INVESTIGATING MANUAL PERFORMANCE WHEN USING PUSH BUTTONS FOLLOWING COLD WATER HAND IMMERSION

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Abstract

The research in this thesis investigates manual performance of humans when using push buttons following cold water hand immersion. An experiment involving 29 human participants was carried out to measure the activation rate for two types of commercially available personal locator beacons after their hands were immersed in either cold water (2 °C) or thermoneutral water (34 °C) for 2 minutes. Similarly, the activation rate was measured for a range of different push buttons mounted on a novel test apparatus after their dominant hand was immersed in both cold (2 °C) and thermoneutral (34 °C) water for 2 minutes. A series of standardized hand dexterity tests were completed to assess the participants baseline tactile sensitivity. The mean baseline performance of participants indicates that they were representative of the general population. The button test apparatus test was developed specifically for this experiment and was comprised of 12 different buttons at different locations on the panel which were varying in size, surface shape and texture. After the participants immersed their dominant hand in the assigned temperature condition, their index finger was guided to the centre of the panel, and they were instructed to find and press as many buttons as they could in a 2-minute time period with only their index finger. Repeat presses were permitted. For both the button panel test and the PLB test, the participants' view was obstructed from seeing the buttons. After the experiments were completed a questionnaire was given to the participants for them to fill out. The questionnaire consisted of a variety of questions which related to performance feedback of both the PLB tests (Stage 2 & Stage 4) and the button panel apparatus test (Stage 3). This was to have results of how they thought they performed in comparison to how they had performed in the experimental session.

Based on the findings from the previous research, it was hypothesized that having cold wet hands would lead to a poorer performance for push button activation than when having warm wet hands.

Additionally, it was hypothesized that a button which was large, protruding, and rough would be activated most frequently.

The results of the study show that temperature does not influence the activation rate for personal locator beacons or the activation rate of the push buttons on the button test apparatus. In addition, button size (large) was the most significant factor, followed by shape (protruding), however button texture was not a significant parameter. For the application of the activation of PLBs false activation rate occurred and this requires further investigation. For the PLB tests which were conducted it was evident that the two devices were difficult to activate for both hand immersion temperature conditions (thermoneutral and warm).

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1.0 Introduction

1.1 Background

Rapid detection and location of casualties following maritime accidents is of paramount importance to ensure their survival. According to the Department of Fisheries and Oceans (DFO), there were an estimated 12,865 active fishing vessels in Canada in 2018 and during the past 10 years, fishing vessels under 60 gross tons have accounted for more than 60% of Canadian vessels lost (TSB, 2018). Additionally, of the 47-fishing vessel related accidents from 2011 to 2017 a person falling overboard represented 43 % of the total fatalities (TSB, 2018). This highlights the importance of having an emergency position indicating radio beacon (EPIRB) on the vessel, which can signal when the vessel runs into difficulties, as well as each crew member carrying a personal locator beacon (PLB) device which can be activated when a person falls overboard.

Emergency location transmitters such as PLBs and EPIRBs transmit an emergency distress signal to alert authorities of an incident and a GPS position to help locate the survivors. PLBs are small, lightweight, and portable handheld devices which, when activated, can help reduce search and rescue time. These devices are normally used for land-based applications such as trekking, hiking, skiing, camping, mountaineering, but can also be used in maritime applications such as fishing, kayaking and recreational boating activities. For maritime applications they are particularly useful for man overboard incidents, and for land-based applications they are useful for a lost hiker who is stranded in a remote location. Their main purpose is to send a distress signal on a 406 MHz frequency with a homing frequency of 121.5 MHz in order for an individual’s location to be identified. The 121.5 MHz homing frequency can be used by an aircraft overhead to locate the device. The beacon sends a 15-digit identification number signal at a 406 MHz distress frequency to Cospas-Sarsat satellites and earth stations in which the beacons information and location is passed onto the nearest rescue coordination centre. Then the rescue coordination centre notifies the local search and rescue authorities. For the most part these devices are activated manually but can also be activated automatically. **Figure 1** shows the sequence of events from the time the beacon is activated to SAR response.

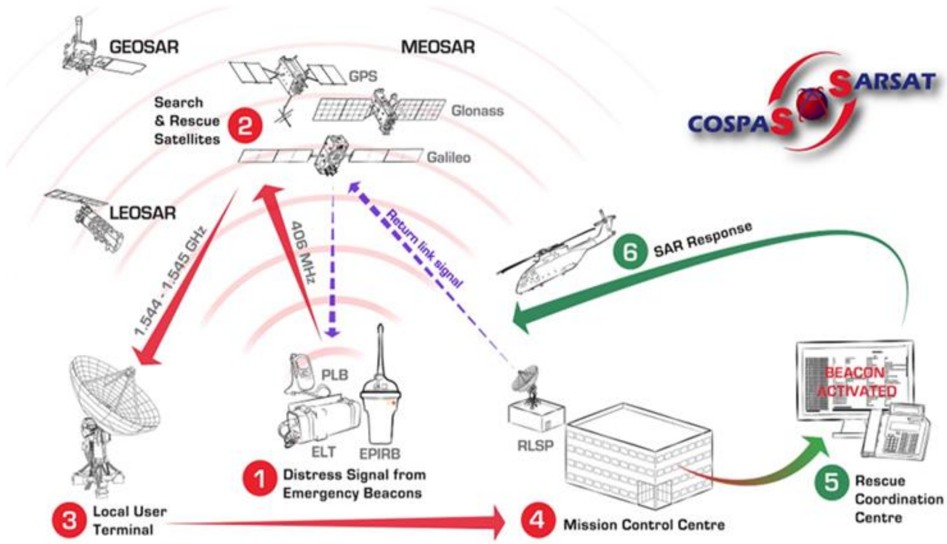


Figure 1: *COSPAS-SARSAT Satellite Search and Rescue System (Sarsat, 2022)*

PLBs can be used in a variety of ways. They can be integrated into personal floatation device (PFD) and activated either in inflation of the PFD, immersion in water or manually. They can be worn on a waist belt and activated manually upon immersion in the water. They can also be carried in a pouch and when the individual wants to use it, they can remove it from the pouch, and it can be activated manually.

Figure 2: *Different PLBs* (International Cospas-Sarsat Programme,2016)

For this study the application of two different PLBs were used. PLB 1 has both its test and activation button on the side of the device, whereas PLB 2 has its test and activation button on the front of the device. For PLB 1 the test button requires depressing it for at least 1 second and then a green light will flash followed by a second long green light and the strobe light. For its activation it requires 1 second and a continuous white flash will go off. For PLB 2 the test button requires it to pushed for 3 seconds and the indicator light flashes once after release. Its ON button requires 2 seconds and will follow by continuous flashing. It should be noted that having both a test and activation button on the device could be confusing to the users, with respect to knowing which one should be depressed when not being able to see the buttons.

The governance structure for emergency radio beacons in Canada is comprehensive and complex. Accident statistics around the world show that when EPIRBs and PLBs are used, the rescue rate increases. However, in Canada significant proportion of maritime activities do not require the use of these devices and it is these sectors where there are a great number of fatalities. It was identified in the Transportation Safety Board of Canada (TSB) 2020-21 annual report that 89% of fatalities in the maritime sector from that year were in the fishing sector and that PLBs/EPIRBs were not used. PLBs/EPIRBs are not required for all maritime activities and in order for distress notifications to be acted upon, the PLB/EPIRB must be capable of surviving the incident, must be correctly activated and must of the signal received by the rescue authorities. These issues relate largely to the governance system which regulates the maritime industry, emergency beacons and radio communications. People involved in maritime survival situations can find themselves exposed to cold water which reduces both their core temperature and the dexterity of their fingers/hands. Activation of a PLB requires that users perform fine manipulative tasks such as deployment of an antenna and pressing a button which may not be visible to them.

False beacon activation refers to unwanted or unintended activation of the device and can occur with both EPIRBs and PLBs. False activation can cause a drain on resources and increase costs as responders are required to first determine if the distress notification is real or not. If this cannot be confirmed, resources must be dispatched to the transmitted location. Although the use of a personal locator beacon is not *required* equipment for fish harvesters, it should be considered a crucial component of maritime life saving equipment. The usability of PLBs during harsh conditions can be a determining factor between a successful or unsuccessful rescue mission.

Given what we know about how cold water reduces manual performance, along with anecdotal evidence from survival training centres that users sometimes struggle to activate PLBs, it is important that we try to understand how humans interact with these devices.

1.2 Main Research Questions

The following questions are of greatest importance in closing the gaps for PLB activation in a maritime environment and they are as follows:

1) Does having cold wet hands as compared to thermoneutral wet hands negatively impact a person's ability to successfully activate commercially available PLBs?

2) Considering button size, texture, and shape, which factor(s) most affect a person's ability to both locate and depress the button when having cold wet hands relative to thermoneutral wet hands?

1.3 Research Hypothesis

It was hypothesized that people with cold and wet hands would find it more challenging to find and depress a button than people whose hands are wet but thermoneutral. This is supported by research (Provins & Morton, 1960, Daanen 2009, M. Ray et al., 2019**)** that when the finger temperature drops below 8°C, there is a reduction in manual dexterity due to the loss of sensitivity. Secondly, it was hypothesized that an activation button which is larger in size, protruding and has a rough texture would be easier to find and depress than a button which is smaller, smoother and either flush or recessed. This hypothesis is supported by previous research conducted by M. Ray et al., (2017) in which it was suggested that manual performance can be improved when using objects which have intrinsic features (shapes, edges, textures) that will prevent slippage from occurring by maximizing grip and object manipulation.

1.4 Human Experiments

In order to investigate the influence of both warm and cold-water hand immersion on the activation rate of PLBs a four-stage experiment was conducted with human participants. For the first stage, participants undertook several standardized tests in order to evaluate dexterity and tactile sensitivity of the dominant hand in a dry thermoneutral state. This was done in order to show whether participants' dexterity and tactile sensitivity was representative of the general population. For the second stage, participants immersed both hands in either cold or warm water and were then asked to activate a commercially available PLB which was obstructed from their view. Participants were given basic instructions about how to properly activate two PLBs. For the third stage, a specially designed and fabricated test apparatus was used, in which a variety of push buttons with different characteristics were mounted on a flat smooth panel. Participants used the index finger on their dominant hand to find and depress as many buttons as possible after a cold-water hand immersion and a thermoneutral water hand immersion (random order). The fourth stage was a retest of the PLB used in stage two with the same water immersion temperature condition as in stage two. Participants were asked to complete a questionnaire after all testing was complete.

It was anticipated that the results obtained from this study would fill some gaps in knowledge in understanding which combination of button design parameters enables an easier activation when a person's hands are both cold and wet. Additionally, the experiments were designed to determine which factor(s) such as button size (large and small), button shape (protruding, recessed, and flat) and button texture (rough and smooth) are the most significant for push button activation rate when a person has cold wet hands. This is important as when PLBs are correctly activated they have the ability to save lives both at sea and on land. Furthermore, this research is beneficial to PLB manufacturers as it will provide new information regarding their design. It can also be used to develop improved regulations governing the design of emergency signalling devices used in cold maritime environments. Additionally, the user community (fish harvesters, recreational boaters) can benefit from the research by improved knowledge about what is important to help ensure PLB activation following cold water immersion. The broad fishing community will be able to improve on the use of safety equipment, their confidence in its use, as well as approaches for better training.

2.0 Literature Review

2.1 Human Experiments in Cold and Wet Environments

2.1.1 Cold Environments

Cold exposure for humans can be a cause of concern as it affects an individual's health, safety, manual work performance as well as their ability to survive. Cold exposure is known for impairing the performance of an individual's manual skills by reducing their finger mobility, grip strength, tactile sensitivity as well as dexterity. M. Ray et al., (2019) identifies factors such as the rate of cooling, the location of the body part which is cooled as well as the nature of a task as factors that all play a significant role on an individual's manual performance in the cold. Additionally, the influence of these above-mentioned parameters on manual performance when exposed to the cold are detailed below (M. Ray et al. 2019):

- Slower rates of cooling lead to a greater decrement in performance than fast rates of cooling for a given skin temperature;
- Peripheral cooling affects manual performance to a greater extent than central cooling;
- The combination of both central and peripheral cooling lead to a more significant impact on manual performance than peripheral cooling alone;
- Tasks which involve the use of fingers are more affected by cold exposure than tasks which involves the use of hands, elbows, or shoulders; and
- Manual performance can still be impaired if either the finger, hand or forearm are independently cooled when other parts of the body are warm.

In order to optimize manual performance, it is important to take into consideration the external factors which contribute to an individual's ability to use their hands. According to R. Heus et al., (1995) manual dexterity is a motor skill in which its range of motion entails a combination of influential factors such as reaction time, sensitivity, nerve conduction, grip strength, time to exhaustion, and mobility. Additionally, the loss of performance of certain tasks when skin temperature is reduced from 24°C to 7°C is shown below in **Table 1**:

Table 1: Task Performance Loss (J. Leblanc, 1956)

Task	Performance Loss (%)
Filling boxes with cubes	11%
Needle and thread through cube	22%
Fastening of screws by hand	26%
Knots in a rope	28%
Fastening screws with a screwdriver	36%
Putting rings around pins	38%

It can be seen in **Table 1** that fine motor skills involving fingers such as putting rings around pins and fastening screws with a screwdriver are manual tasks which represent the highest performance percentage loss in a cold environment at 36% and 38% respectively. This indicates that the function of fingers due to peripheral cooling are more likely to impede skills that involve more fine skills such as precise finger movements as opposed to tasks which focus more on the use of the hands for more gross movements for the manipulation of an object. This is important for the research in this thesis because when using a PLB, precise finger movements are needed in order to push on the activation button and deploy the antenna in an emergency situation.

Daanen et al., (1993) conducted a study which concluded that there is a decrease in finger dexterity at temperatures which are lower than 15℃ when using the Purdue Pegboard shown in **Figure 3**. In the same study, **Figure 4** depicts a graphical representation of the reduction in performance (%) with a wind chill equivalent temperature -15℃ for grip force, hand, and finger dexterity with respect to exposure duration. A study conducted by Fox (1967) also found that manual dexterity deteriorates when the hand's skin temperature is below 8℃. Additionally, Havenith et al., (1992) found that hand cooling reduces both the speed and precision of performing a manual task. Also, that the loss of dexterity in the cold is attributed to the increased viscosity of the synovial fluid of joints, which decreases one's mobility thus their ability to execute manual tasks.

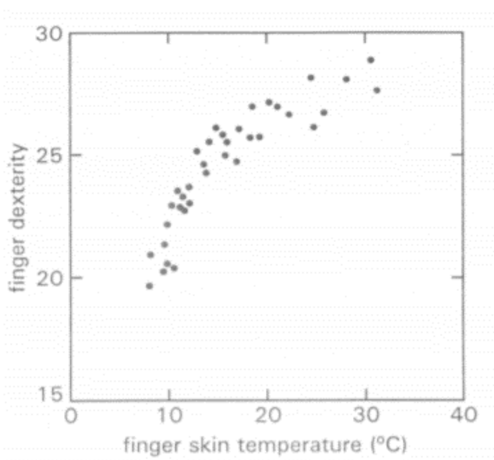


Figure 3: *Relationship between hand skin temperature and finger dexterity score measured by purdue pegboard test* (H. Daanen, 1993)

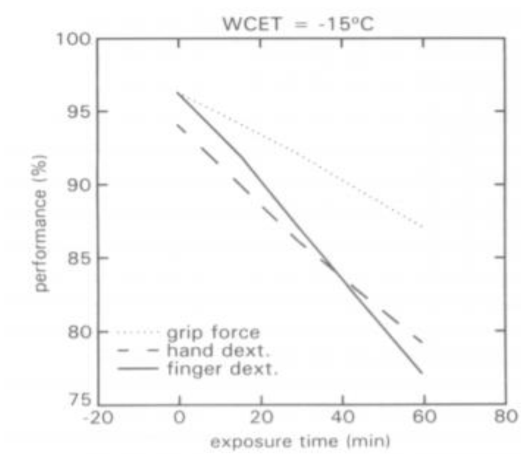


Figure 4: *Performance reduction (%) for grip force and hand and finger dexterity* (H. Daanen, 1993)

According to Daanen et al., (2009) cold exposure may be the cause of an increased number of accidents due to performance deterioration and there are factors which heavily how long this takes to occur. These consist of climatic factors (ambient temperature, wind speed, relative humidity, solar radiation), personal factors (fat insulation, susceptibility to cold, acclimatization), metabolic rate and clothing insulation. Daanen et al., (2009) conducted an experiment to assess manual performance deterioration in the cold using the estimated wind chill equivalent in order to investigate the decrease in finger and hand dexterity, and grip force for nine combinations of ambient temperature (–20°C, –10°C and 0°C) and wind speeds (0.2, 4 and 8 m·s^{-2}) in a controlled chamber. It was found that dexterity was highly related to the wind chill equivalent and exposure duration, and that this duration primarily influenced fine dexterity tasks more than force delivery (Daanen et al., 2009). Similarly, this agrees with the results in **Table 1** above from 1956 where there is a stronger deterioration in the cold involving finger dexterity tasks. In the study of Daanen et al., (2009) it was found that finger and hand dexterity decreased by 12% after being exposed to –21°C wind chill equivalent temperature (WCET) for 25 mins. Additionally, when the WCET was –10°C with an exposure time of 30 mins, the dexterity of fingers and hands decreased 6% and 3% for force deterioration. Overall, it was concluded that finger dexterity is severely impaired when the finger skin temperature drops below 14°C. It can be seen from **Figure 5** below that a finger skin temperature below 10°C, there is a more significant decrease in the finger dexterity, as shown by the Purdue Pegboard test score.

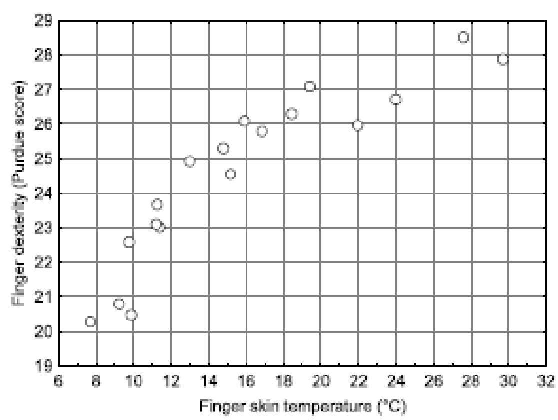


Figure 5*:* *Finger Dexterity vs. Finger Skin Temperature Purdue Pegboard* (Daanen et al., 2009)

With regards to mean skin temperature and its influence on manual dexterity, a study conducted by Tanaka et al., (1983) was completed in order to evaluate the thermal reaction and manual performance during cold exposure while wearing cold protective clothing. In this experiment, subjects partook in a 15 second counting task using a manual counter as fast as possible with their right hand. It was found that there was a strong correlation between the counting task performance and the skin temperatures of the hand, the finger, and the upper arm, mean skin temperature and mean body temperature during cold exposure (Tanaka et al., 1983).

Cheung et al., (2008) conducted two experiments in order to evaluate the effects of local and core body temperature on grip force. The first experiment was evaluating local hand cooling under 8°C, while the second experiment evaluated core body temperature (pre-heated to 0.5°C, pre-cooled to 0.5°C) with cold hands and an individual's ability to perform coordinated grip force tasks for a cylindrical load lifting unit. The results from the first experiment indicated that the tactile sensitivity score from the two-point discrimination test and the score of the Purdue Pegboard test had been reduced, however the grip force increased with a cooled hand during the cylindrical load lifting task. For the second experiment, the core cooling body temperature did not affect the grip force or the temporal coordination for the actions of lifting and grasping for the cylindrical load lifting task (Cheung et al., 2008). However, tactile sensitivity was impaired as well as manual dexterity.

Figure 6: *Cylindrical Lifting Task* (Cheung et al., 2008)

Wiggen et al., (2011) carried out a study on the effects of cold exposure on the manual performance of workers wearing standard protective clothing for when working in a low intensity work environment. In this experiment, subjects were exposed to cold temperatures 5°C, -5°C, -15°C and -25°C. Tests conducted were the Semmes Weinstein monofilaments (tactile sensitivity), Purdue Pegboard, Minnesota dexterity test and a grip test using a grip dynamometer. When finger temperatures were lowered to less than 8°C, participants dropped out of the experiment. This is in accordance with the work of Provins & Morton (1960) in which tactile sensitivity is impaired at temperatures lower than 8°C. The main findings were that for temperatures of -5°C and -15°C with respective exposure times of 50 minutes and 100 minutes, finger dexterity was reduced, since with lower tissue temperatures there is an increased resistance in finger joints which results in reduced mobility (Hunter, 1952). This led the authors to conclude that with temperatures lower than -5°C, manual performance is impaired. However, interestingly with cold temperatures no significant changes in grip strength were found and similar results were yielded for the four temperatures tested.

According to Renburg et al., (2020) exposure to the cold can impair the control of voluntary movement by triggering the shivering response. Renburg et al., (2020) conducted an experiment on the effect of mild whole-body cold stress on isometric force control during hand grip and key pinch tasks which lasted 10 mins. In this study, a group of male participants performed hand grip and key pinch tasks in both 8℃ and 25℃ in a controlled environment. The main findings of the experiment were that manual dexterity is reduced by peripheral cooling, and that induced degradation in manual performance does not seem to be applicable to isometric force control. Additionally, it was identified that the manner in which one responds to cold conditions can differ based on the type of manual task being performed (Renburg et al., 2020).

