
ill. 41 https://www.shearwater.com/products/teric/
ill. 42 https://www.biofeedback-tech.com/biofeedback-shop/nexus-respiration-sensor
ill. 43 https://healthcare-in-europe.com/en/news/chest-mounted-pulse-oximetry.html
ill. 44 https://buy.garmin.com/da-DK/DK/p/530376
ill. 52 https://flybubble.com/blog/choose-the-right-reserve-parachute
ill. 51 https://survitecgroup.com/survitecproducts/16981/Halo-YourInflightGuardian
ill. 58 https://gearjunkie.com/quiksilver-highline-airlift-aqualung-inflatable-flotation-surf-vest
ill. 59 https://www.onyxoutdoor.com/p/m-24-manual-inflatable-life-jacket-pfd
ill. 60 http://golem13.fr/kingii/
ill. 69 https://prometheusdesignwerx.com/collections/watch-accessories/products/expedition-watch-band-compass-kit-ti-od-green?variant=27832871239
ill. 70 https://ww2.scubapro.com/en-GB/HKG/instruments/computers/products/galileo-hud.aspx
ill. 74 https://www.boatingmag.com/visual-distress-signal-choices/
ill. 76 https://www.seareq.de/en/products/enos
ill. 77 https://www.divealert.com/index.php/divealert-plus
ill. 75 https://www.force4.co.uk/item/Force-4/Odeo-LED-Flare-Mk3/D9D
ill. 102 Provided by Martin Jørgensen
ill. 105 https://www.shearwater.com/
ill. 107 https://www.aquarianaudio.com/h1c-hydrophone.html
ill. 118 https://nofilmschool.com/2012/11/gopro-hero3-4k-more-sample-videos
ill. 136 https://www.amazon.com/Garmin-Descent-Watch-Sized-Computer-Features/dp/B076H2YL3V
https://www.dewalt.com/products/power-tools/drills/drills-and-hammer-drills/20v-max-xr-brushless-cordless-3speed-hammer-drilldriver-tool-only/dcd996b
https://www.thinkablestudio.com/zebra3600
https://www.cykelgear.dk/tilbehor/cykelcomputer-tilbehor/tilbehor-til-cykelcomputere/garmin-bike-speed-sensor-2?gclid=CjwKCAjw7-P1BRA2EiwAXoPWA-y_1ooEDQqaDZLVWTdx92THdtBFqCzvkvK1j8zQtkgBImDRSeu8bBoCbEkQAvD_BwE
https://buy.garmin.com/en-US/US/p/592606/pn/010-01879-00

AALBORG UNIVERSITY
DENMARK