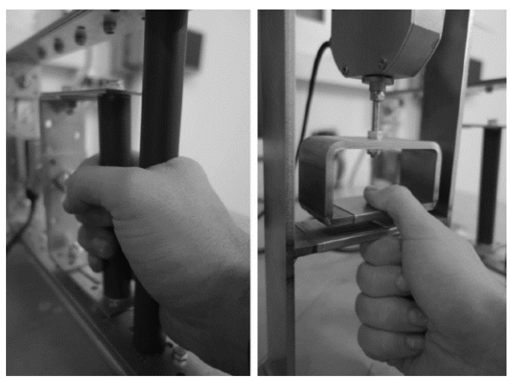


Figure 7: *Experimental Set-up (left hand grip, right: pinch task),* (Renburg et al., 2020)

Some examples of additional studies which evaluated the adverse effects of cold exposure on manual performance are outlined below in **Table 2** (Ray et al., 2019) :

Table 2: *Effects of Cold Exposure on Manual Performance* (M. Ray et al., 2019)

Effects of Cold Exposure on Manual Performance		
Study	**Main Objective**	**Main Findings**
Clark (1961)	Investigated the effect of the influence of cold exposure duration and hand skin temperature on finger and hand dexterity using a knot tying test	A reduction in manual performance was found with hand skin temperatures less than 12.7℃ and 15.5℃ for hand temperature
Clark & Cohen (1960)	Investigated the effect of fast versus slow cooling rates for finger and manual dexterity performed using a know untying test	Slow cooling resulted in a larger decrement in manual performance than faster cooling
Gaydos (1958)	Investigated the effect of cooling the body while maintaining normal hand temperatures on manual performance (tests included knot tying and block stringing)	Hand temperature plays a key role in fine manipulation and that the body can be cooled to an uncomfortable temperature while not affecting manual performance if the surface temperature of the hands is maintained. Reduction in dexterity with hand skin temperature (10-13℃)
Hunter et al. (1952)	Investigated the effect of cold exposure on finger speed movements (joint viscosity)	Found that when fingers were cooled to 12.2℃ finger flexion is reduced
Lockhart (1966)	Investigated the effect of peripheral cooling versus central cooling and the combined effect of both on finger dexterity and manual performance using knot tying, block stringing and block packing	Concluded that cooling the hands impaired performance more than central cooling in 2/3 of the tasks and the combined cooling of the hands in combination with central cooling represented the most impairment for tasks. Central cooling caused insignificant impairment
Lockhart et al. (1975)	Investigated whether cold exposure has a more significant impact on finger dexterity or manual dexterity	Finger dexterity is more strongly impacted than manual dexterity
Riley and Cochrane (1984)	Investigated the effect of ambient temperature on manual dexterity, finger dexterity and tapping	Concluded cold exposure impaired manual and finger dexterity but not tapping
Rogers and Noddin (1984)	Investigated the effects of different levels of cold exposure on tapping, aiming, wrist and finger speed , finger, and manual dexterity	Concluded finger and manual dexterity was affected, however tapping, reaction times and aiming was not
Bensel and Lockhart (1974)	Investigated manual dexterity during whole body cold exposure as a function of time to cold induced vasodilation response and performed finger and manual dexterity tests	Manual performance tasks were affected by -6.7℃ ambient temperature , skilled movements involving wrists and fingers were the most impacted and cold exposure impaired manual performance

An important point which was addressed in Ray et al., (2019) review paper of cold exposure and manual performance is that there is limited research regarding studies on open tasks. Open tasks account for the variability in the environment and as a result can increase complexities regarding task performance due to the nature of the dynamic conditions which can be experienced. Most research involves closed task conditions in which a predictable and controlled environmental setting is established and subjects are, for the most part, performing tasks with limited body movement and orientation; often stationary.

Ray et al., (2019) identified that a greater understanding of manual performance in the cold with respect to body orientation, body transport and body stability should be further examined, since in a dynamic environment increased cognitive and motor demands are often needed for manual tasks. With respect to PLBs used at sea, the environment is often unpredictable and unsettling, which can put a strain on an individual's ability to perform manual tasks. For example, if one were to fall overboard, high winds, waves and the combination of a cold and wet environment can contribute to the decrement of an individual's manual performance. Thus, such circumstances should be considered in research studies.

2.1.2 Training in the cold

Training, in particular, is of great importance for an individual's safety as well as their ability to perform manual tasks in a cold environment. Especially, with regards to survival skills necessary in emergency situations, as well as the skills required for everyday work performance. A potential lack of experience with training in cold environments and a lack of suitable emergency response equipment under diverse and rapidly changing weather conditions could potentially contribute to the quick escalation of an incident. Individuals must be capable of performing a desired task in the range of environmental conditions which could be encountered.

A person's knowledge and preparedness of how to manoeuvre a challenging and life-threatening cold exposure situation is vital to improve chances of survival. For instance, in a marine setting on a vessel, an individual should be familiar with the procedures and equipment in place, and they should have a full understanding of the system's functions and capabilities. Regarding the use of a PLB, an individual should feel comfortable operating the device in both a cold and wet environment. This environment can place additional constraints on an individual's manual performance capabilities (decrement in manual dexterity and sensitivity); thus, training should allow for an understanding of the skills required for its effective use, in order to develop means to enhance user success and operability.

Shephard (1985) states that if complex manual tasks are to be performed in cold environments there is a need for training in these cold exposure conditions in order to allow for adaptation and acclimatization. Additionally, complex tasks in cold conditions would involve more training and would impose greater control demands and are more sensitive than simple tasks (Pilcher et al., 2002). According to Shea & Morgan (1979) motor learning research demonstrates that switching between tasks randomly is better than performing only one task alone for a series of trials. However, Hebert et al. (1996) identifies that performing only one task, considered blocked practice, may be more beneficial for individuals if a lower skill set is required. Porter & Magill (2010) suggest that starting with low levels of contextual interference and gradually increasing this level throughout training can facilitate better retention practices as well as the transfer of motor skills. Thus, for the usage of a PLB the impact of its design should be explored, especially regarding how it can contribute to an increase in its operability and whether this would entail more or less training and how often training is required for improved skill retention and application.

An interesting point made by Ray et al. (2019) is that an additional factor which should be considered for increasing the transfer of training for a target environment is practice specificity effects. Ray explains that individuals can rely on the type of sensory information that is available and when alternate sources of sensory information in training is different than normal use, it can lead to a performance decrement. Similarly, he suggests that if a group is trained solely in a warm environment to perform manipulative tasks, this group would suffer a greater performance loss than a group which altered between a variety of thermal conditions, since doing so allowed them to be more flexible with sensory information needed for their performance. Furthermore, Ray et al. (2019) identified that open tasks in a demanding environment will require variable practice and multiple variation of a motor skill. Thus, while training in a variety of temperature conditions, trainees would have to adapt to changes required for their performance such as finger mobility and force production. This is applicable to PLB use, since PLBs will be used in a range of environmental condition which pose different challenges than a conventional closed task setting.

Clark & Jones (1962) investigated manual performance during cold exposure as a function of practice level and the thermal conditions of training. The effects of thermal training conditions involving varied thermal experience for warm or cold hands was assessed on the basis of a successive knot tying test. It was found that training reduced the size of performance decrement associated with cold exposure, however the continual cold experience did not. It was concluded that if cold experience had been facilitated early in learning, the reduction in performance was found to be less than if learning was received later. It was suggested that a subject should learn not solely how to perform a given manual task with cold or warm hands in particular, but to alter the temperature conditions for performance, since doing so can ensure minimal effects of cold exposure, while ensuring an acceptable performance when experiencing optimally warm temperature conditions (Clark & Jones, 1962).

Immink et al. (2012) examined the role of temperature on motor skill learning. In this study, subjects used an isometric precision grip task with forehand temperatures of 40℃ to 45℃ or 10℃ to 15℃. The results of the study demonstrated that learning based performance is dependant on the reinstatement of temperature conditions present during practice. It was found that conflicting temperature conditions during training and testing resulted in motor performance decrements.

Muller et al. (2011) conducted the test and retest reliability of a Purdue Pegboards performance in both cold ambient conditions (5℃) and thermoneutral conditions (25 ℃). The main objective of the study was to determine whether thermoneutral performance can predict cold performance. It was found that room temperature performance did not affect the performance in the cold. It was recommended that a 60-minute time period be used for cold exposure to reduce finger temperature in order to evaluate manual dexterity for workers (Muller et al., 2011). Additionally, a study conducted using Purdue Pegboard in 1984 by Riley and Cochran demonstrated that exposure to 1.7 ℃ air for a 60-minute duration caused a reduction in Purdue Pegboard performance when compared to room temperature performance. It was also noted that the Purdue Pegboard is a simple task and that more complex tasks could show a different outcome in the cold (Mullet et al., 2011).

Oksa et al. (2006) executed an experiment to assess how training for disassembling and assembling a weapon (rifle) and patrol data message terminal as well as loading a pistol magazine in different temperatures impacts the performance of military skills in a cold environment. This involved training in warm conditions (19℃), cold conditions (-15℃) as well as the combination of warm and cold conditions. The main findings were that training first in a warm condition and then in a cold condition reduced performance time from 6% to 28% as opposed to training solely in a warm environment (Oksa et al., 2006). Also, training in cold conditions enabled subjects to be faster than in warm environments. It was identified that training only in a warm environment resulted in the lowest level of performance in a cold environment and that there was no difference under the laboratory conditions how long it took the groups to learn the different skills It was recognized that both training and adaptability to the cold play a vital role in the ability to perform motor skills and that training first in a warm environment and then a cold environment can be considered preferential.

King et al. (2020) investigated whether training in the cold could improve performance in cold conditions. In this study the effect of both cold water and thermoneutral training was evaluated by the performance of the Grooved Pegboard task. This was achieved by immersing the hand of the participants in cold water (2℃) and in thermoneutral water (34℃). The main conclusion drawn from this study was that cold training improved dexterity but not task speed (King et al., 2020).

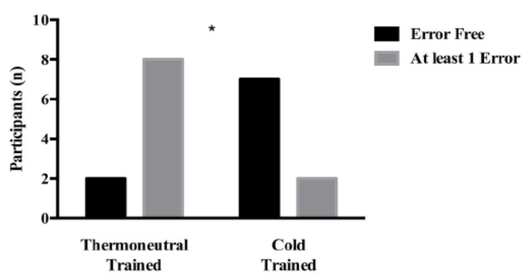


Figure 8: *Thermoneutral and Cold Trained Groups* (M. King et al., 2020)

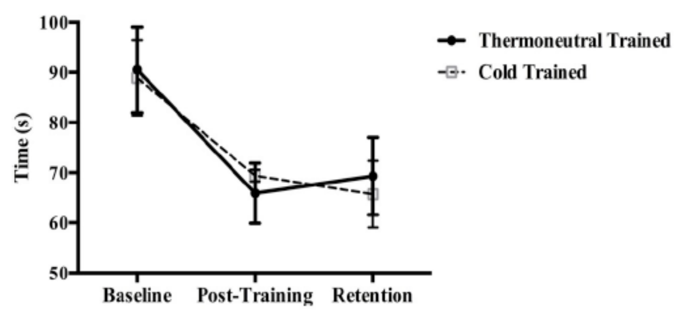


Figure 9: *Performance of Grooved Pegboard Task* (M. King et al., 2020)

It can be seen from **Figure 9** above that for the cold trained groups there were few subjects in the Grooved Pegboard task which had at least 1 or more errors, which shows that accuracy was enhanced by cold training. According to Marteniuk & Wenger (1970) this notion is supported since practicing motor tasks in cold environments was shown to improve performance later in the cold. Furthermore, Hordacre et al., (2016) support the notion that cold stress during training can enhance learning. **Figure 8** above shows that for the retention of cold trained groups their performance for the Grooved Pegboard task was slower with a more delayed retention than the thermoneutral trained groups.

2.1.3 Wet Environments

People who work in a maritime environment will experience both cold and wet conditions which will influence their task performance, especially regarding their manipulative abilities and actions. Fish harvesters will often immerse their hands in water when performing tasks such as pulling lines, nets, and other equipment out of the water (Ray et al., 2017). Additionally, finger dexterity and fine manipulative tasks are of great importance for occupational tasks or for accessing and using safety equipment in a situation of distress. This is relevant for the usage of PLBs since object manipulation is required for grasping the device and the use of fine finger motor skills is required to both configure and activate the device.

Skin friction and hydration are influencing parameters on an individual's manual performance when their hands are immersed in water. Daanan et al., (1993) denotes that the heat loss of wet hands is equal to twice the heat loss of dry hands in still air, and three times the heat loss when wet and exposed to windy conditions. When an individual's hands are immersed in water the coefficient of friction can be reduced, leading to the requirement of higher grip forces to grasp and manipulate the object (Lefevre & Thonnard, 2009). Ray et al. (2017) identifies that perhaps when skin friction increases as well as skin hydration that the immersion duration itself can be seen as an independent entity which contributes to the manner in which hand manipulability is influenced by hand immersion. Additionally, tactile sensitivity is considered an influencing factor for manipulative actions since grip force adjustments due to changes in friction depend on tactile sensitivity.

Cheung et al. (2003) investigated the changes in manual dexterity due to short-term hand and forearm immersion in 10°C water. The main objective of this study was to understand the amount of time it takes for manual dexterity impairment, especially during the initial stages of immersion. This is important as it can aid with the design of survival equipment and protective clothing for maritime applications. The main results of the study showed that short-term cold immersion impaired both fine and gross manual dexterity. Purdue Pegboard test result scores decreased significantly after 300 seconds of immersion. This shows that impairment of manual dexterity occurs within the first 5 minutes of cold-water immersion. Cheung et al. (2003) attributes this impairment to the reduction in receptor sensitivity, joint viscosity, blood flow, muscle contractility and skin surface nervous conduction.

Ray et al. (2019) examined the timeline for hand function following exposure to 2°C water in order to better understand the timeline for hand function, especially regarding its sufficient duration for occupational tasks and the manual skills needed for performing in a cold-water environment. For the fine manual dexterity assessment, Purdue Pegboard was used and for tactile sensitivity the Touch-Test and Semmes Weinstein monofilaments were used. Tactile sensitivity and dexterity were evaluated every 30 seconds. It was found for both fine manual dexterity and tactile sensitivity, impairment occurred after being immersed in cold water for 90 seconds. However, for the entire group of participants, the index finger temperature dropped below 8°C between 90 and 120 seconds when, which represents the critical temperature threshold. This temperature threshold causes a reduction in manual dexterity and tactile sensitivity in accordance with previous research (Heus et al., 1995; Fox, 1967).

Ray et al. (2017) conducted an experiment in order to investigate the influence of hand immersion on manual performance. The main objective was to explore whether immersing one's hand in thermoneutral water affects manual performance and tactile sensitivity and whether the duration of hand immersion influences these parameters. The Purdue Pegboard, Grooved Pegboard, reef knot untying and Touch-Test were used to assess performance. The tests consisted of short exposure immersion (10 seconds), long exposure immersion (10 minutes) and no water immersion. It was found that tactile sensitivity was not affected by hand immersion, however some motor tests (Purdue Pegboard, reef knot untying) were affected. In particular, the Purdue Pegboard demonstrated a 11% performance decrement for short exposure and an 8 % for long exposure. The time of the reef knot untying task increased by 15% for short exposure for the duration of the task. The Grooved Pegboard task did not show a performance decrement for hand immersions. According to Ray et al. (2017) this is because the edges of grooved pegs make them easier to manipulate compared to round pegs in the Purdue Pegboard which are smooth. Thus, manual performance can be improved when using objects which have intrinsic features (shapes, edges, textures) that will prevent slippage from occurring by maximizing grip and object manipulation.

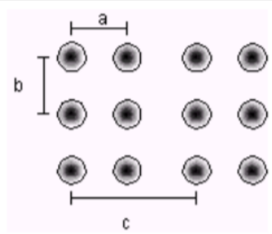
Ray et al. (2018) examined the combined effect of cold and moisture on manual performance and tactile sensitivity. In this study, subjects performed tactile sensitivity and motor assessment with dry hands, wet hands, cold and dry hands, and finally cold and wet hands. In order to evaluate manipulative performance, the Purdue Pegboard test, the Grooved Pegboard test, and reef knot untying test was used. For tactile sensitivity, the Touch-Test and the Two-Point Discrimination test were used. The study demonstrated that the combination of cold and moisture affected manual performance more than either a cold or wet condition individually. For the Grooved Pegboard test the cold caused a performance decrement but hand moisture did not. For the Purdue Pegboard and knot untying tasks, the cold and wet hand condition showed the largest performance loss. For tactile sensitivity, the Touch-Test showed there was no difference between the cold and wet hand condition to the cold hand condition and for the two-point discrimination test that tactile sensitivity was not reduced in the cold. Similarly, to the study by Ray et al., (2017), it was recommended to design tools with ridges, bumps, grooves, and high friction coatings to prevent them from slipping. Additionally, it was addressed that task complexity and the rate of cooling are parameters which can interact with both cold and hand moisture, but further research is needed in this area (Ray et al., 2017).

Morrison & Zander (2008) conducted a study in order to evaluate the effects of pressure, cold and gloves on hand skin temperature and manual performance of divers. As part of the experiment for the assessment of tactile sensitivity, enlarged Braille characters were used. The divers had to feel and identify the Braille characters by touch while viewing a display of Braille characters as a reference source. In this case, Braille characters were presented on a board in four rows, and in each row the size of the characters was reduced. For measuring tactile sensitivity, the total number of characters needed to be correctly identified in a 4 minute per row time span. It can be seen from **Table 4** that the second largest braille tab size (6.5 mm) scored the highest for the tactile sensitivity score for 4℃ water submersion. When divers were asked to rate their preference in tab space the second large character size was preferred over the smaller 3.5 mm tab size. Overall findings of the study showed that neoprene gloves do not provide adequate thermal protection in 4C water, and that impairment of manual performance is dependent on the type of task, depth, and exposure time (Morrison & Zander, 2008).

Table 3: Effect of row (braille size and spacing) on tactile sensitivity score when wearing neoprene gloves in cold water (J.B. Morrison & J.K. Zander, 2008)

Tactile Sensitivity Score (4 °C water)									
Tab Size (mm)	Spacing (mm)	0.4 msw				40 msw			
11	28.0	3.9±2.1				4.0±2.4			
6.5	16.0	4.6±3.6				4.6±3.8			
5	12.5	2.7±2.6				3.3±4.0			
3.0	7.5	0.33±0.5				1.4±2.2			
		0.4 msw				**40 msw**			
Statistics		F	Sig.	η^2	Power	F	Sig.	η^2	Power
main effect		11.0	0.00	0.6	1.0	4.6	0.00	0.4	0.8
Regression		$y = -0.2x^2 + 2.7x - 6.4$				$y = -0.1x^2 + 2.1x - 3.7$			
		$R^2 = 0.98$				$R^2 = 0.99$			

Table 4: Size and Spacing of Braille Characters for Tactile Sensitivity Test (J.B. Morrison & J.K. Zander, 2008)

Diagram of characters	**Tab Size and Spacing**				
	**Dimension**	**Row 1 (mm)**	**Row 2 (mm)**	**Row 3 (mm)**	**Row 4 (mm)**
	Tab Base	11	6.5	5.0	3.5
	Tab Height	5.0	3.5	3.0	2.5
	A	28	16	12.5	7.5
	B	28	16	12.5	7.5
	C	70	42	31	18

2.2 Manual Performance and Activation

2.2.1 PLB Activation

Operability of a PLB in an emergency situation is of paramount importance to notify rescue authorities that help is required. In a maritime setting, an individual may be exposed to both a wet and cold environment, so being able to properly activate a PLB is crucial. According to the National Search and Rescue Secretariat (2000) "the PLB shall be capable of being activated by one person with mitts in thermal extremes, rain, ice, spray, packed snow, and dirt. Its activation and deactivation of the shall be performed manually." Additionally, the PLB should not be accidentally activated by environmental extremes and therefore the activation button of the PLB should be encased and secured inside the product, appearing as untouchable and inaccessible so accidental activation can be avoided. When an individual becomes immersed in water their response for activating the beacon must be quick and at the same time they may not have the ability to see the buttons due to splashing of oncoming waves or darkness of the night. As such it may be difficult for an individual in these circumstances to see the buttons and to distinguish where the activation “ON” button is located versus the “TEST” button. Therefore, button size, shape and texture are factors which contribute to a successful beacon activation.

2.2.2 Push Button Design and Arrangement

The push button is one of the most commonly used control devices and studies have been carried-out to quantify some of the important parameters of a push button design such as diameter, resistance, displacement and the spacing between buttons. According to Kantowitz & Sorkin (1983) the accessibility, ease of use, safety and freedom of error are the four most important operational requirements of any pushbutton. Zwahlen (1993) evaluated push button arrangements in automobiles and identified that when a push button arrangement is correctly designed it should minimize activation time, foveal eye fixation times as well as errors resulting from fewer repeated pushes. In his study, a model was developed so that a designer could determine the size, spacing and shape of push buttons (round, square and rectangle) based on the desired probability level for pushing the correct button using a fingertip width.

Zwahlen (1993) recognized that the spacing of push buttons in recent automobile dashboards has decreased, thus designing smaller buttons which are closer together will require more eye concentration to find the buttons. Zwahlen also noted that there were few studies available regarding the human performance to activate/deactivate a push button in a dynamic environment.

Additionally, there is limited research on the size and spacing of push buttons specifically to improve activation rate.

There is available literature for selected conditions and shapes based on recommended push button sizes and spacing for PC Program Probability values. Diffrient et al., (1981) found that the highest probability of pushing the correct button (99.81% success rate) was found for a square button with a side length of 25 mm, a population percentile value of fingertip width of 50 and a percent of fingertip width of 25. The highest probability of pushing the correct circular button (80.1%) was those with a side length of 3 mm, a population percentile value of fingertip width of 50 and a percent of fingertip width of 12.5. Similarly, Kantowitz &Sorkin (1983), Woodson et al., (1992) and Sanders & McCormick (1993) found that a square button led to a higher probability of pushing the correct button than a circular button and that a population percentile value of fingertip width of 50 and a respective percent fingertip width of 25 is desired for activating the correct button.

Tao et al., (2018) conducted an experiment which examined the effect of different button design characteristics for touchscreen use. For the study, button size, button shape, button spacing, and visual feedback were the parameters of interest. Button sizes were selected between 7.5 mm to 27.5 mm in 5 mm increments, button spacing was either absent, or respective distances of 1 mm and 3 mm, visual feedback was either present or absent, and the button shapes were horizontal and vertical rectangles as well as square shaped (Tao et al., 2018). The study identified that button shape, size and spacing were the most influential parameters on touchscreen use. The most optimal button shape for performance was square in which the medium to larger sized buttons performed the best.

Figure 10 below demonstrates that the completion time for the task decreased as button size increased for the three button shapes (square, vertical rectangle, and horizontal rectangle) and the square button required less time overall. Participants were faster with square buttons than rectangular, likely because square button area is large and is more proportional and easier to depress for the tip of a person's finger than a rectangular button. From the study it was also found that as button spacing increased, the time to complete the task decreased. Also, when button spacing increased the visual search for the buttons could also increased, leading to a longer time to find the button compared to when the buttons were located closer together. As a result, users can type faster for buttons which have not too small spacing as opposed to large spacing (Tao et al., 2018). Sun et al., (2017) found that wearing gloves did not affect the interaction with the computer touch screen except with the smallest buttons and spacing of zero, but interestingly the participants themselves felt that not wearing gloves was better than wearing gloves for performance. There still seems to be limited research on the area of push button shape and design for button activation time, especially regarding buttons which are round.

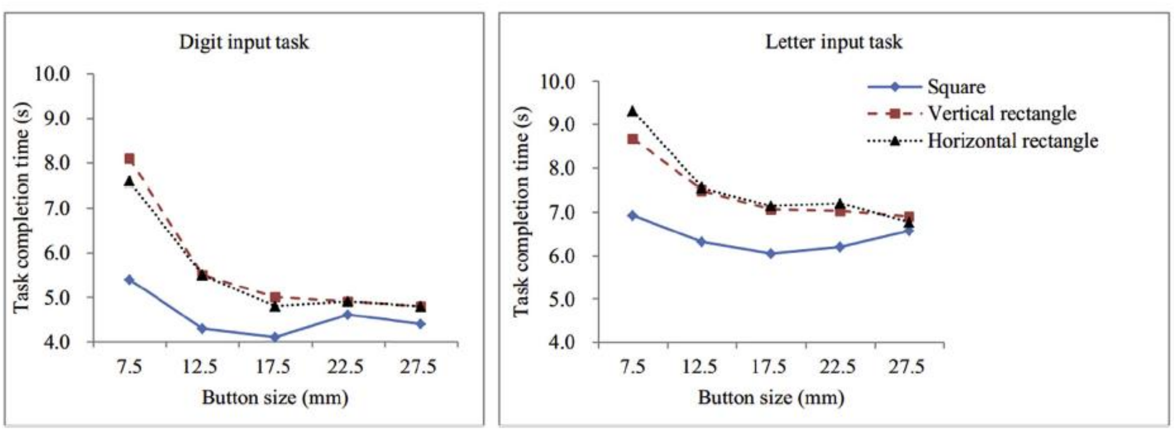
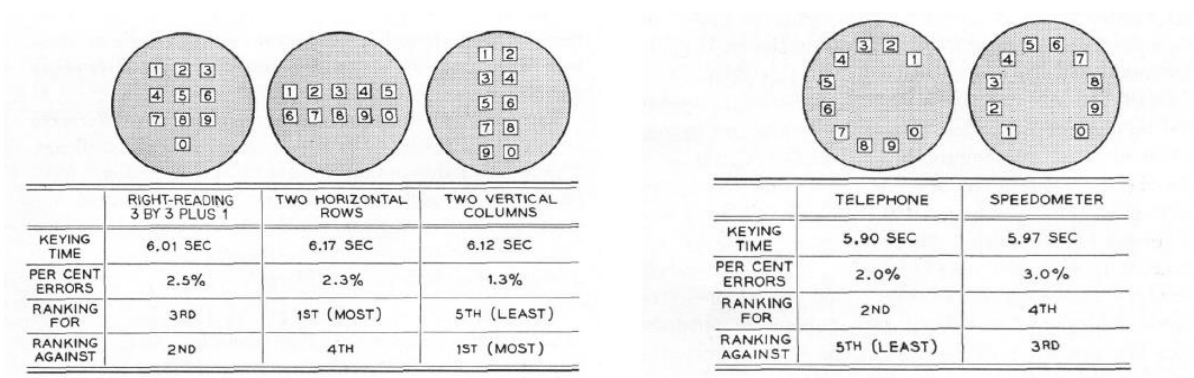


Figure 10: *Task Completion Time vs. Button Size* (D. Tao et al., 2018)

Different push button arrangements for keysets and their associated operating characteristics can affect user preference as well as keying performance. Other parameters which influence keying performance are practice, number length, display media and the familiarity with the telephone number (i. e. the required sequence of the buttons) being used (Deininger, 1960). Deininger (1960) investigated desirable push button characteristics for push button keysets, focusing on push button arrangements, button top and lettering characteristics as well as the force displacement characteristics of the keysets. This was investigated in order to identify which type of keysets individuals could use accurately and easily for push button telephones.



	RIGHT-READING 3 BY 3 PLUS 1	TWO HORIZONTAL ROWS	TWO VERTICAL COLUMNS
KEYING TIME	6.01 SEC	6.17 SEC	6.12 SEC
PER CENT ERRORS	2.5%	2.3%	1.3%
RANKING FOR	3RD	1ST (MOST)	5TH (LEAST)
RANKING AGAINST	2ND	4TH	1ST (MOST)

	TELEPHONE	SPEEDOMETER
KEYING TIME	5.90 SEC	5.97 SEC
PER CENT ERRORS	2.0%	3.0%
RANKING FOR	2ND	4TH
RANKING AGAINST	5TH (LEAST)	3RD

Figure 11: *Five Push Button Arrangements* (L. Deninger, 1960)

It can be seen that of the five different push button arrangements depicted above, the circular telephone arrangement resulted in the lowest amount of keying time of 5.90 seconds and the two horizontal rows arrangement resulted in the highest keying time of 6.17 seconds, respectively. However, the keying time between the 5 keying arrangements is quite similar. The most preferred design for the users was the two horizontal rows of push buttons. Additionally, in this study, with respect to push button size it was determined that keying with the smallest button top (3/8"x3/8") was worse than keying with the middle-sized top (1/2"x1/2") and keying with the largest top (5/32"x3/4") was in the middle (Deininger, 1960). Additionally, in this study it was found that by increasing the dimensions of a square button from 0.37 inches to 0.69 inches, the keying time decreasing from 6.35 to 5.83 seconds and the error of pushing adjacent buttons decreased from 7.1% to 1.3 %. Participants referred a button spacing of 0.75 inches (for the two horizontal rows of push buttons) over 0.84 inches.

In this experiment, some of the participants memorized all the digits before keying them in, where others did not memorize and read from the display. In this case the results with respect to keying time differed between the participants, with the faster keying times from individuals who memorized the digits. In order for there to be consistency in the results, all should have keyed the digits while reading them as opposed to memorizing the digits before keying them in. Also, it should be recognized keying experience plays a role in the keying time results.

Lei et al., (2019) conducted a study with Braille reading which demonstrated that the physical characteristics of tactile input can influence behavioral aspects associated with reading Braille. It was found that at a lower Braille height dot condition there were slower reading rates and an increase in a repeat in regressions as opposed to a medium dot height condition and the high dot condition. Thus, it was found that by reducing the physical intensity or clarity of the visual input signal ultimately resulted in decreased performance during reading (Lei et al.,2019).

2.2.3 Push Button Activation Performance

According to Kim et al., (2018) modern buttons are typically engineered for comfort, speed, and reliable activation. The activation of the button itself is defined as the depth at which it generates a signal. For the most part buttons are activated by a downward stroke within the first 20 ms of the button being pressed and can have a total duration of 100 ms (Kim et al., 2018). This study shows that impact activation of a button proves more effective for a rapid and repetitive button pressing, especially when the button is depressed at its optimal impact point. This can, as a result, improve the performance success rate for pressing a physical button. The experiment by Kim et al., (2018) used just two different button designs (physical button and touch button) but more buttons could be used for future research. The impact activation is deemed to be beneficial due to the stronger stimulation of the fingertip allowing the human motor system to calibrate its outputs better in the fast-tapping task (Kim et al., 2018).

Oulasvirta et al., (2018) conducted a study on the neuromechanics of four different types of push buttons which included linear, tactile, touch and mid-air push buttons. A linear button is one which is smooth and produces little noise, whereas the tactile button has a small bump and produces moderate noise. It was found that the linear button had an activation time of 52 ms, a perceptual error of 47 ms, a peak muscle force of 1.65N and an activation success of 92 percent, whereas the tactile button had an activation time of 43 ms, a perceptual error of 40 ms, a peak muscle force of 1.41 N and an activation success of 82 percent (Oulasvirta et al., 2018). This shows ultimately that the tactile push button required less force and less time for activation in comparison to the force and activation time required for the linear push button. This indicates that the tactile button was the easiest button to activate.

Figure 12 shows the motor system with respect to activating a push button. It shows that low error for button activation occurs when the estimated and perceived activation occur almost simultaneously. The high error for push button activation is represented by a greater difference between the perceived activation and the expected perceived activation.

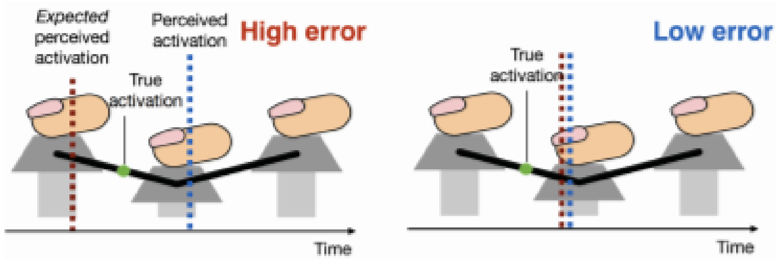


Figure 12: *Perceptual Control of a Push Button* (Oulasvirta et al.,2018)

2.2.4 Push Button Activation Force

In keyboard design, the key characteristics are measured from their associated force and travel parameters. When a key is depressed, the key travel distance is the difference between when the key is at rest and the point at which the button is depressed to the bottom. Often, the force exerted on the keys exceeds the amount of force needed to activate them and according to Armstrong et al., (1994) this could range from 2.5 to 4.6 times the needed amount of activation force. According to HFES (1988), key activation force ranges between 0.25 and 1.5 N with a key displacement between 1.5 and 6.0 mm.

Radwin & Jeng (1997) conducted a study on the activation force and travel of key switch design parameters to investigate the overexertion in repetitive key tapping. The experiment examined the index finger of the dominant hand when used to depress a single key as swiftly as possible with visual and auditory feedback provided to the participant upon successful key activation. Results showed that having more key over travel from a distance of 0 to 3 mm required less force during key tapping tasks. It was determined that key tapping rate significantly increased when the key activation force decreased from 0.71 to 0.31 N and the minimum peak exertion force and maximum key-tapping performance occurred when make force was 0.31 N and over travel was 3.0 mm

(Radwin & Jeng, 1997). Ultimately, reduced exertions when over travel is increased can result from the small increment in force from the over travel while the finger decelerates against the resistance of a spring (Radwin & Jeng, 1997). Similar to a keyboard key, the button of a PLB could require a greater force for activation depending on its button style (e.g., concave, convex or flat).

2.2.5 Haptic Perception

For everyday object manipulation, human sensing for perceiving a surface texture is fundamental in order to accurately identify an object. Haptics is divided into two main sensory modalities, which are kinesthesis and tactile sense. According to Tzafestas (2003), kinesthesis involves the perception of muscular effort and tactile sense involves cutaneous information from the contact/interaction of the human skin and an external environment. As such, this enables perception of the touched objects surface characteristics and texture. With regards to a PLB, an important button parameter related to activation would be the tactile sense so that an individual can recognize the activation button to be able to depress it when needed. In this case, the texture of the button and the size and shape of the button are important physical properties to consider for ease of activation. Klatzky et al., (2013) states that perceiving the material properties of objects through touch is more important than the perception of shape. In addition, the fingertips can sense a raised element at a height of a micrometer and, as such, can distinguish smooth surfaces from textures made by submicrometer elements (Klatzky et al., 2013). Perceptual properties associated with the sensations from touching a material’s surface can be categorized as rough, slippery, compliant, warm, and cool. For a PLB, perceptual properties to be considered would be roughness of the buttons, also slipperiness and temperature when the device is wet.

Haptic roughness perception is commonly studied with a task named *magnitude estimation* in which a number representing an intensity of roughness is assigned to a surface and is felt by the individual after the object has been touched. Through this magnitude estimation, it can be established how roughness varies depending on object surface geometry and the density and shape of its textural elements. With respect to a PLB, tactile roughness perception is associated with the physical characteristics of the device such as button surface texture, spacing between buttons, the height of the buttons, and the height of the surface elements of the button shape. Kahrimanovic et al., (2009) conducted a study on the haptic perception of roughness through two different experiments. In the first experiment, participants examined different dot patterns in which distances between the dots varied. This enabled the researchers to investigate the effect of rough and smooth adaptation levels for the perceived roughness of a subsequently examined surface. The second experiment involved a rough or smooth inducer stimulus which was felt with one finger and then the effect of roughness perception with an adjacent finger was analyzed (Kahrimanovic et al., 2009). From the first experiment it was found that adapting to a rough surface decreased the perception of a surface scanned subsequently with the adapted finger. However, adapting to a smooth surface increased the perceived roughness of surfaces scanned before the smooth surface.

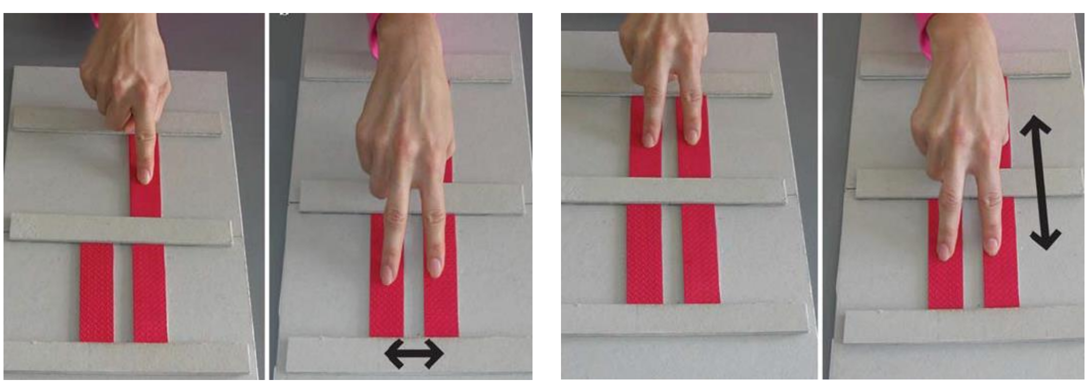


Figure 13: *Haptic Perception of Roughness Experiments* (M. Kahrimanovic et al., 2009)

A study carried out by Lederman & Taylor (1972) investigated fingertip force, surface geometry and the perception of roughness by active touch. It was found that perceived roughness of a grooved metal plate increased when the fingertip force increased and when wider groves were used. The main finding was that roughness really depends on the force applied between the fingertip and the metal surface. Depicted in **Figure 14** below is a graphical representation of perceived roughness versus true groove width with 3 different fingertip forces. It shows the greatest perceived roughness is with the highest fingertip force, and with the largest groove width.

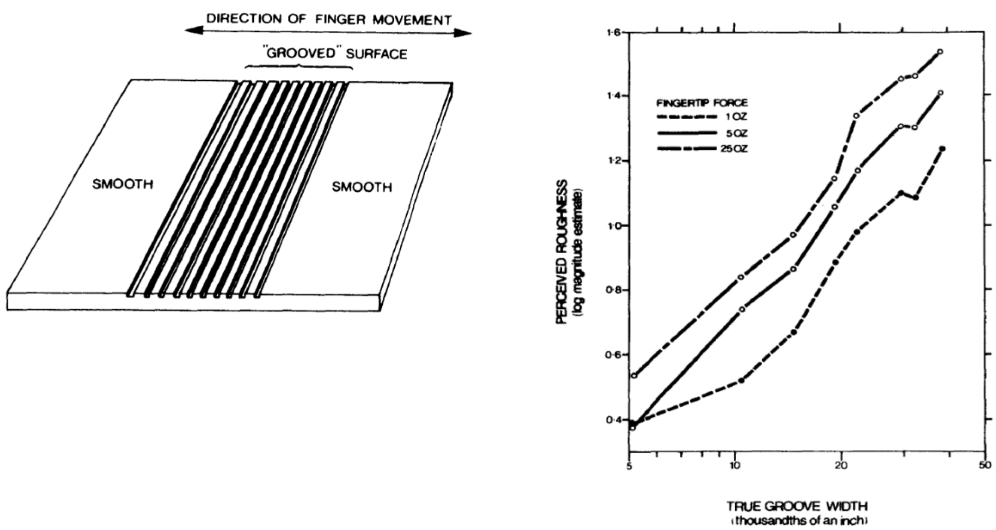


Figure 14: *Perceived Roughness vs. Groove Width* (Lederman & Taylor, 1972)

Headley & Pawluk (2011) investigated the roughness perception of textures on a haptic display matrix in order to understand how individuals who are visually impaired perceived texture on a matrix display. The experiments examined the influence of groove width, ridge width and area (number of pins) on the perceived texture. It was found that ridge width, groove width and contact area were all significant parameters contributing to the sensation of roughness and that magnitude of sensation of roughness increased when contact area increased (Headley & Pawluk, 2011).

Kayawari et al., (2014) conducted a study to evaluate the hardness of silicone rubber buttons based on tactile and visual information. Based on tactile information only, when the six different levels of thickness were used for the silicone buttons depicted in **Figure 16**, it was found that thicker buttons were perceived as softer, but when the participants had visual information and could see the buttons, the opposite occurred, and thinner buttons were perceived to be softer. Another experiment using 9 silicone pieces of different hardness showed that when the hardness value was 60 degrees or lower with a difference of hardness value of 5 it was easier to distinguish the difference in hardness than when exceeding 60 degrees. In the case of the button design on a PLB, perhaps the amount by which the buttons are protruding or recessed could influence the hardness, which is felt, and the amount of force needed to depress a button. The way that participants touched the buttons, whether it was by stroking them with finger movements or pushing on them, could attribute to the quality of the object rather than the object's hardness (Kayawari et al., 2014).

Figure 15: *Evaluation Silicone Button Tactile Sense Only* (T. Kavawari et al.,2014)

Figure 16: *Nine Silicone Buttons of Varying Hardness* (T. Kayawari et al., 2014)

Moore (1974) examined the tactile and kinaesthetic aspects of push buttons, especially highlighting the importance of button design and layout when visual identification of the buttons is not possible. The focus of the study was on push buttons used for primary control of industrial equipment. Normally, these buttons are 1 to 3 cm in diameter with flat, domed (protruding), or dished (recessed) surfaces. For emergency stop buttons, domed (protruding) surfaces allow for a larger surface to depress (Moore, 1974). The 25 different button shapes used by Moore for testing tactile discrimination are depicted below in **Figure 17**. In the study, the shapes of the push button surfaces used six different control functions (start, stop, delayed stop, inch, slow and reversed) while the subjects were blindfolded. It was found that the preferred start buttons were dished in the centre (recessed) and the preferred stop buttons were raised in the centres (protruding). The most recommended button for start was button 24, and for stop was 23. The study recommended that button tops should be distinguished by touch and gross shape, covering an area which could be touched by one finger, and the shapes used should neither be uncomfortable nor difficult to depress. Additionally, tactile push buttons must be distinguishable from the surface upon which they start, as well as from each other, especially for buttons with a large surface area, the shapes should be recognizable without prolonged search. Moore (1974) indicated that in previous research of tactual discrimination of numerals, geometric forms, and letters, psychologists found that when a subject could move their fingers on the shape's surface, an increased accuracy was observed.

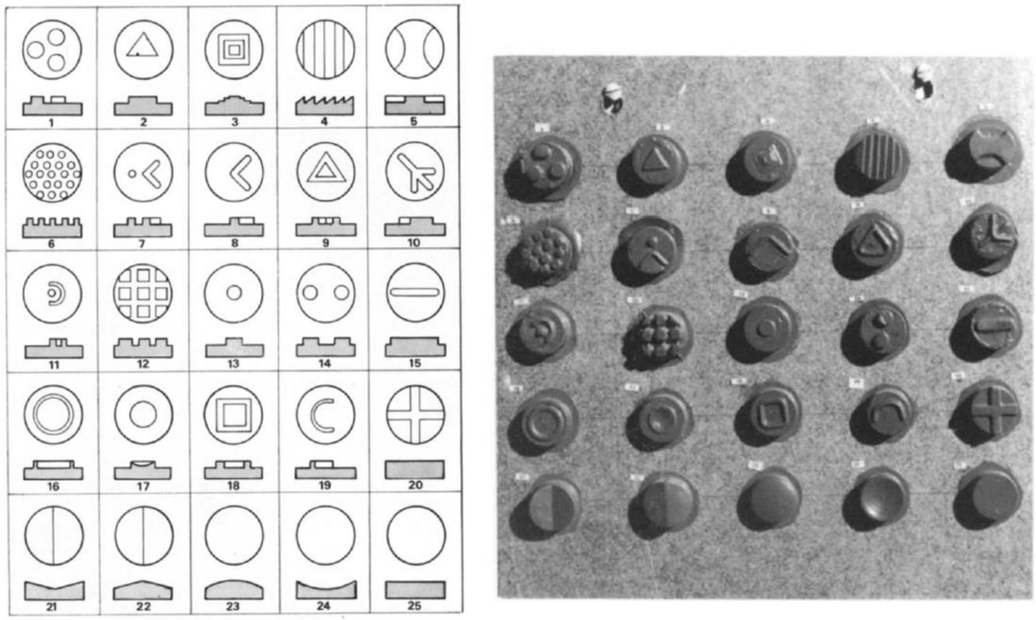


Figure 17: *25 Shaped Surfaces Tested for Tactile Discriminality (T.G. Moore, 1974)*

3.0 Design of Experiments

3.1 Main Objective

The main objective of the experiments was to determine the effect of button design characteristics on activation rate for PLB users with cold wet hands compared to thermoneutral wet hands, in order to determine if a decrement in performance could be measured and suggest improvements which could enable easier activation of a PLB. The experiments were conducted in four experimental phases and data was collected from human participants to determine if having cold and wet hands negatively affects a person's ability to successfully locate and activate the "ON" button of emergency signalling devices. Additionally, a button panel was fabricated in which 12 buttons varying in size, shape and texture was used in order to make observations regarding button selection and activation when obscured from view. This button assessment system allowed for determination of which combination of button design characteristics could improve activation rate.

The panel was obscured because it is anticipated that in a maritime distress situation at sea when an individual is suddenly immersed in cold water they may not have the time or the ability to see the activation button on the PLB to successfully locate it and depress it.

It is known that when an individual's hands are exposed to cold water there is a loss in finger dexterity and tactile sensitivity which could make it more difficult for an individual to successfully activate a PLB. According to Ray et al., (2019), if the hands are immersed in 2C water, a decrement in manual dexterity can occur after being exposed for two minutes. Therefore, this temperature condition and exposure duration were selected for the experiments discussed in **Section 3.4**. For comparison, a thermoneutral water condition of 34C was selected, to align with Ray et al., (2019).

3.2 Factorial Design

It was decided that the main factors which play a role in locating an activation push button on a PLB are:

1) Button Size (Large vs. Small)
2) Button Texture (Contrasting vs. Non- contrasting)
3) Button Shape (Flush vs. Recessed vs. Protruding)

These three main factors were selected for the experimental design because they are typical for the ranges observed for commercially available PLBs. All these factors can impact the haptic perception (sense of touch) to locate a push button as well as the amount of force needed to depress a push button. Therefore, they are significant parameters to consider in an experiment investigating the push button design.

The three factorial (3^k) design led to 12 different buttons varying in size, texture, and shape. This is depicted below in **Table 5**. Button size at two levels, button texture at two levels and button shape at three levels.

Table 5: Twelve Buttons with Associated Characteristics

Condition	Button Size		Button texture		Button Shape		
	Small	Large	Non-contrasting	Contrasting	Recessed	Flush	Protruding
1	X		X		X		
2	X		X			X	
3	X		X				X
4	X			X	X		
5	X			X		X	
6	X			X			X
7		X	X		X		
8		X	X			X	
9		X	X				X
10		X		X	X		
11		X		X		X	
12		X		X			X

3.3 Design of Emergency Beacon Button Assessment System

3.3.1 Panel Layout

A test apparatus for examining the effect of different button designs was required in order to conduct the experiments. A configuration for a panel layout needed to be finalized before contracting MUN Technical Services Electronics Division for its fabrication. Considering the 12 different button designs (3 surface shapes, 2 textures and 2 sizes), it was decided that a smooth, flat, square panel (300mm x 300mm) would be appropriate for random layout of the different buttons.

In order to determine an arrangement for the button panel design, a simple MATLAB program was developed which generated random locations for the 12 buttons. The method used for generating the random points on the surface was a fixed angle, random radius method which gave a random distribution of the points by providing equally spaced angles on the panel. This was achieved by randomly generating a radius along each theta and using the radius and theta to convert a given position for the x and y coordinates of each of the buttons. The buttons were positioned in such a way that they were not too close to the edge of the panel, they were not too close to the center of the panel and the distance between any two points also was not too close. In this case, the minimum radius was 20 mm from the panel's center, the maximum radius was 135 mm from the panel's center, and the proximity between each button had a minimum distance of 40 mm between one another.

The twelve random button locations were assigned characteristics by randomly choosing the button characteristics from a hat. The final button properties for the 12 different button configurations that were selected are shown in Section 3.4.2 alongside the final button panel layout.

3.3.2 Selection of Button Particulars

By analyzing six commercially available PLBs, it was found that the diameter of the "ON" button of the PLBs ranged from 0.6 cm to 1.3 cm in diameter. Therefore, it was decided to use 0.5 cm for the smaller button diameter with a recess height and protruding height of 0.5 mm. For the larger button, a diameter of 1.0 cm was selected with a recess height and protruding height of 1 mm. These particulars were used in order to keep consistency from small button to large button with respect to the ratio of depth and diameter. The final button designs were made in AutoCAD and are shown in **Figure 18** for the small buttons and in **Figure 19** for the large buttons.

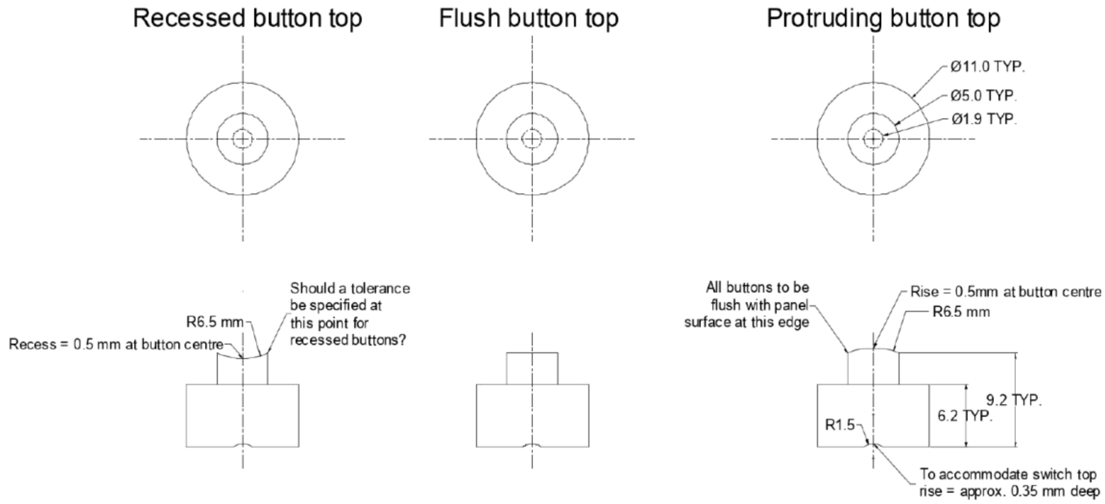


Figure 18: *Small Button Particulars*

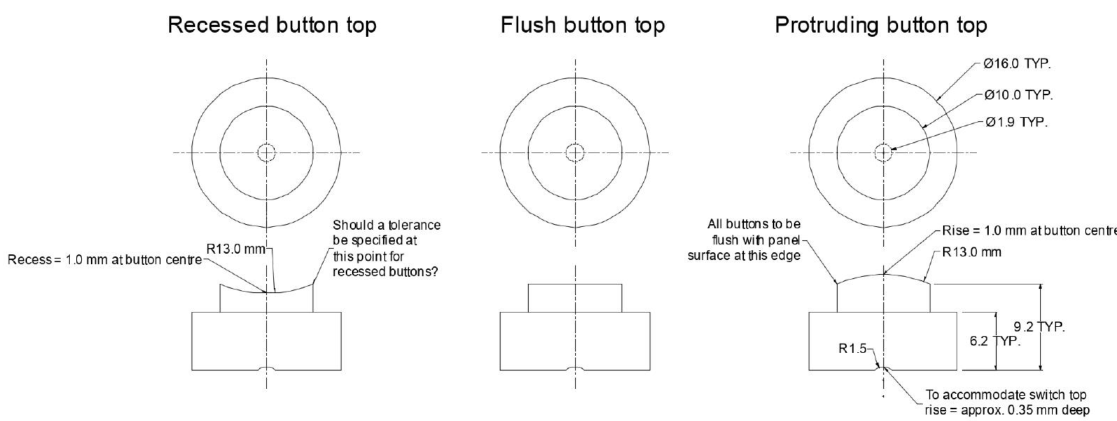


Figure 19: *Large Button Particulars*

Figure 20: *Button Panel System*

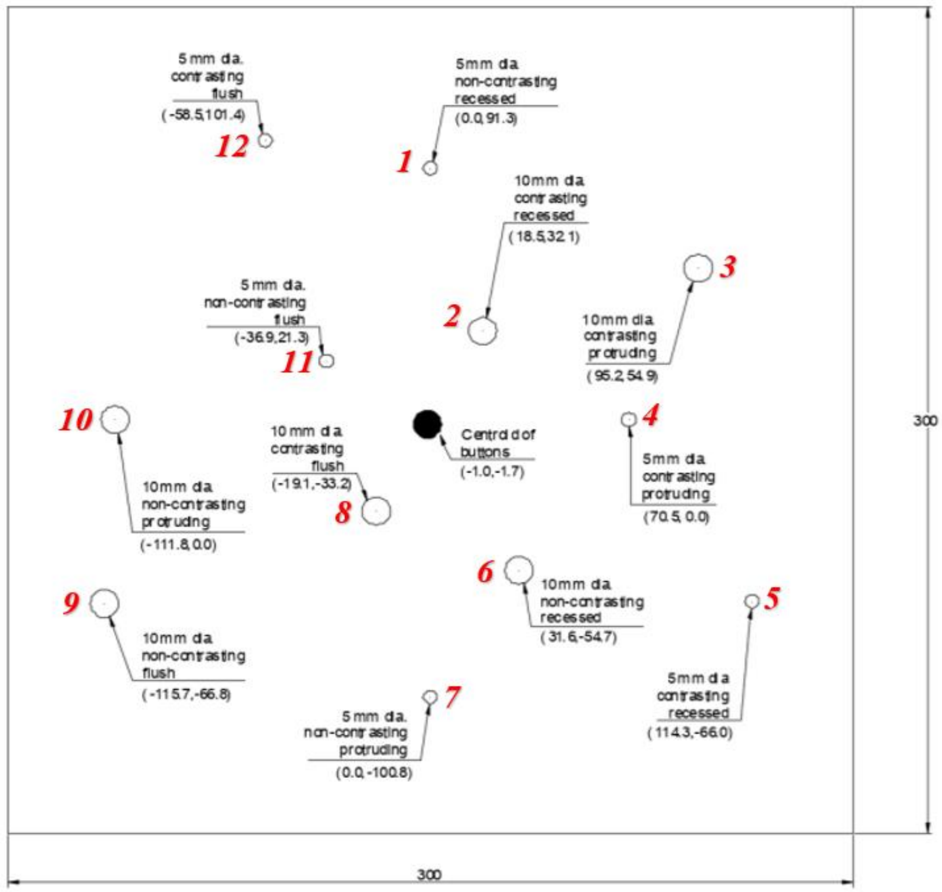


Figure 21: *Button Assessment System Panel Layout*

Table 6: Button Particulars

Button	**Button Characteristics**		
Number	**Size**	**Shape**	**Texture**
1	small	recessed	smooth
2	large	recessed	rough
3	large	protruding	rough
4	small	protruding	rough
5	small	recessed	rough
6	large	recessed	smooth
7	small	protruding	smooth
8	large	flat	rough
9	large	flat	smooth
10	large	protruding	smooth
11	small	flat	smooth
12	small	flat	rough

MUN Technical Services Electronics Division was contracted to design, fabricate, and assemble the button panel system to simulate different emergency locator beacon button characteristics (Emergency Beacon Button Assessment System). They were provided the AutoCAD drawings for the design components and there were frequent discussions and meetings in collaboration with them for selecting the most appropriate button mechanism. In the end a tact Switch (RAFI Micon 5) configuration mounted on small proto-boards was selected and the actuators were custom 3D printed by MUN Technical Services. The button configuration selected is shown below in **Figure 22** and the board/button mechanical side view **Figure 23**.

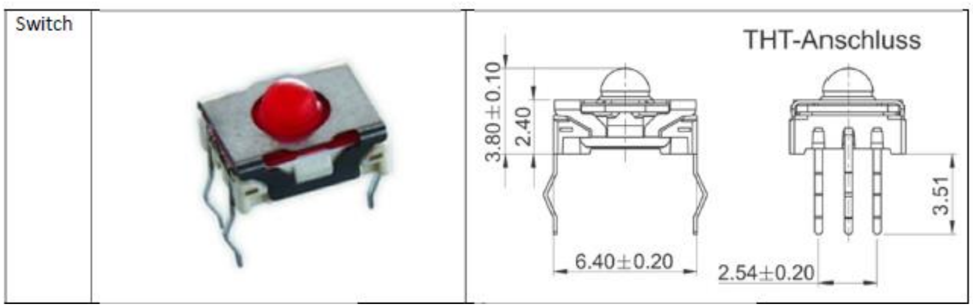


Figure 22: *Button Configuration*

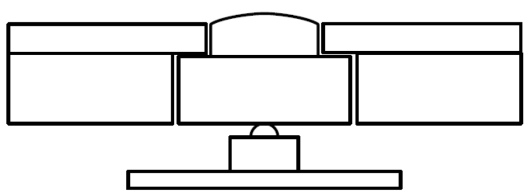


Figure 23: *Board/Button Mechanical Side View*

The button assessment system was designed and built so the buttons simulated the real world feeling of PLB activation buttons, with respect to the amount of force needed to press them (around 850 g-force), button travel, haptic feedback and the “click” of the button.

3.3.3 How the Emergency Beacon Button Assessment System Works

Upon the emergency beacon button assessment system being powered, the controller immediately monitored a capacitive touch sensor at the centre of the panel. When a participant's index finger was positioned in the centre of the panel, the red LED light flashed rapidly to indicate that the controller was ready. When the participant moved their finger away from the centre, the status LED turned solid, and the controller monitored for buttons being pressed. Each time a button was pressed, the corresponding LED would light-up. This enabled easy recording of the timing and order of button presses. In order to start a new run, the controller must be reset by unplugging it from the power source and plugging it in again.

3.4 Pilot Testing

Given that this type of experiment had not been done before, pilot testing was conducted with both warm hand immersions as well as with cold hand immersions in order to observe skin finger temperature over time to see how long it would take the hands to both warmup and cool down. Results from pilot testing for the thermoneutral wet as well as the thermoneutral cold would provide information to refine the real experiments with respect to the time given to the participants for the button panel pushing portion of the experiments. Based on the results from the initial pilot testing a time could be established for the button test duration. It should be noted that the pilot testing was completely separate from the experiments and did not use the same individuals for the real set of experiments.

3.4.1 Initial Pilot Testing Thermoneutral Wet Condition

For the initial thermoneutral wet pilot testing condition, 8 students participated by immersing their dominant hand for 2 minutes in the thermoneutral water bath (34C). The index finger temperature of their dominant hand was recorded using a k type thermocouple before putting their hand in the thermoneutral water bath. Using a stopwatch, the 2 minutes was timed while their dominant hand was immersed up to their wrist in the thermoneutral water. As soon as their dominant hand was removed from the water after the 2 mins, their index finger temperature was recorded (t=0) with a k type thermocouple and again every 15 seconds for 285 seconds (4.75 minutes). This pilot testing was conducted in order to observe whether there are differences in finger skin temperature over time and how long it takes for the skin finger temperature to warm up and get back to their initial dry skin finger temperature.

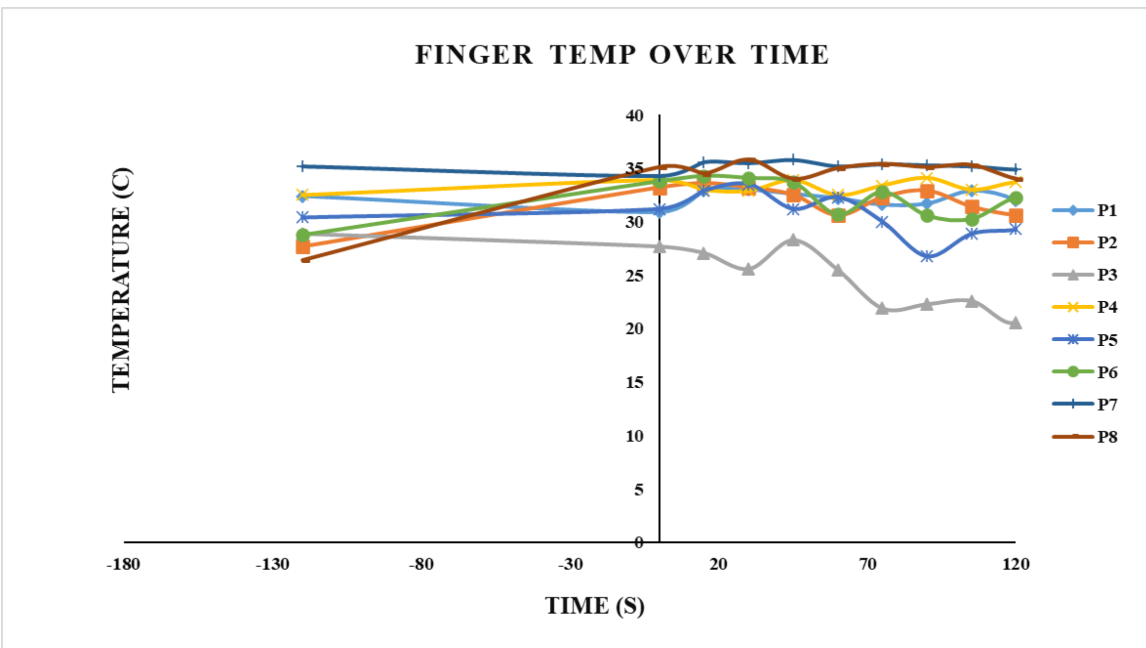


Figure 24: *Finger Temperature over Time for Warm Wet Hands*

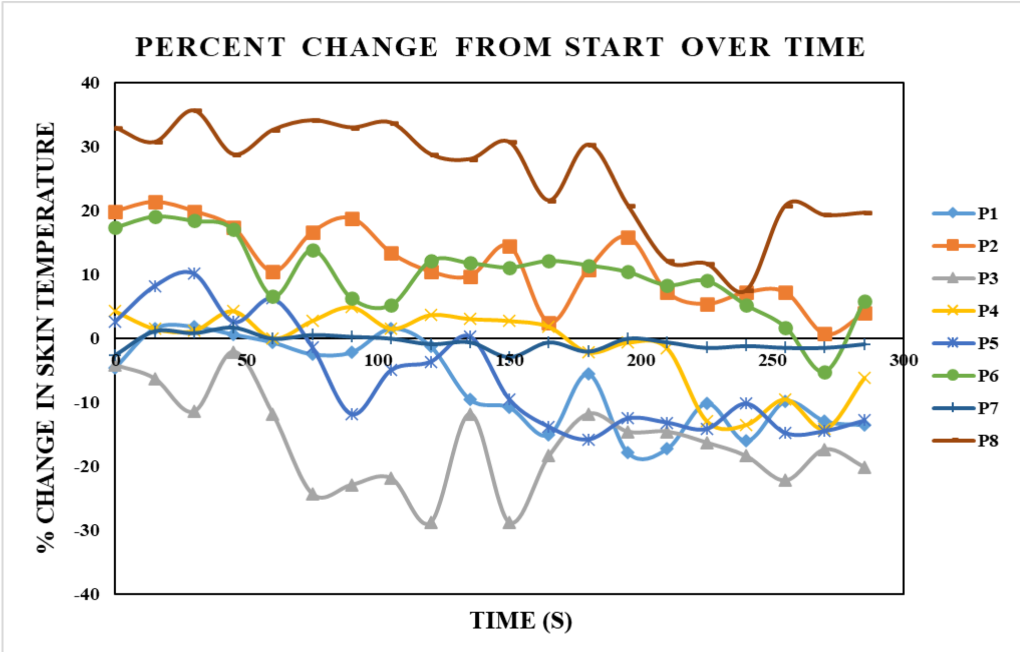


Figure 25: *Percent Change in Skin Finger Temperature vs. Time (S) for Warm Wet Hands*

It can be seen in the plot for finger temperature over time in **Figure 24** that all the data from the 8 participants follows a similar trend, in which the starting temperature only differs slightly from the final temperature reading at 285 seconds. The initial skin temperature before warm water immersion ranges from 26.4 degrees Celsius to 35.2 degrees Celsius at the 120 seconds (2-minute mark) the skin temperature readings are between 20.6 degrees and 34.9 degrees and at the 285 second mark for the most part the initial skin temperature reading before warm water immersion is greater than that of the reading at the 285 seconds. This indicates that even after 285 seconds having wet warm hands the skin finger temperature of the participants is not fully warmed up to their initial dry skin finger temperature. The percent change in skin temperature vs. time plot in **Figure 25** shows that the percent change in skin temperature decreases slightly with increasing time.

3.4.2 Initial Pilot Testing Cold Wet Condition

For the initial cold wet pilot testing condition, 10 participants immersed their dominant hand for 2 minutes in the cold-water bath. The index finger temperature of their dominant hand was recorded using a k type thermocouple before placing their hand in the cold-water bath. Using a stopwatch, the 2 minutes was timed while their dominant hand was immersed to their wrist in the cold water. As soon as their dominant hand was removed from the cold water after the 2 mins, their index finger temperature was recorded right away (t=0) with a k type thermocouple probe and again every 15 seconds for a duration of 285 seconds (4.75 minutes). This pilot testing was conducted in order to observe the relationship of finger skin temperature over time and to see how long it takes for their hands to warm up following a cold exposure. This is of importance because the time it takes for the dominant hand to rewarm will be considered as a baseline for the time given in the experiments for push button activation when their dominant hand is both cold and wet.

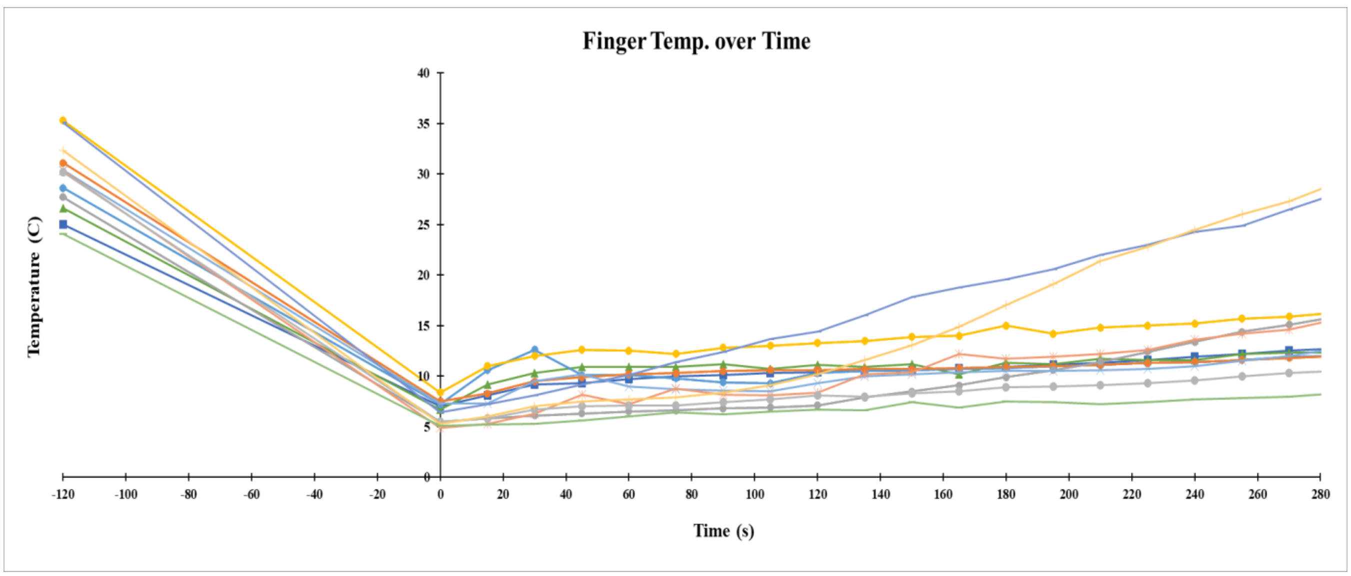


Figure 26: *Finger Temperature over Time for Cold Wet Hands*

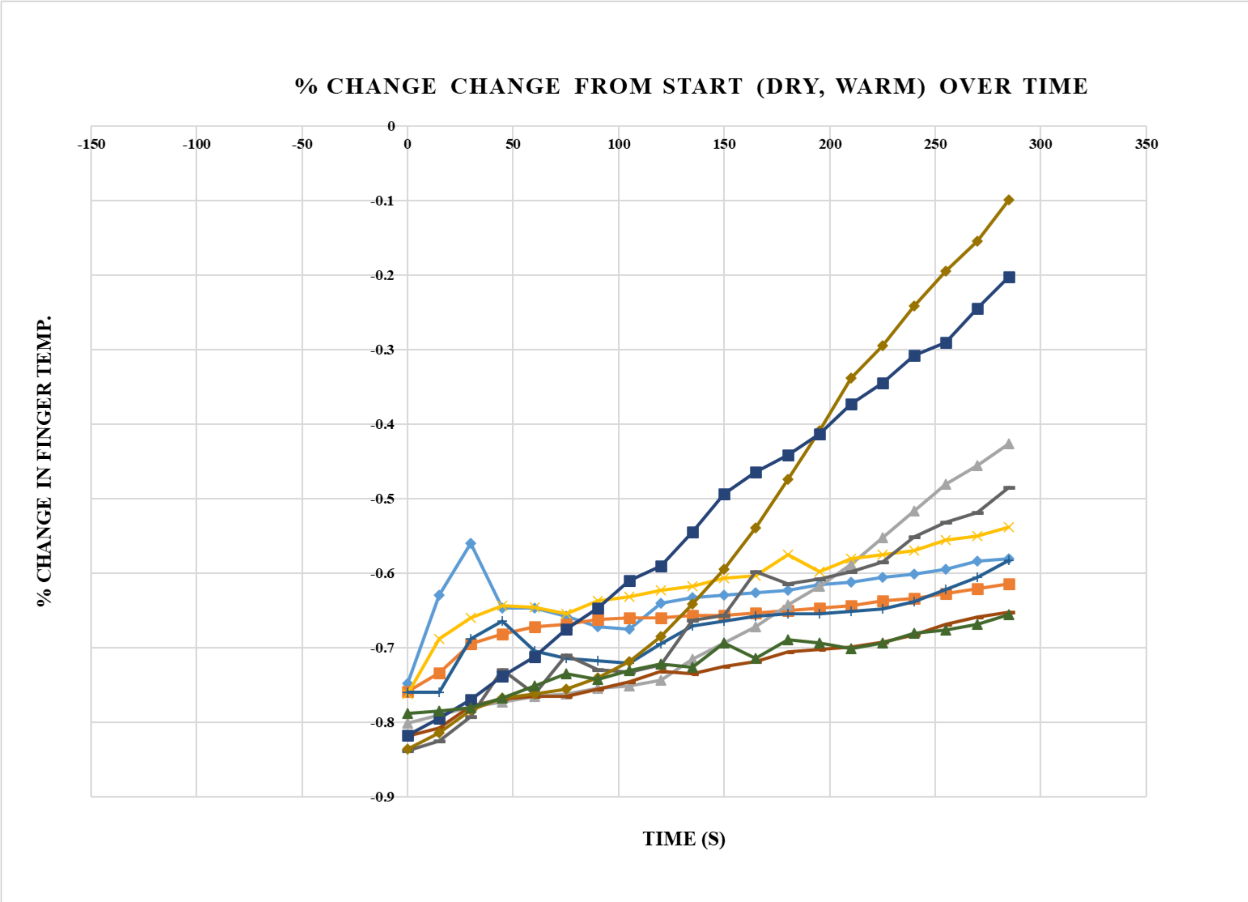


Figure 27: *Percent Change in Skin Finger Temperature from Start over Time for Cold Wet Hands*

The skin finger temperature over time for cold wet hands in **Figure 27** is showing a similar trend among the 10 participants and that between 85 and 135 seconds (about 105 seconds) the skin finger temperature gradually increases further to the 285 seconds time frame. Similarly, the percent change in skin finger temperature of the cold wet hands starts to increase between 100 and 150 seconds and continues to increase until the 285 seconds time frame is reached. This shows that 120 seconds (2 mins) is a reasonable prediction for the time it takes for the hands to warm up. It seems reasonable that if participants were given a 2-minute period to search for buttons, their finger temperature would not be expected to warm significantly. The average skin temperature (C) for cold wet hands versus time (s) is shown in Figure 31. This data is also given below in **Table 7**.

It shows that at 120 seconds the average finger skin temperature of the cold wet hands was 9.84 degrees Celsius. The table also shows from 105 seconds to 285 seconds there is a steeper increase in the average skin finger temperature as opposed to before the 105 second mark.

Table 7: Time (s) vs. Average Temperature (C) for Cold Wet Hands

Time (s)	Average Temperature of 10 Participants
-120	30.51
0	6.31
15	7.25
30	8.31
45	8.66
60	8.64
75	8.92
90	9.07
105	9.34
120	9.84
135	10.5
150	11.09
165	11.63
180	12.18
195	12.53
210	13.09
225	13.58
240	14.21
255	14.77
270	15.34
285	16.04

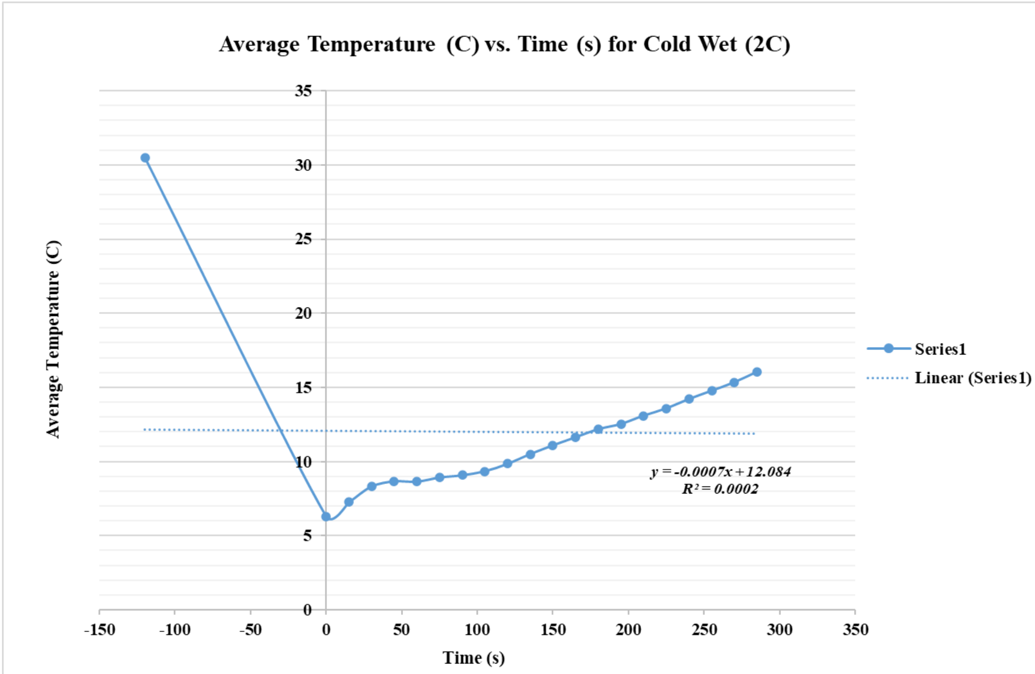


Figure 28: *Average Skin Finger Temperature (C) vs. Time (S) for Cold Wet Hands*

In **Figure 28** for the average skin finger temperature against time for cold wet hands there is an approximately linear increase in average skin finger temperature from 120 seconds (about 10 degrees) onwards as a steep increase as average skin finger temperature approaches a time of 285 seconds. This shows that around the 120 second time frame, the skin finger temperature is starting to warm.

4.0 Experimental Methods

Prior to student recruitment, an ethics application was completed for the Interdisciplinary Committee on Ethics in Human Research (ICEHR) and approved on October 28th, 2021 (file # 20221821) in order to conduct face to face interactions with research participants.

Two circulating water baths which have been used for similar studies (e.g., Ray et al., 2019) were setup in a laboratory space in Memorial University's Engineering Building. One bath had cold water at a temperature of +2°C and the other had water set to typical skin temperature of approximately +34°C to provide the thermoneutral condition. Water temperatures were recorded using k type thermal probes and logged using an Omega RDXL4SD thermometer/logger. Each of the water baths contained 95 litres of water. In order to maintain consistent temperatures in the baths, separate digital display thermoregulators (HCTB-3020) were used. For the cold water, a dip cooler (RCTB-3050) and ice were also used. A video camera was used throughout testing to record each participant as a backup to any manual data collection methods used (ex. stopwatch). Only the participants' hands were recorded for the experiments. Following a briefing about the research study and the completion of the consent form, participants took part in the four stages of the experiment.

Figure 29: *Thermoneutral Water Bath 34 °C (Left) and Cold-Water Bath 2 °C (Right)*

4.1 Stage 1: Standardized Testing

The first phase of the experiment involved a series of five different standardized tests which were used to evaluate hand dexterity and tactile sensitivity of the participants' hands in a dry thermoneutral state. The tactile sensitivity tests included the two-point discrimination test (to measure the participants ability to distinguish that two nearby objects touching the skin are two different distinct points as opposed to one point) and the Von Frey monofilament test (to measure tactile sensitivity in the fingers). The two-point discrimination test was done for both static two-point discrimination measurements as well as for moving two-point discrimination measurements. Both had a similar procedure in which the larger distance was used for touching and asking whether the participant felt one or two points. The best score out of 7 for 3 trials was recorded and if they got 4 out of 7 or more then the distance was further decreased and the smallest distance in mm was recorded. A normal distance for both tests is 6 mm and under for the two points. For the Von Frey monofilament test there were a series of monofilaments of different thickness. The thinnest monofilament was tapped 3 times on the participants index finger and this process was repeated moving up in monofilament size until it was felt on the tip of the index finger and that measurement was recorded.

The manual manipulative tests for dexterity consisted of the pinch strength test which used the participants' thumb and index finger on their dominant hand to measure pinch gauge force in lbs/kg shown in **Figure 30**. The grooved pegboard test was also used to measure object manipulation by the speed of filling the board from left to right (top to bottom) placing all pegs in the groves of the board. The time it took to fill the board once was recorded in seconds. Additionally, the circumference (cm) of the tip of the participants index finger on their dominant hand was measured and recorded three times.

Figure 30: *Standardized Tests*

4.2 Stage 2: PLB Test First Round

This stage of the experiment was conducted in order to determine whether participants could successfully activate a commercially available PLB. Basic training was provided to the participants on how to activate two commercially available PLBs. The activation button on each of the respective devices was shown to the participants as well as the test button on each of the devices. The participants were instructed that in order to activate the PLBs, the activation button needs to be pressed and held for around 3 seconds in duration. After instructing the participants regarding how to use the PLBs, their initial skin finger temperature was recorded. Directly afterwards they were asked to immerse both of their hands in either the thermoneutral water bath (34℃) or the cold-water bath (2℃) for 2 minutes. The temperature condition was selected randomly by flipping a coin and assigning either a warm or cold temperature condition to the participant. Following this, their skin surface temperature of the dominant hand index finger was recorded using a k-type thermocouple to record their temperature immediately after the immersion. Participants were then instructed to put both their hands in an enclosure (a poster board with a large hole) which prevented them from seeing their hands. They were instructed to look straight ahead at a dot on the poster board and then handed one of the PLBs and asked to activate it. When the participant believed they had activated the device they were told to lay it on the table. The objective of this phase of the experiment was to determine whether the PLB was correctly activated after minimal training and exposure to either cold or thermoneutral water. The PLB training instructions explained to the participants can be found in **Appendix E**.

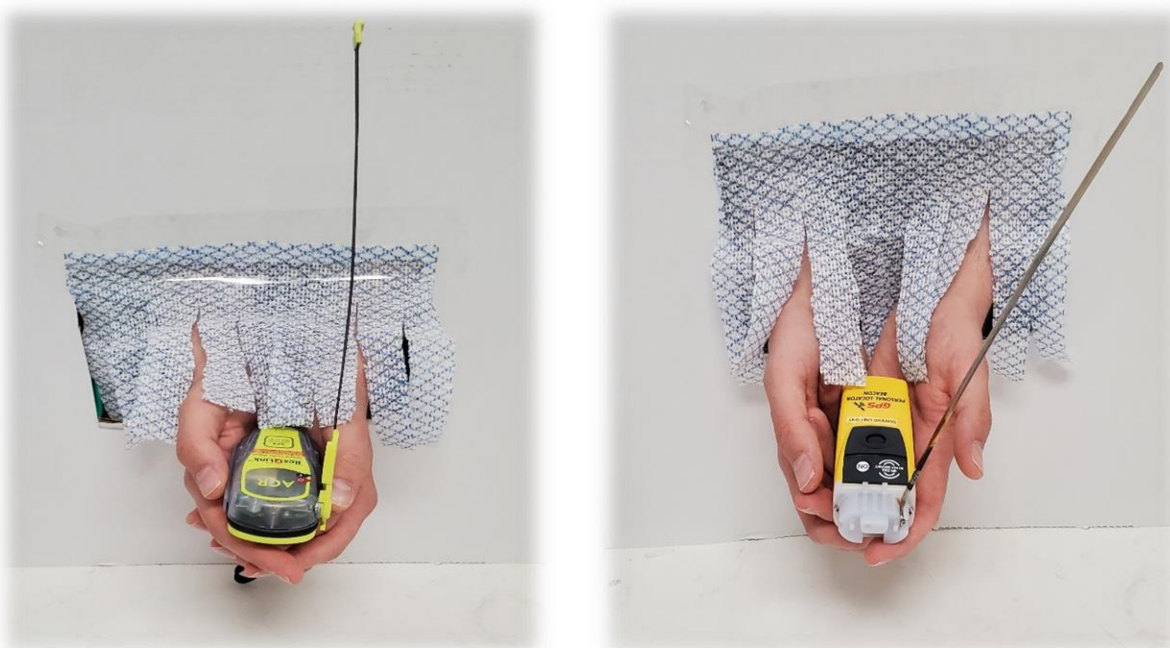


Figure 31: *Two Commercial PLBs Used for Stage 2 & Stage 4*

4.3 Stage 3: Generalized Button Testing

The main objective of the generalized button testing phase was to determine whether certain push button characteristics attribute to a greater likelihood of button activation when using either cold wet hands or warm wet hands.

For step 1 of this stage of the experiment the same hand immersion condition the participant had used in Stage 2 of the experiment was used with a two-minute re-exposure to that temperature condition with only their dominant hand. After that, the participants' skin finger temperature of their dominant hand was recorded. Following that the index finger of their dominant hand was guided to the centre of the emergency beacon button apparatus system (described above) which they was obscured from their view. The button pressing system was placed in a box, with an opening large enough for one hand to go through and the participants hand was recorded for the entire duration of this phase by a GoPro video camera on a tripod. After their index finger was guided to the centre of the button pressing apparatus, only the index finger of the participants' dominant hand was used to find and press as many buttons as they could in a 2-minute time frame. The button panel had a starting orientation which was selected randomly from picking a piece of paper out of a box. The panel had four orientations (North, South, East, West).

For step 2 of this stage, the same procedure was followed as in step 1 but the orientation of the square panel of the button apparatus was rotated to a different orientation (also selected randomly). This is so the participants cannot remember the first orientation that was used. Then the participants' dominant hand was immersed in a different water temperature condition than the first test. As such, all the participants did both the warm and the cold condition for the beacon button assessment test. Whereas, for the PLB test only one temperature condition was used.

The main objective of the generalized button testing phase was to determine whether certain push button characteristics attribute to a greater likelihood of button activation when using either cold wet hands or warm wet hands.

Figure 32: *Button Panel Setup*

4.4 Stage 4: Repeat Activation of PLBs

Stage 4 consists of repeating Stage 2 of the experiment with the same hand immersion condition as in Stage 2, but no further training was provided on how to use the PLBs. The same PLB from Stage 2 was used again. This was to determine whether they could remember the instructions after time had elapsed.

4.5 Experiment Questionnaires

After Stage 4 was complete the participants were given a questionnaire to complete. The questionnaire consisted of a variety of questions primarily relating to their cold hand immersion activation rate and warm hand immersion activation rate feedback for both the PLB tests and the button panel apparatus test.

4.6 Data Acquisition Methods

For the standardized testing phase of the experiments (stage 1) data was manually recorded on a data collection sheet and later analysed with Excel. For the PLB activation phase of the experiments (stage 2) data was recorded manually on the data collection sheet. Additionally in stage 2 temperature data was logged via the Omega RDXL4SD thermometer as well as index finger temperatures recorded manually using the k-type thermocouples. For the generalized button testing phase of the experiments (stage 3), the participants' hands were video recorded using a HERO3 GoPro video camera. Additionally, when performing video analysis after testing, data was recorded in an Excel spreadsheet. For Stage 4 of the experiment (repeat PLB activation), the same data collection methods were followed as were in stage 2.

Upon the completion of all experimental sessions the SSD card from the video camera was saved on the researcher's laptop and backed-up to a secure server. Additionally, the data obtained from the SSD card of the Omega RDXL4SD thermometer was downloaded and stored on the researcher's laptop in an excel file format for corresponding data temperatures and their associated times of the session.

5.0 Analysis of Results

5.1 Participant Demographics

There were a total of 29 participants with an average age of 29 years (std = 7.5). There were 15 females and 14 males of which 28 were right-handed and 1 was left-handed. The population were in normal range for the results obtained from the standardized tests.

5.2 PLB Test (Stage 2 and Stage 4)

A total of 29 people participated in both Stage 2 and Stage 4 testing. Due to random selection of the temperature condition, 12 participants were selected for the cold temperature condition, and the remaining 17 participants were selected for the thermoneutral temperature condition. Two different PLBs were used - PLB 1 had both the activation and test button next to one another on the left side of the device, whereas PLB 2 had both the test and activation button on the front of the device (the test button in the centre front, and activation front top left). A total of 13 participants used PLB 1 (4 for the cold condition and 9 for the thermoneutral condition for both Stage 2 and Stage 4). A total of 16 participants used PLB 2 (8 for the cold condition and 8 for the thermoneutral condition for both Stage 2 and Stage 4). The temperature data collected before and after thermoneutral hand immersion for Stage 2 is shown in **Table 8**, and the data before and after thermoneutral hand immersion for Stage 4 is shown in **Table 9**.

Table 8: Summary Stage 2 Finger Temperature Data for PLB Test Thermoneutral Condition

Stage 2: PLB Test		
	Starting Finger Temperature (C)	Temperature After First Warm Immersion (C)
Mean	31.6	33.2
SD	3.8	2.2
Max Value	35.3	34.9
Min Value	23.7	25.3

Table 9: Summary Stage 4 Finger Temperature Data for PLB Test for Thermoneutral Condition

Stage 4: PLB Repeat Warm		
	Starting Finger Temperature (C)	Temperature After Second Warm Immersion (C)
Mean	22.2	32.8
SD	4.2	1.0
Max Value	30.9	34.3
Min Value	15.0	30.6

The temperature data before and after the cold-water hand immersion for Stage 2 is shown in **Table 10**, and the temperature data before and after the cold-water hand immersion for Stage 4 is shown in **Table 11**.

Table 10: Summary Stage 2 Finger Temperature Data for PLB Test for Cold Condition

Stage 2: PLB Test		
	Starting Finger Temperature (C)	**Temperature After First Cold Immersion (C)**
Mean	32.7	8.9
SD	2.1	2.0
Max Value	35.8	12.0
Min Value	27.6	5.5

Table 11: Summary Stage 4 Finger Temperature Data for PLB Test for Cold Condition

Stage 4: PLB Repeat Cold		
	Starting Finger Temperature (C)	**Temperature After Cold Immersion (C)**
Mean	29.6	10.8
SD	2.9	4.6
Max Value	33.7	24.0
Min Value	25.1	6.4

In general, not considering cold separate from warm, **Figure 33** shows the proportion of people who correctly activated the devices compared to those who did not activate. This plot shows the results for both PLBs used and for Stage 2 and Stage 4 of the experiment.

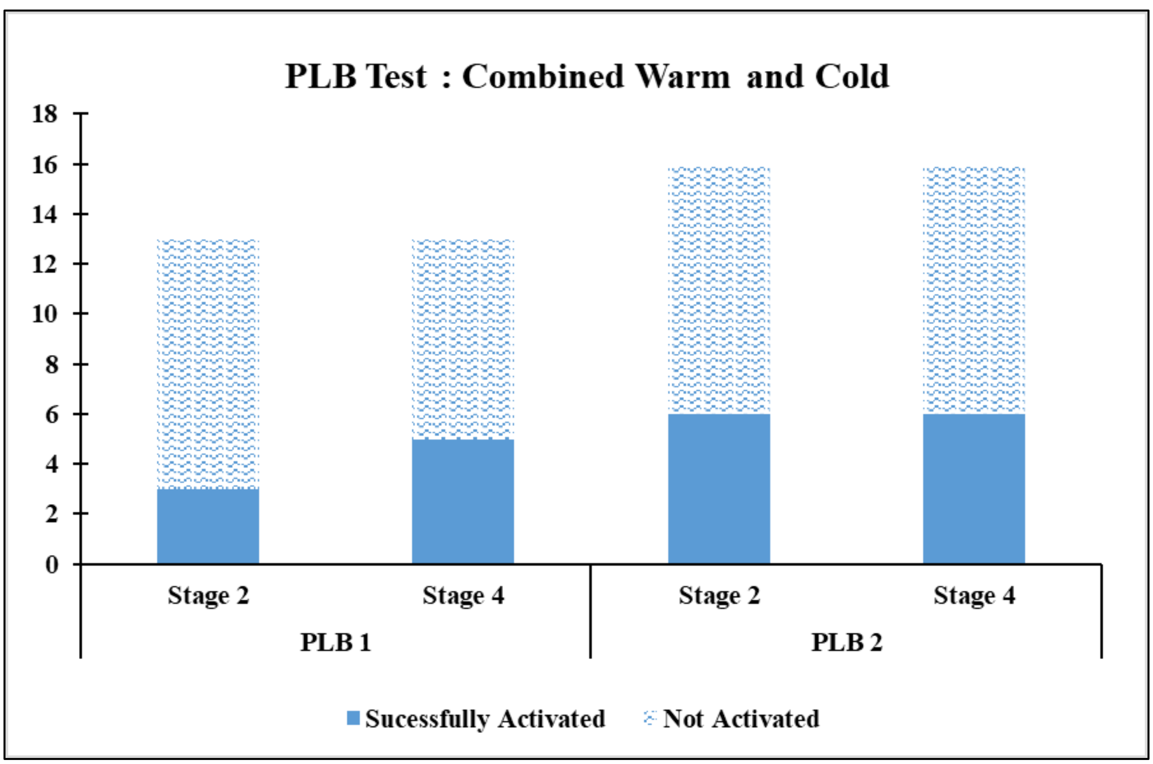


Figure 33: *PLB Test Categorized by Device and Stages for Combined Temperature Conditions*

It can be seen from **Figure 33** above that for PLB 1, more successful activations occurred in Stage 2 than in Stage 1, with 3 people successfully activating the device in Stage 2 and 5 people successfully activating the device in Stage 4. This means for PLB 1 that in Stage 2 that 10 people didn't correctly activate the device, whereas in Stage 4, 8 people didn't correctly activate the device. For PLB 2 it can be seen there is no difference in successful activation between stage 2 and Stage 4, both having 6 people who correctly activated the device and 10 people who did not successfully activate the device. Across both stages for both devices, more people were unsuccessful with activating the devices than successful. For PLB 2 out of the 16 participants for Stage 2 and Stage 4, around 38% correctly activated the device, and for PLB 1 23% in stage 2 and 38% in Stage 4 for correct activation.

When breaking down all possible outcomes for Stage 2 and Stage 4 by both device and temperature (cold or warm) for the PLB Test there were 4 main outcomes which occurred:

1. Beacon Successfully Activated

2. Only Test Button Pushed

3. Both the Test and the Activation Button Pushed

4. No Buttons Successfully Pushed

The data summary table for these four different outcomes for both PLBs and both temperature conditions are displayed in **Table 12**.

Table 12: Summary for PLB Tests for Stage 2 and Stage 4 for both Warm and Cold Hand Immersions

Cold Condition		
Stage 2 Outcomes Summary	**PLB 1**	**PLB 2**
Successfully Activated	2	2
Test Button Pressed	1	2
Both Test Button and Activation Button Pressed	0	0
No Buttons Pressed	1	4
Total	**4**	**8**
Warm Condition		
Stage 2 Outcomes Summary	**PLB 1**	**PLB 2**
Sucessfully Activated	1	3
Test Button Pressed	7	2
Both Test Button and Activation Button Pressed	0	1
No Buttons Pressed	1	2
Total	**9**	**8**
Cold Condition		
Stage 4 Outcomes Summary	**PLB 1**	**PLB 2**
Sucessfully Activated	2	3
Test Button Pressed	1	2
Both Test Button and Activation Button Pressed	0	0
No Buttons Pressed	1	3
Total	**4**	**8**
Warm Condition		
Stage 4 Outcomes Summary	**PLB 1**	**PLB 2**
Sucessfully Activated	2	2
Test Button Pressed	5	4
Both Test Button and Activation Button Pressed	1	1
No Buttons Pressed	1	1
Total	**9**	**8**

The outcomes for both Stage 2 and Stage 4 with PLB 1, it is evident that in the warm condition for both stages, the test button was pressed the most. In Stage 2 the test button was pressed by 7 participants and in Stage 4 by 5 participants. For Stage 2 the activation button was only pressed by one participant and in Stage 4 by 2 participants. Both buttons pressed only occurred for one participant in Stage 4 for the warm condition. For the cold condition no buttons pressed was the same as in the warm condition by one participant in each of the stages. For both Stage 2 and Stage 4 in the cold, 2 participants correctly activated the device. And in both Stage 2 and Stage 4 for the cold nobody pushed both the test or the activation button, and 1 person pressed the test button.

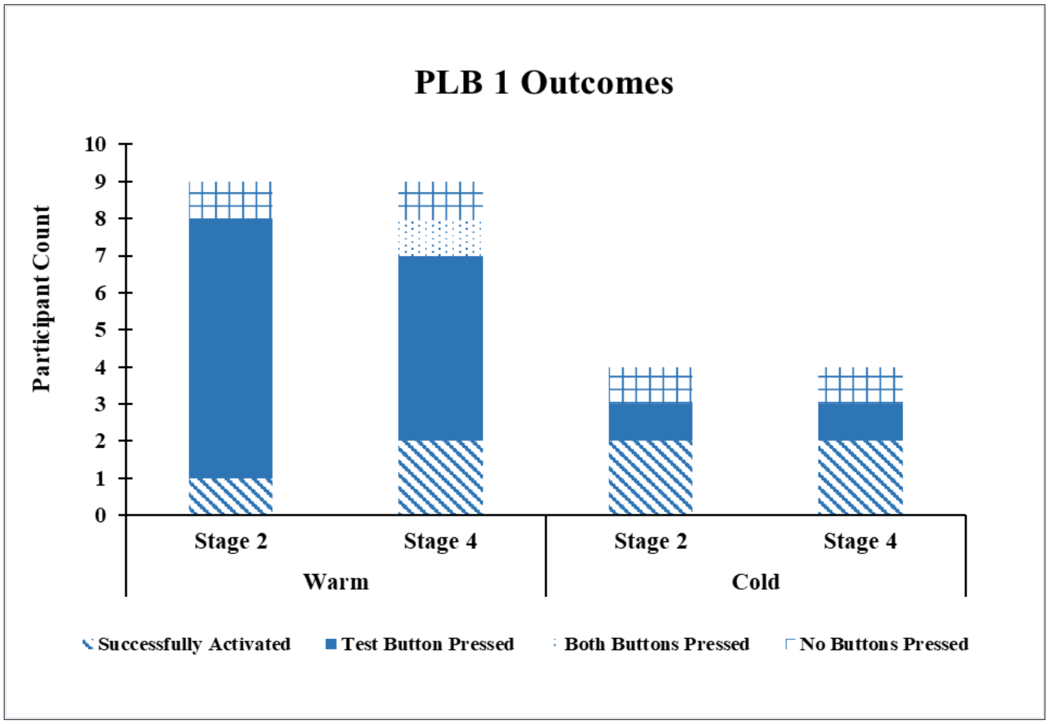


Figure 34: *PLB 1 Outcomes for PLB Tests*

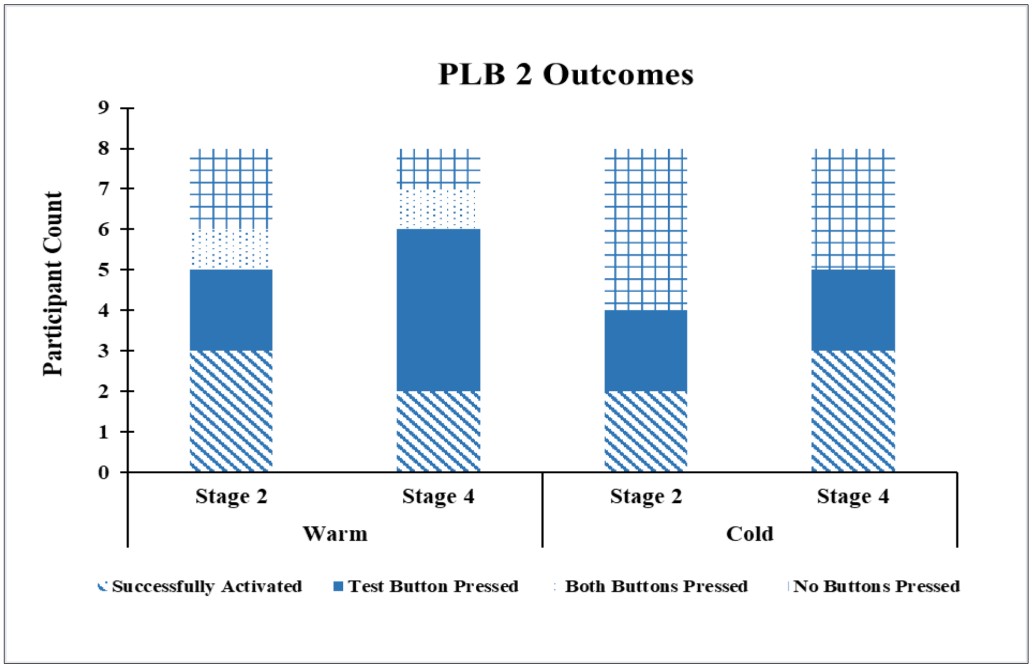


Figure 35: *PLB 2 Outcomes for PLB Tests*

For PLB 2 outcomes shown in **Figure 35**, for the warm condition more beacons were successfully activated in Stage 2 (3 participants) than in Stage 4 (2 participants). The test button was pressed more in Stage 4 (warm) by 4 participants. In Stage 2 the test button was pressed in the warm by 2 participants. For the warm condition, both buttons were pressed by 1 participant in both Stage 2 and Stage 4. In Stage 2 for the warm condition, it can be seen that more participants did not push any of the buttons (2 people). For the cold condition, less participants successfully activated the device in Stage 2 (2 people), then in Stage 4 (3 people). It can be seen in Stage 2 for the cold, more participants pushed no buttons correctly (4 participants) as opposed to in Stage 4 (3 participants). In both Stage 2 and Stage 4 of the cold the test button was equally pushed in both the stages by 2 participants. Overall, it can be seen that for PLB 2, more participants pressed the test button in the warm condition than in the cold condition. It can also be seen that between the warm and cold condition the same number of participants successfully activated the device. This suggests that temperature does not play a significant role in successful beacon activation. When considered in the context of a real emergency situation, this is a positive result since immersion in cold water would not be expected to reduce PLB activation performance.

When comparing PLB 1 to PLB 2, more participants pressed the test button on with PLB 1 for the warm condition overall for both Stage 2 and Stage 4. For the warm condition for both Stage 2 and Stage 4 more participants successfully activated PLB 2 than for PLB 1 for Stage 2 and Stage 4 for the warm condition.

5.3 Panel Orientation

There were four different orientations used for the button panel tests (North, South, East, and West). The North orientation was used 15 times, the South orientation was used 15 times, the East orientation 13 times and the West orientation 15 times. A summary of the total presses for each button in those orientations is displayed in **Table 13**, along with a normalization of the number of buttons pressed divided by the total number of times that specific orientation was used.

Table 13: Summary Button Panel Orientation and Total Button Presses

Orientation	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Sum Total Times Pressed												
North	0	52	48	18	2	41	29	58	44	94	18	12
South	1	49	79	24	4	50	21	57	35	37	11	6
East	9	37	47	22	2	32	23	37	35	41	20	15
West	4	40	61	23	2	38	22	48	50	66	11	5
Sum Total Times Pressed Divided By Number of Times Orientation Used												
North	0.0	3.5	3.2	1.2	0.1	2.7	1.9	3.9	2.9	6.3	1.2	0.8
South	0.1	3.3	5.3	1.6	0.3	3.3	1.4	3.8	2.3	2.5	0.7	0.4
East	0.7	2.8	3.6	1.7	0.2	2.5	1.8	2.8	2.7	3.2	1.5	1.2
West	0.3	2.7	4.1	1.5	0.1	2.5	1.5	3.2	3.3	4.4	0.7	0.3

It can be seen in **Figure 36** the total number of presses for each button based on the panel orientations of North, South, East, and West. From observation, button number 3 differs with more presses in the south orientation and button number 10 with more presses in the north orientation. Otherwise, there appears to be little difference in button press rate for the panel orientation, suggesting that the data from different orientations can be combined to form a single dataset, thus ignoring orientation as a factor. In order to confirm whether panel orientation is a factor for total button presses, analysis was conducted using Design Expert software and is provided in **Section 5.4.3**.

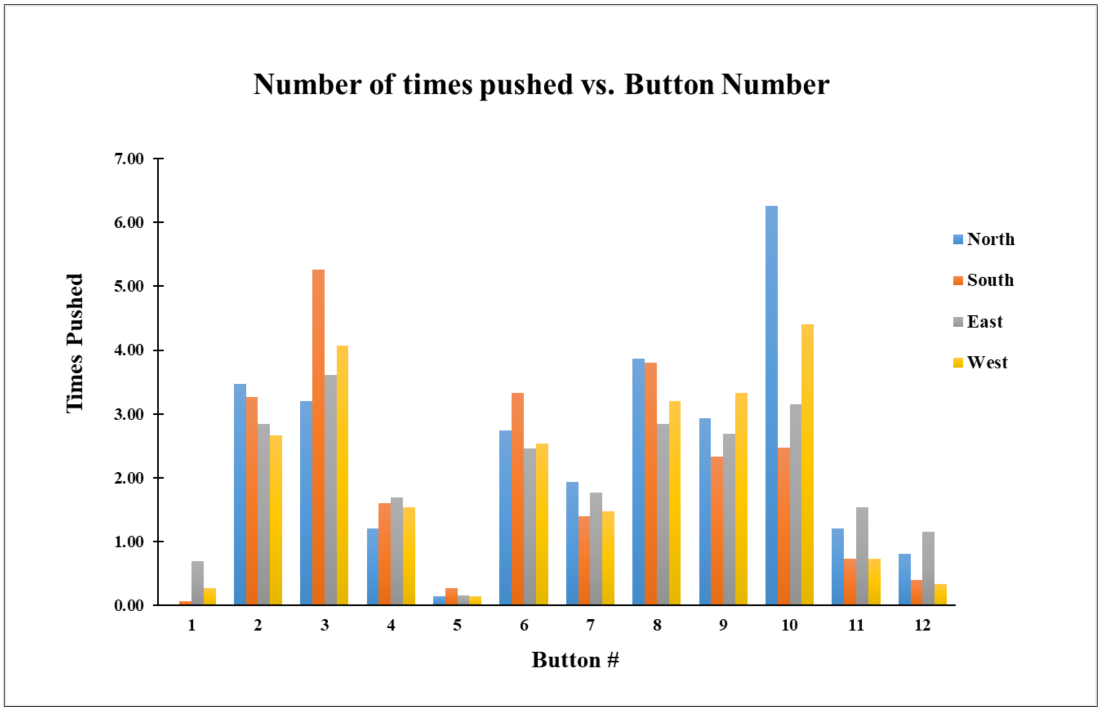


Figure 36: *Total Button Presses for each Panel Orientation*

5.4 Button Test (Stage 3)

For the button panel test, the same 29 individuals participated in both the warm temperature condition and the cold temperature condition. The temperature data after warm water hand immersion is seen in **Table 14** and the temperature data after cold water hand immersion can be seen in **Table 15**.

Table 14: Summary Stage 3 Finger Temperature for Warm Condition for Button Test

Stage 3: Button Panel Test Warm			
	Starting Finger Temperature (C)	Temperature Warm Immersion (C)	Temperature after button test
Mean	26.4	32.9	29.1
SD	6.1	1.4	3.1
Max Value	34.2	34.7	33.7
Min Value	13.5	28.6	22.3

Table 15: Summary Stage 3 Finger Temperature for Cold Condition for Button Test

Stage 3: Button Panel Test Cold			
	Starting Finger Temperature (C)	Temperature Cold Immersion (C)	Temperature after button test
Mean	24.5	8.5	19.7
SD	7.7	2.5	4.2
Max Value	34.5	17.0	33.1
Min Value	10.1	5.8	12

Performing video analysis for this stage of testing, the number of times each different button was pressed for each participant, for both the warm and cold temperature condition, data was entered in Excel for analysis and graphing. **Table 16** below outlines the total number of times each individual button was pressed for both the warm and cold temperature condition.

Table 16: Button Coordinates (X,Y) on the Panel

Buttton No.	Button X Coordinate	Button Y Coordinate
1	0	91.3
2	1.8	32.1
3	95.2	54.9
4	70.5	0
5	114.3	-66
6	31.6	-54.7
7	0	-100.8
8	-19.1	-33.2
9	-115.7	-66.8
10	-111.8	0
11	-36.9	21.3
12	-58.5	101.4

Table 17: Summary Data Stage 3: Number of Times each Button was Pressed

Button No.	Warm	Cold	Button Particulars
10	118	120	large protruding smooth
3	116	119	large protruding rough
8	101	99	large flat rough
2	95	83	large recessed rough
9	92	72	large flat smooth
6	90	71	large recessed smooth
7	52	43	small protruding smooth
4	46	41	small protruding rough
11	33	27	small flat smooth
12	17	21	small flat rough
5	6	4	small recessed rough
1	9	7	small recessed smooth

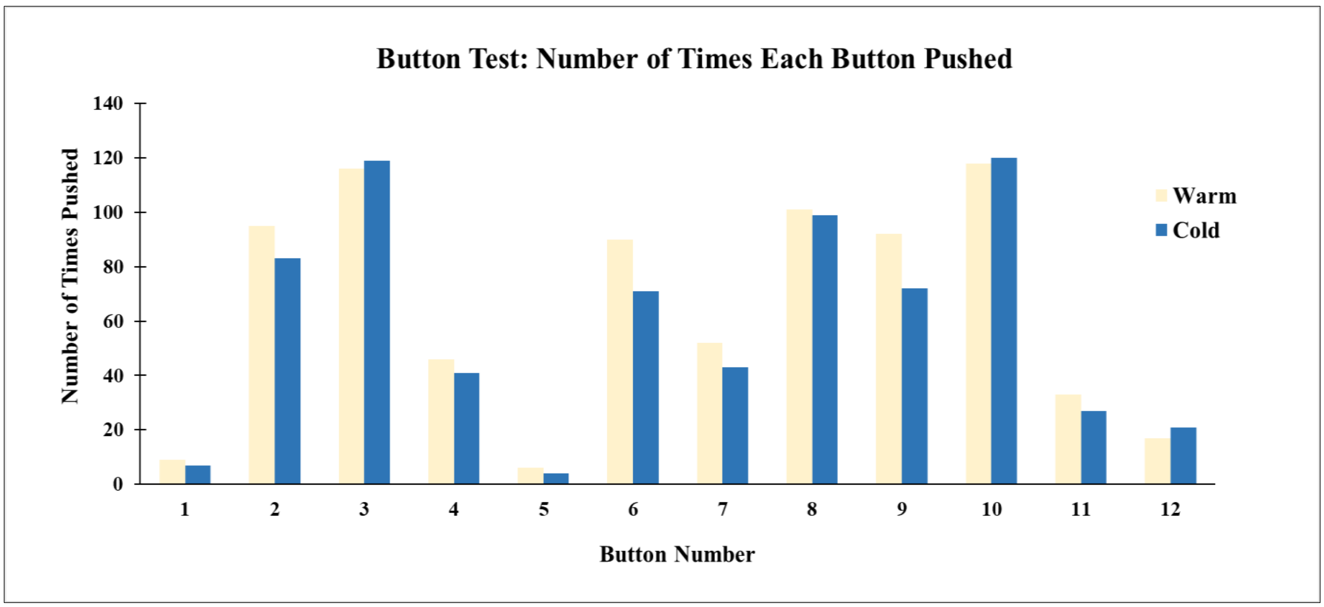


Figure 37: *Number of Times each Button was Pushed*

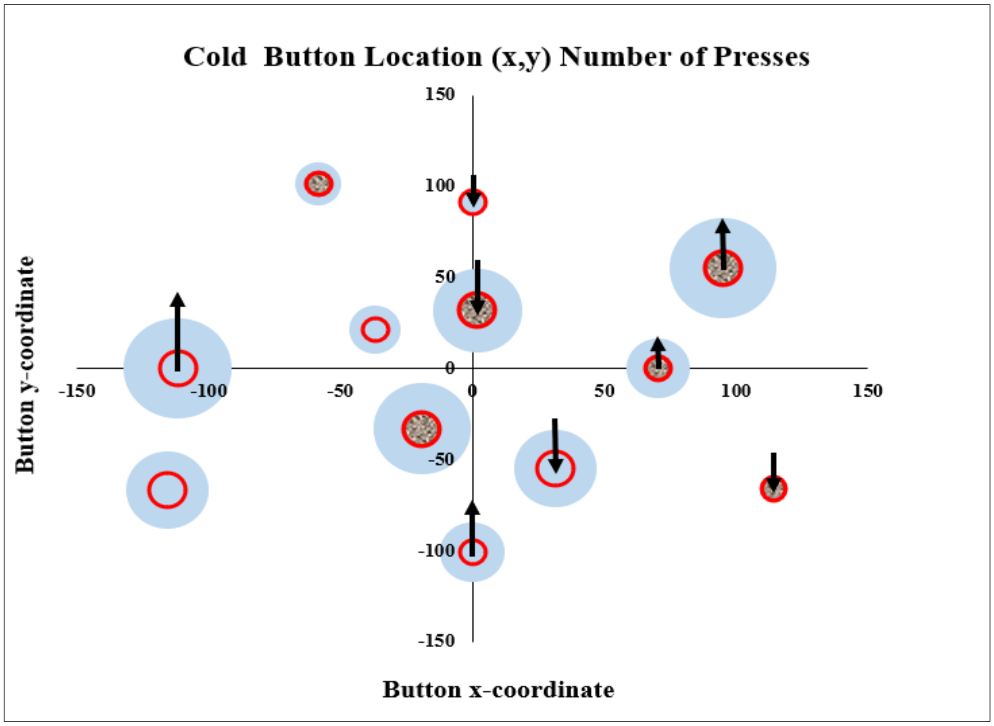


Figure 38: *Total Cold Button Presses*

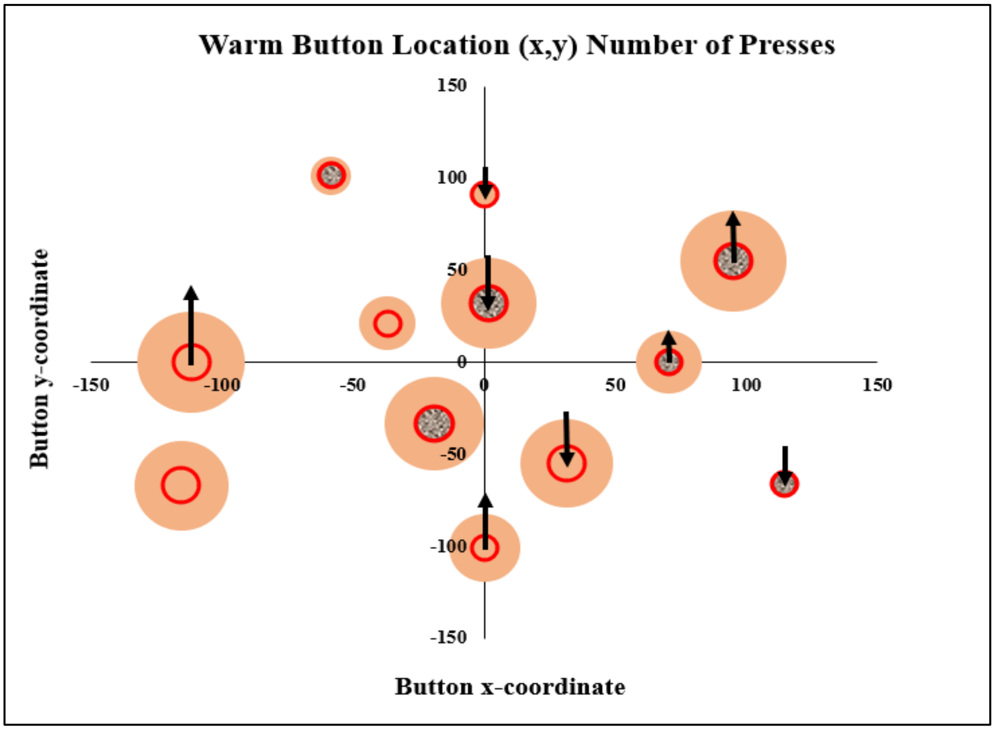


Figure 39: *Total Warm Button Presses*

Figure 37 shows the number of times each individual button was pushed (button 1 to 12) with orange representing the warm temperature condition and blue representing the cold temperature condition. The button pressed the most times for both the warm and cold temperature condition was number 10 which was large in size, protruding and a smooth texture. The second most pressed button was number 3 which was also large in size, protruding but with a rough texture. For button 10 there is 2% difference between the warm and cold temperature condition for total button presses and for button 3 there is 3% difference between the warm and cold temperature condition. The third most pressed button was number 8, which was large, flat, and rough. For button number 8 the percent difference between the presses for warm and cold was around 2 percent. The fourth most pressed button was number 2 which was large, recessed, and rough with a respective percent difference between warm and cold of 13 percent. The fifth most pressed button was number 9 which was large, flat, and smooth and the percent difference among warm and cold for that button number was about 22 percent.

The sixth most pressed button was number 6 which was large, recessed, and smooth with a difference between warm and cold of 21%. The seventh most pressed button was number 7 which was small, protruding, and smooth with a difference between warm and cold of around 17%. The eighth most pressed button was number 4 which was small protruding and rough with a difference between warm and cold of 11%. The ninth most pressed button was number 11 which was small, flat, and smooth with a difference between cold and warm of about 18%. The tenth most pressed button was number 12 which was small, flat, and rough with a difference between warm and cold of 24%.

The eleventh most pressed button was number 5 which was small, recessed, and rough with a difference between warm and cold of around 33%. The button pressed the least overall was number

1 which was small recessed and smooth, with the difference between warm and cold being around 22%.

It can also be seen that there is more of a difference between warm and cold for certain button types. For the large button types such as large, flat, smooth, and large, flat, recessed the respective difference between both warm and cold was around > 20 percent. However, for the most pressed buttons such as large protruding smooth, large protruding rough and large flat rough the percent difference between warm and cold was around 2, 3 and 2 percent. For the buttons pressed the least which were small, recessed, rough and small, recessed smooth there was a difference between warm and cold of around 33 percent and 22 percent respectively. This could be investigated further by looking into specific button types (flat, recessed) with additional experiments

Overall, the total presses in the warm condition were 775 presses for any button compared to the cold with 707 presses which is a difference of about 9%, suggesting little difference between warm and cold conditions. **Figure 38** and **Figure 39** also supported visually that there was a slight difference between total buttons pressed in the warm compared to cold. In those diagrams the arrow pointing upwards depicted the protruding button types, and the arrows pointing downwards the recessed button types. Also, the rough buttons are shown in grey, the smooth are depicted in a plain colour and the large vs. small was shown through the small and large red circles.

However, to further optimize the design and to conduct a more in-depth analysis between the warm and cold for button particulars and for determining the significant design factors for both warm and cold a design expert software analysis was carried out in **Section 5.4**.

5.4.1 Design Expert Analysis Cold Temperature Condition

In Design Expert software, for the cold temperature condition, the different buttons, and their design factors (size, shape, and texture) were used as inputs with the total number of times each of those buttons were pressed in the cold.

Table 18: Data Input for Cold Total Button Presses Design Expert Software

		Factor 1	Factor 2	Factor 3	Response 1
Std	**Run**	**A:Button Size**	**B:Button Texture**	**C:Button Shape**	**Total times pressed**
1	1	Large	Rough	Protruding	119
10	2	Small	Rough	Recessed	4
2	3	Small	Rough	Protruding	41
4	4	Small	Smooth	Protruding	43
8	5	Small	Smooth	Flat	27
7	6	Large	Smooth	Flat	72
5	7	Large	Rough	Flat	99
12	8	Small	Smooth	Recessed	7
9	9	Large	Rough	Recessed	83
6	10	Small	Rough	Flat	21
11	11	Large	Smooth	Recessed	71
3	12	Large	Smooth	Protruding	120

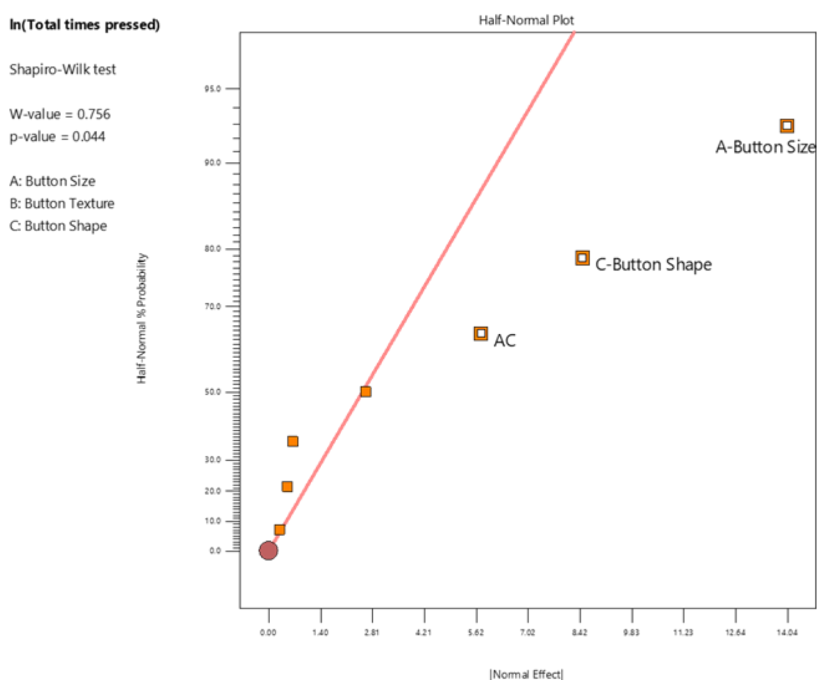


Figure 40: *Half Normal Plot Cold Button Presses*

Table 19: ANOVA Table of Results for Factorial Model for the Cold Condition (Natural Log Transformation)

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	13.09	5	2.62	62.26	< 0.0001	significant
A-Button Size	8.29	1	8.29	197.14	< 0.0001	
C-Button Shape	3.24	2	1.62	38.51	0.0004	
AC	1.56	2	0.781	18.58	0.0027	
Residual	0.2522	6	0.042			
Cor Total	13.34	11				

The Model F-value of 62.26 implies the model is significant. P-values less than 0.0500 indicate the model terms are significant. In this case A (Button Size) and C (Button Shape) are significant model terms as well as interaction AC. Button size is more significant than button shape and button texture is not a significant factor.

Table 20: Model Fit Statistics for Cold Button Presses

Std. Dev.	0.205	**R^2**	0.9811
Mean	3.69	**Adjusted R^2**	0.9653
C.V. %	5.56	**Predicted R^2**	0.9244
		Adeq Precision	21.5008

The Predicted R^2 of 0.9244 is in reasonable agreement with the Adjusted R^2 of 0.9653, as the difference is less than 2. The Adeq precision ratio is greater than 4 at 21.5008 indicating a good model.

Table 21: Optimization Table of Results for Total Cold Button Presses

Number	Button	Button	Button Shape	Total times	Desirability	
1	**Large**	***Smooth***	**Protruding**	**122.037**	**0.999**	**Selected**
2	Large	*Rough*	Protruding	122.037	0.999	
3	Large	*Rough*	Flat	86.221	0.897	
4	Large	*Smooth*	Flat	86.221	0.897	
5	Large	*Smooth*	Recessed	78.397	0.869	
6	Large	*Rough*	Recessed	78.397	0.869	
7	Small	*Smooth*	Protruding	42.88	0.691	
8	Small	*Rough*	Protruding	42.88	0.691	
9	Small	*Rough*	Flat	24.318	0.524	
10	Small	*Smooth*	Flat	24.318	0.524	
11	Small	*Rough*	Recessed	5.404	0.082	
12	Small	*Smooth*	Recessed	5.404	0.082	

It can be seen from **Table 21**, that after optimization that both the large rough protruding button and the large smooth protruding button have equal desirability of 0.999 for the most button presses for maximization of button presses of 122.037 times pressed and for minimization of button presses both the small smooth recessed and the small rough recessed yield the smallest desirability value of 0.082 with 5.404 button presses.

5.4.2 Design Expert Analysis Warm Temperature Condition

In Design Expert for the warm temperature condition the different buttons and their design factors (size, shape, and texture) were used as inputs with the total number of times each of those buttons were pressed in the warm.

Table 22: Data Input for the Warm Condition Design Expert

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:Button Size	B:Button Texture	C:Button Shape	Total times pressed
6	1	Small	Rough	Flat	17
8	2	Small	Smooth	Flat	33
5	3	Large	Rough	Flat	101
11	4	Large	Smooth	Recessed	90
10	5	Small	Rough	Recessed	6
4	6	Small	Smooth	Protruding	52
12	7	Small	Smooth	Recessed	9
9	8	Large	Rough	Recessed	95
3	9	Large	Smooth	Protruding	118
2	10	Small	Rough	Protruding	46
7	11	Large	Smooth	Flat	92
1	12	Large	Rough	Protruding	116

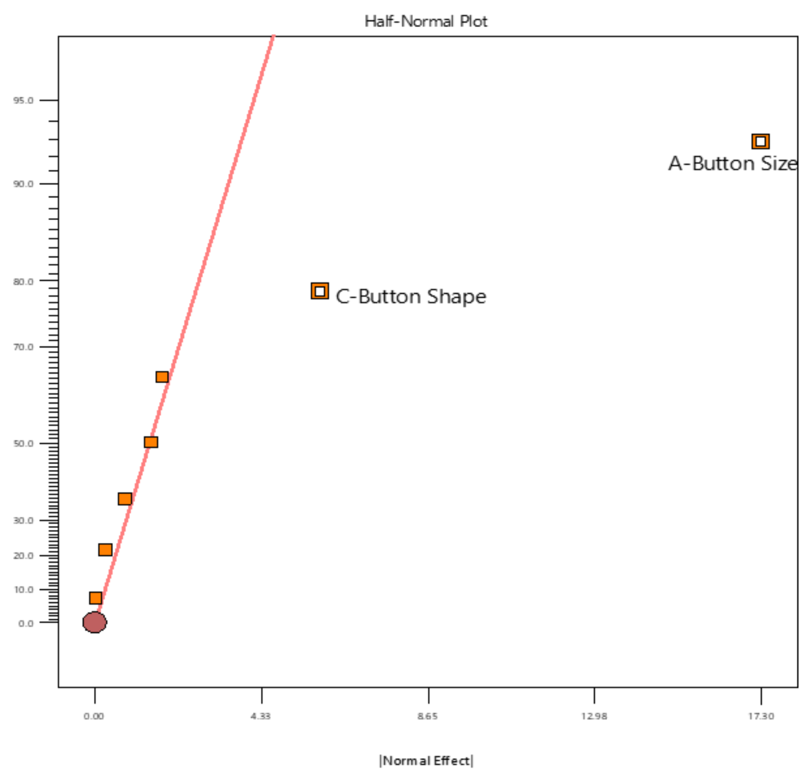


Figure 41: *Half Normal Plot Warm Button Presses*

Table 23: ANOVA Table of Results for Warm Factorial Model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	19066.25	3	6355.42	138.66	< 0.0001	significant
A-Button Size	16800.08	1	16800.08	366.55	< 0.0001	
C-Button Shape	2266.17	2	1133.08	24.72	0.0004	
Residual	366.67	8	45.83			
Cor Total	19432.92	11				

The Model F-value of 138.66 implies the model is significant. P-values less than 0.0500 indicate the model terms are significant. In this case A (Button Size) and C (Button Shape) are significant model terms. Button size is more significant than button shape and button texture is not a significant factor.

Table 24: Model Fit Statistics for Warm Button Presses

Std. Dev.	6.77	**R^2**	0.9811
Mean	64.58	**Adjusted R^2**	0.9741
C.V. %	10.48	**Predicted R^2**	0.9575
		Adeq Precision	27.5882

The Predicted R^2 of 0.9575 is in reasonable agreement with the Adjusted R^2 of 0.9741, as the difference is less than 2. The Adeq precision ratio is greater than 4 at 27.5882 indicating a good model.

Table 25: Optimization Table of Results for Warm Button Presses

Number	Button Size	Button Texture	Button Shape	Total times pressed	Desirability	
1	**Large**	***Rough***	**Protruding**	**120.417**	**1.000**	**Selected**
2	Large	*Smooth*	Protruding	120.417	1.000	
3	Large	*Smooth*	Flat	98.167	0.823	
4	Large	*Rough*	Flat	98.167	0.823	
5	Large	*Rough*	Recessed	87.417	0.727	
6	Large	*Smooth*	Recessed	87.417	0.727	
7	Small	*Smooth*	Protruding	45.583	0.353	
8	Small	*Rough*	Protruding	45.583	0.353	
9	Small	*Smooth*	Flat	23.333	0.155	
10	Small	*Rough*	Flat	23.333	0.155	
11	Small	*Smooth*	Recessed	12.583	0.059	
12	Small	*Rough*	Recessed	12.583	0.059	

It can be seen from **Table 25**, that after optimization both the large rough protruding button and the large smooth protruding button have equal desirability of 1.000 for the most button presses for maximization of button presses of 120.417 total times pressed. For minimization of button presses both the small smooth recessed and the small rough recessed yield the smallest desirability value of 0.059 with 12.583 total button presses.

5.4.3 Design Expert Analysis to Consider Panel Orientation

In order to confirm whether panel orientation was a significant factor or not, an analysis in Design Expert software was carried out where each button characteristic along with the total number of times the button was pressed in that given orientation was inputted into the software. In this case, as shown in Section 5.4.1 and Section 5.4.2, temperature was not a significant factor in the design as the outcomes for both the cold and the warm as well as their significant factors (button size and button shape) and the optimization results for maximum button presses yield the same button configuration.

Table 26: Data Input for Design Expert Software for Total Button Presses for Each Orientation

		Factor 1	Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:Orientation	A:Button Size	B:Button Texture	C:Button Shape	Total times pressed
36	1	W	Small	Smooth	Recessed	4
44	2	W	Small	Rough	Recessed	2
9	3	N	Small	Rough	Protruding	18
11	4	E	Small	Rough	Protruding	22
16	5	W	Large	Rough	Protruding	61
23	6	E	Large	Smooth	Flat	35
26	7	S	Small	Rough	Flat	6
42	8	S	Small	Rough	Recessed	4
2	9	S	Small	Smooth	Protruding	21
4	10	W	Small	Smooth	Protruding	22
43	11	E	Small	Rough	Recessed	2
14	12	S	Large	Rough	Protruding	79
3	13	E	Small	Smooth	Protruding	23
1	14	N	Small	Smooth	Protruding	29
21	15	N	Large	Smooth	Flat	44
25	16	N	Small	Rough	Flat	12
35	17	E	Small	Smooth	Recessed	9
29	18	N	Large	Rough	Flat	58
46	19	S	Large	Rough	Recessed	49
15	20	E	Large	Rough	Protruding	47
22	21	S	Large	Smooth	Flat	35
12	22	W	Small	Rough	Protruding	23
40	23	W	Large	Smooth	Recessed	38
45	24	N	Large	Rough	Recessed	52
32	25	W	Large	Rough	Flat	48
6	26	S	Large	Smooth	Protruding	37
7	27	E	Large	Smooth	Protruding	41
37	28	N	Large	Smooth	Recessed	41
27	29	E	Small	Rough	Flat	15
48	30	W	Large	Rough	Recessed	40
20	31	W	Small	Smooth	Flat	11
39	32	E	Large	Smooth	Recessed	32
28	33	W	Small	Rough	Flat	5
41	34	N	Small	Rough	Recessed	2
17	35	N	Small	Smooth	Flat	18
34	36	S	Small	Smooth	Recessed	1
47	37	E	Large	Rough	Recessed	37
33	38	N	Small	Smooth	Recessed	0
8	39	W	Large	Smooth	Protruding	66
19	40	E	Small	Smooth	Flat	20
31	41	E	Large	Rough	Flat	37
18	42	S	Small	Smooth	Flat	11
30	43	S	Large	Rough	Flat	57
24	44	W	Large	Smooth	Flat	50
10	45	S	Small	Rough	Protruding	24
5	46	N	Large	Smooth	Protruding	94
13	47	N	Large	Rough	Protruding	48
38	48	S	Large	Smooth	Recessed	50

Table 27: Initial ANOVA Table of Results for Total Button Presses per Orientation Factorial Model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	18612.83	6	3102.14	34.15	< 0.0001	significant
A-Orientation	444.33	3	148.11	1.63	0.1971	
B-Button Size	15552	1	15552	171.21	< 0.0001	
D-Button Shape	2616.5	2	1308.25	14.4	< 0.0001	
Residual	3724.17	41	90.83			
Cor Total	22337	47				

The Model F-value of 34.15 implies the model is significant. P-values less than 0.0500 indicate the model terms are significant. In this case B (Button Size) and D (Button Shape) are significant model terms. Button size is more significant than button shape and button texture is not a significant factor, nor is panel orientation.

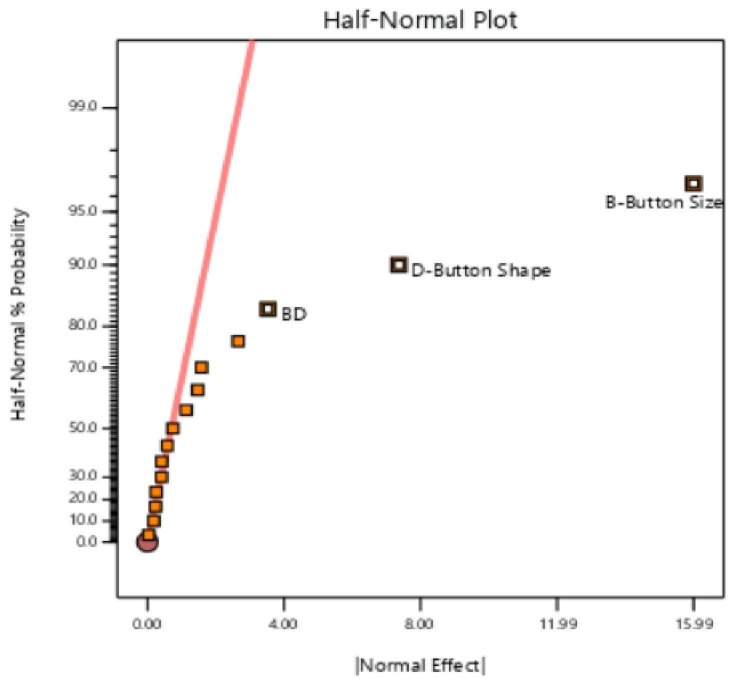


Figure 42: *Final Half-Normal Plot for Total Button Presses per Orientation*

Table 28: Final Model Fit Statistics for Each Panel Orientation Total Button Presses

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	211.62	5	42.32	66	< 0.0001	significant
B-Button Size	163.98	1	163.98	255.72	< 0.0001	
D-Button Shape	37.66	2	18.83	29.37	< 0.0001	
BD	9.97	2	4.99	7.78	0.0013	
Residual	26.93	42	0.6413			
Cor Total	238.55	47				

The Model F-value of 42.32 implies the model is significant. P-values less than 0.0500 indicate the model terms are significant. In this case B (Button Size) and D (Button Shape) and interaction BD are significant model terms. Button size is more significant than button shape.

Table 29: Model Fit Statistics for Total Button Presses for Each Panel Orientation

Std. Dev.	0.8008	**R^2**	0.8871
Mean	5.09	**Adjusted R^2**	0.8737
C.V. %	15.75	**Predicted R^2**	0.8525
		Adeq	21.433

The Predicted R^2 of 0.8871 is in reasonable agreement with the Adjusted R^2 of 0.8737, as the difference is less than 2. The Adeq precision ratio is greater than 4 at 21.433 indicating a good model.

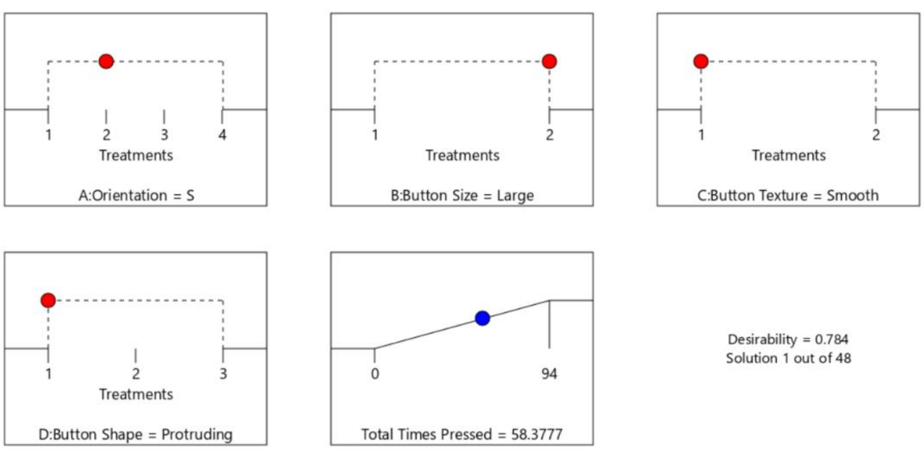


Figure 43: *Optimization Max Total Button Presses for Combined Warm/Cold Design Each Orientation*

It can be seen in **Figure 43**, that in order to maximize the total number of button presses it aligns with a large, smooth, and protruding button with a total of 58.3777 presses and a desirability of 0.784.

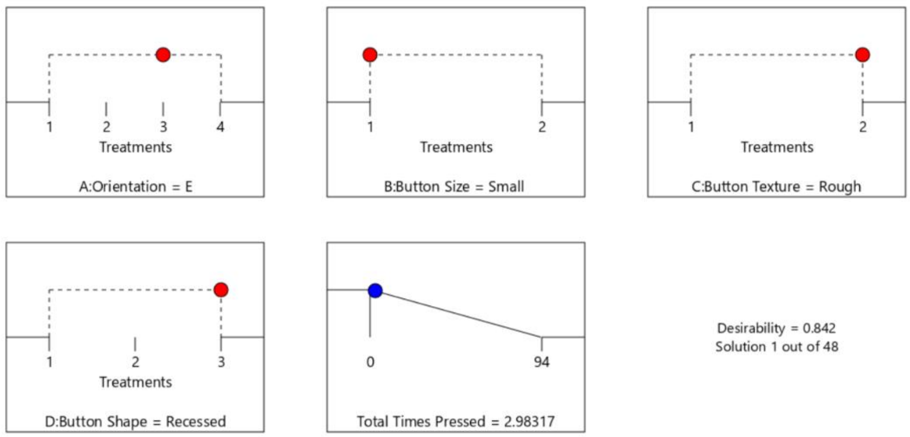


Figure 44: *Optimization Min Total Button Presses for Combined Warm/Cold Design Each Orientation*

It can be seen in **Figure 44**, that in order to minimize the total number of button presses it aligns with a small, rough, and recessed button with a total of 2.98 presses and a desirability of 0.842.

5.5 Main Findings Participant Performance

In order to investigate the participants' performance, three different categories were investigated. The first category was the largest number of button presses in general for the cold session. The second was the number of different button types which were found and pressed and the third was the number of small button designs which were found and pressed.

5.5.1 The Cold Condition

Figure 45 shows the total button presses for each participant in the cold temperature condition. These button presses are for any button on the panel, representing the total amount of button clicks in the cold experimental session. It can be seen from **Figure 45**, that the greatest number of times any button was pressed equated to around 41 presses and the minimum number of presses at around 12 button presses and the mean is around 24 button presses. 12 participants were above the mean value for total button presses and 17 participants were below the mean for total buttons presses.

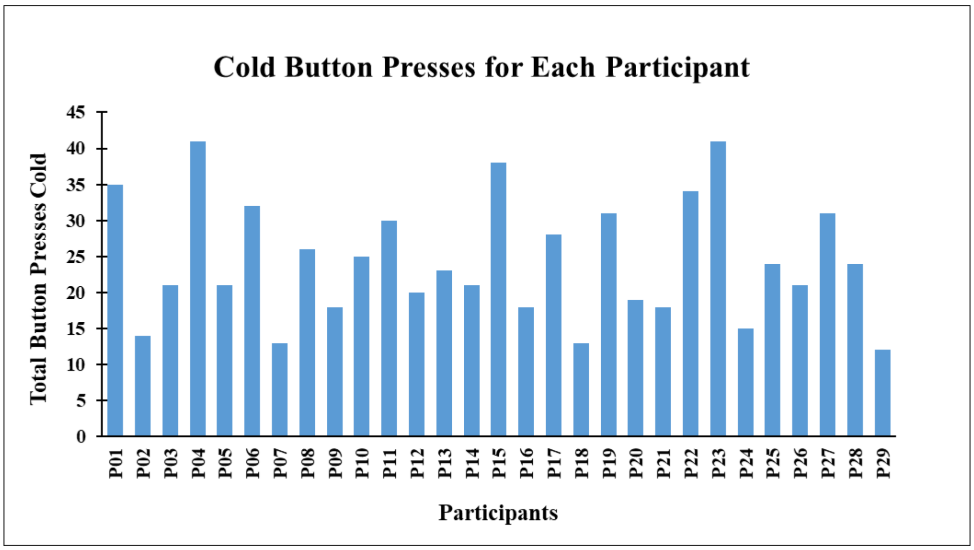


Figure 45: *Total Button Presses in the Cold for Each Participant*

Figure 46 shows the number of different button types (out of 12) that each participant pushed having a cold wet hand. The graph shows that the most variety of button types pressed had a maximum of 12 (all button designs) and a minimum of 4 button designs, with a sample mean of around 8 different button designs pressed. **Table 30** shows in more detail the breakdown of the variety of different buttons pressed for the cold. It can be seen for the most part that the participants either found 6, 8 or 9 different button types and that only 2 out of the 29 participants found all of the button types. This only but exemplifies the importance of button size regarding both finding and depressing a button.

Table 30: Variety of Buttons Pressed in the Cold by the Participants

Variety of Different Buttons Pressed	Number of Participants	Percentage
Four button types pressed	1	3%
Five button types pressed	1	3%
Six button types pressed	5	17%
Seven button types pressed	4	14%
Eight button types pressed	5	17%
Nine button types pressed	5	17%
Ten button types pressed	3	10%
Eleven button types pressed	3	10%
All button types pressed	2	7%

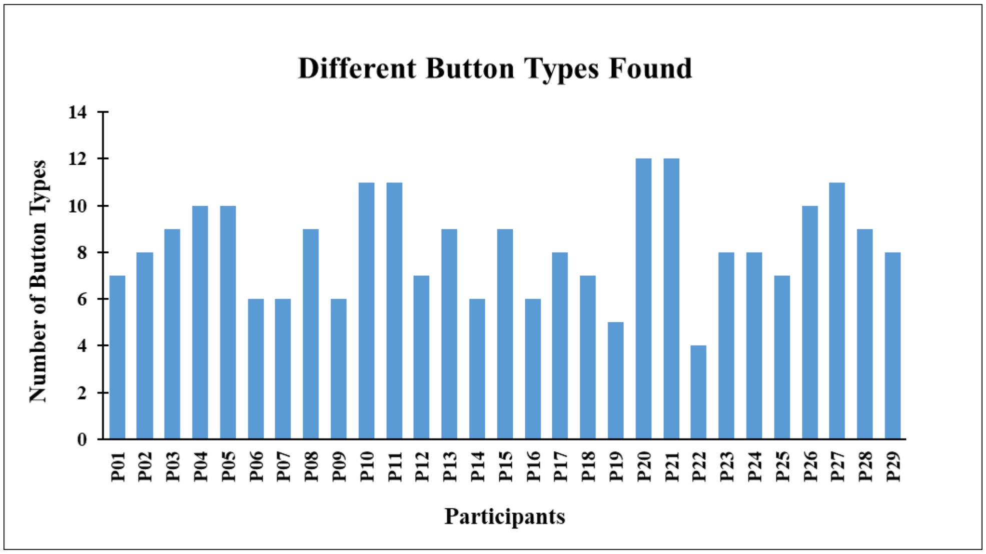


Figure 46: *Number of Different Buttons Pushes in the Cold for each Participant*

Figure 47 shows how many of the small buttons each of the participants pushed in the cold temperature condition. It can be seen from the graph that the small button designs pressed most often was 6 buttons by only 2 participants and the least number of small buttons pressed corresponded to finding no small buttons which was 7 of the participants. Overall, the average number of small buttons pressed by participants was around 2.5 small button designs out of the six, which represents pressing less than half of the 6 small button types. This is shown in more detail in **Table 31** for the breakdown of pushing small button designs.

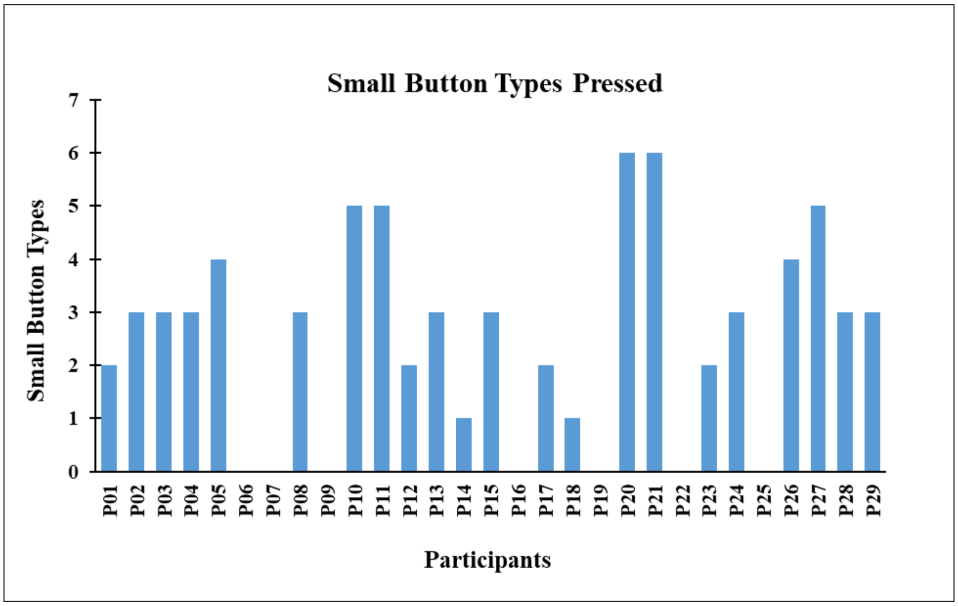


Figure 47: *Amount of Small Button Types Pressed in the Cold for each Participant*

Table 31: Number of Small Button Designs Pressed by Participants in the Cold

Small Button Breakdown	Number of Participants	Percentage
Pressed no small buttons	7	25%
Pressed one small button	2	7%
Pressed two small buttons	4	14%
Pressed three small buttons	9	32%
Pressed four small buttons	2	7%
Pressed 5 small buttons	3	11%
Pressed 6 small buttons (all)	2	7%

5.5.2 The Warm Condition

Figure 48 shows the total button presses for each participant in the warm temperature condition. It can be seen from **Figure 48**, that the greatest number of times any button was pressed equated to around 56 times and the minimum number of times any button was pushed was 11 times, with a mean of around 27 pushes. 13 participants were above the mean value and 17 participants were below the mean for total buttons presses for the warm.

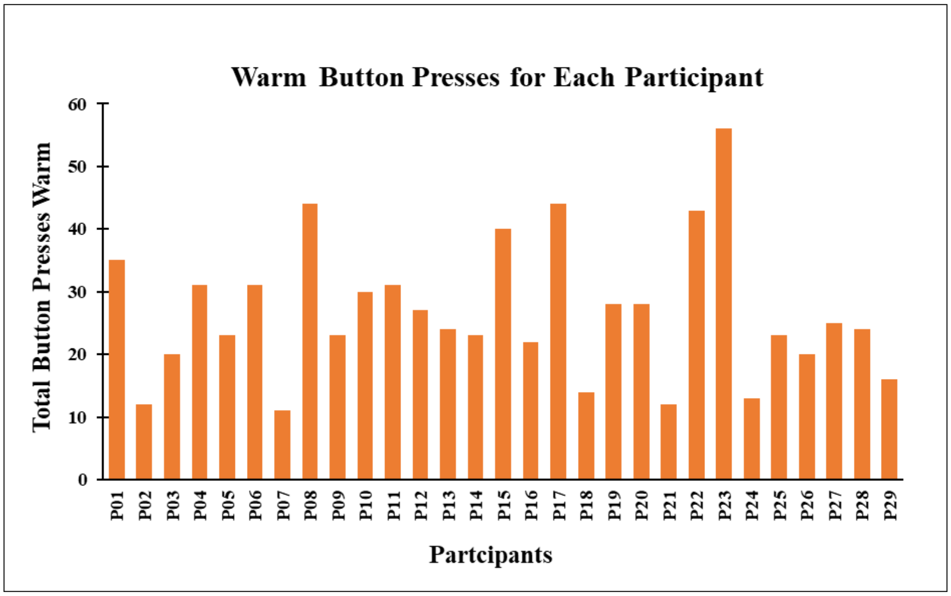


Figure 48: *Total Button Presses in the Warm for each Participant*

Figure 49 shows the number of different button types (out of 12) that each participant pushed having a warm wet hand. The graph shows that the most variety of button types pressed had a maximum of 11 button designs and a minimum of 4 button designs, with a sample mean of around 8 different button designs pressed. This sample mean is the same as in the cold temperature condition for variety of button designs pressed. **Table 32** shows in more detail the breakdown of the variety of different buttons pressed in the warm. It can be seen for the most part that the participants either found 11 different button types and that none of the participants found all button designs.

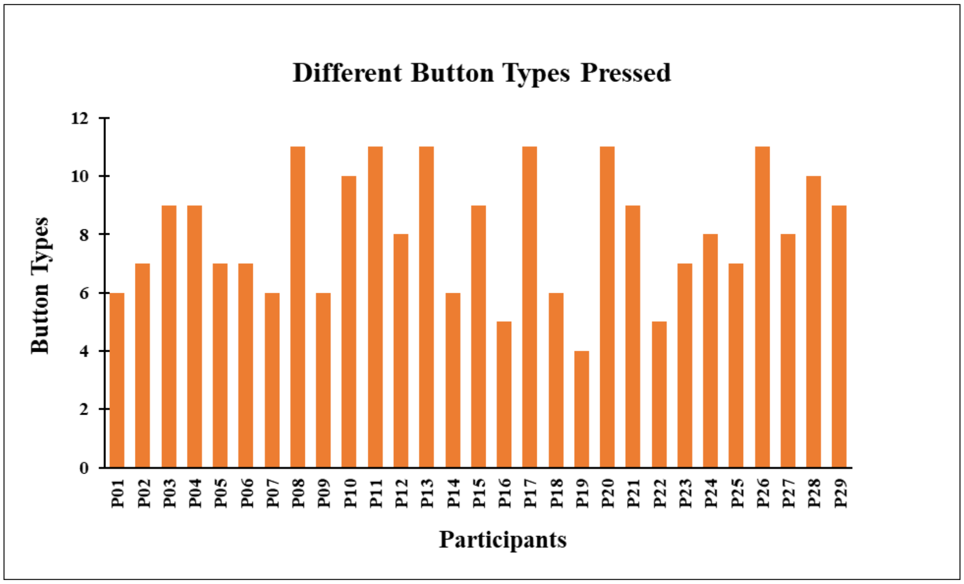


Figure 49: *Number of Different Buttons Pushed in the Warm for each Participant*

Table 32: Variety of Buttons Pressed in the Warm by Participants

Variety of Different Buttons Pressed	Number of Participants	Percentage
Four button types pressed	1	4%
Five button types pressed	2	7%
Six button types pressed	5	18%
Seven button types pressed	5	18%
Eight button types pressed	3	11%
Nine button types pressed	5	18%
Ten button types pressed	2	7%
Eleven button types pressed	6	21%
All button types pressed	0	0%

Figure 50 shows how many of the small buttons each of the participants pushed with a warm wet hand. It can be seen from the graph that the most small button designs pressed was 5 different designs by 7 participants and the least number of small buttons pressed corresponded to finding no small buttons which was 8 of the participants. Overall, the average number of small buttons pressed by participants was around 2.4 small button designs out of the six, which represents pressing less than half of the 6 small button types. This is shown in more detail in **Table 33** for the breakdown of pushing small button designs.

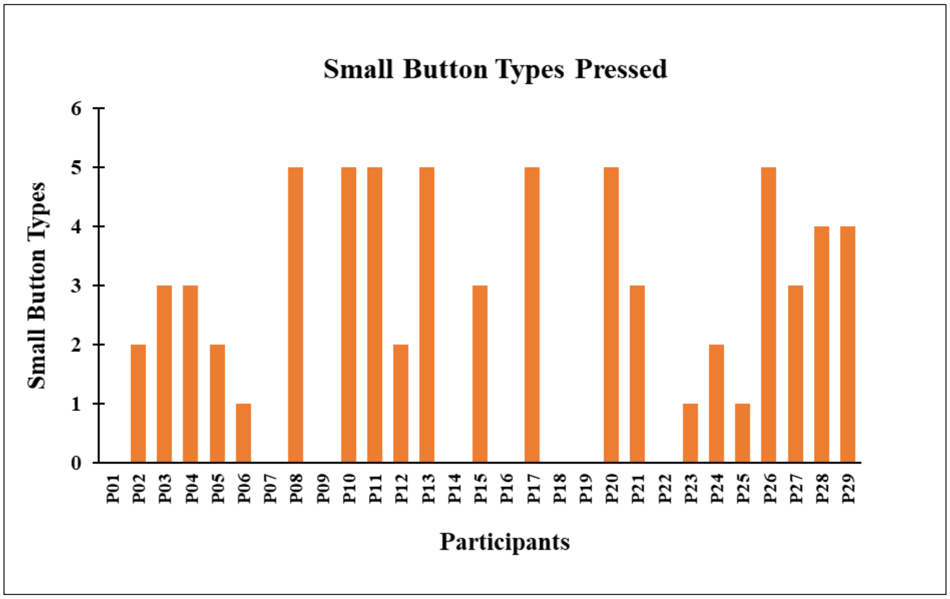


Figure 50: *Amount of Small Button Types Pressed in the Warm for each Participant*

Table 33: Number of Small Button Designs Pressed by Participants in the Warm

Small Button Breakdown	Number of Participants	Percentage
Pressed no small buttons	8	29%
Pressed one small button	3	11%
Pressed two small buttons	5	18%
Pressed three small buttons	5	18%
Pressed four small buttons	2	7%
Pressed 5 small buttons	7	25%
Pressed 6 small buttons (all)	0	0%

Table 34: Summary Table Comparing Warm and Cold Button Performance

	Cold	Warm
Total Button Presses		
Mean	24.4	26.7
Std	8.4	10.9
Min	12	11
Max	41	56
Variety of Different Button Designs Pressed		
Mean	8.2	8.1
Std	2.1	2.1
Min	4	4
Max	12	11
Variety of Small Different Button Designs Pressed		
Mean	2.5	2.4
Std	1.9	1.9
Min	0	0
Max	6	5

5.5.3 Main Findings of Participant Performance

Table 35 outlines the top five participants and the worst five participants for the button test which were rated by analyzing the different button designs found as well as the number of small button types pushed.

Table 35: Top Performance & Low Performance Button Panel Test

Top Performance			
	Temperature	**Different Button Types found**	**Small Button Types Found**
P20	**Cold**	100%	100%
P21	**Cold**	100%	100%
P08	**Warm**	92%	83%
P10	**Cold**	92%	83%
P11	**Cold**	92%	83%
Low Performance			
	Temperature	**Different Button Types found**	**Small Button Types Found**
P22	**Cold**	33%	0%
P19	**Warm**	33%	0%
P16	**Warm**	42%	0%
P19	**Cold**	42%	0%
P22	**Warm**	42%	0%

It can be seen that two participants with the best performance had their dominant hand immersed in the cold temperature condition. Interestingly, the worst performance for pushing a variety of button designs was also found in the cold temperature condition. When looking at the top five participants the main findings were that 4/5 of them were females and all of those females had a smaller tip circumference measurement of their index finger (less than the sample mean). Also, half of the females had a very high Purdue pegboard score (very fast time in seconds) in comparison to the sample mean. The male participant had a higher pinch strength (lbs) than the sample mean. With respect to the lowest performance, two of the participants performed poorly in both the warm and cold button test experimental session. Of the participants who had a poorer performance 4/5 cases had a lower pinch strength than the sample mean and a poorer Purdue pegboard score (longer time in seconds) which was higher than the sample mean. Additionally, in 3/5 cases the index fingertip circumference was larger than the sample mean. These results suggest that finger size might also play a role in a person's ability to activate smaller buttons.

5.6 PLB Questionnaire

In the questionnaire at the end of the experiment, for the section on the PLB tests for both Stage 2 and Stage 4, questions were asked regarding both the confidence of PLB activation as well as the ease of use for PLB activation. The results from the participants are shown below in **Figure 51** and **Figure 52**. Both of these graphs consist of temperature conditions being combined, as temperature was deemed not to affect PLB activation.

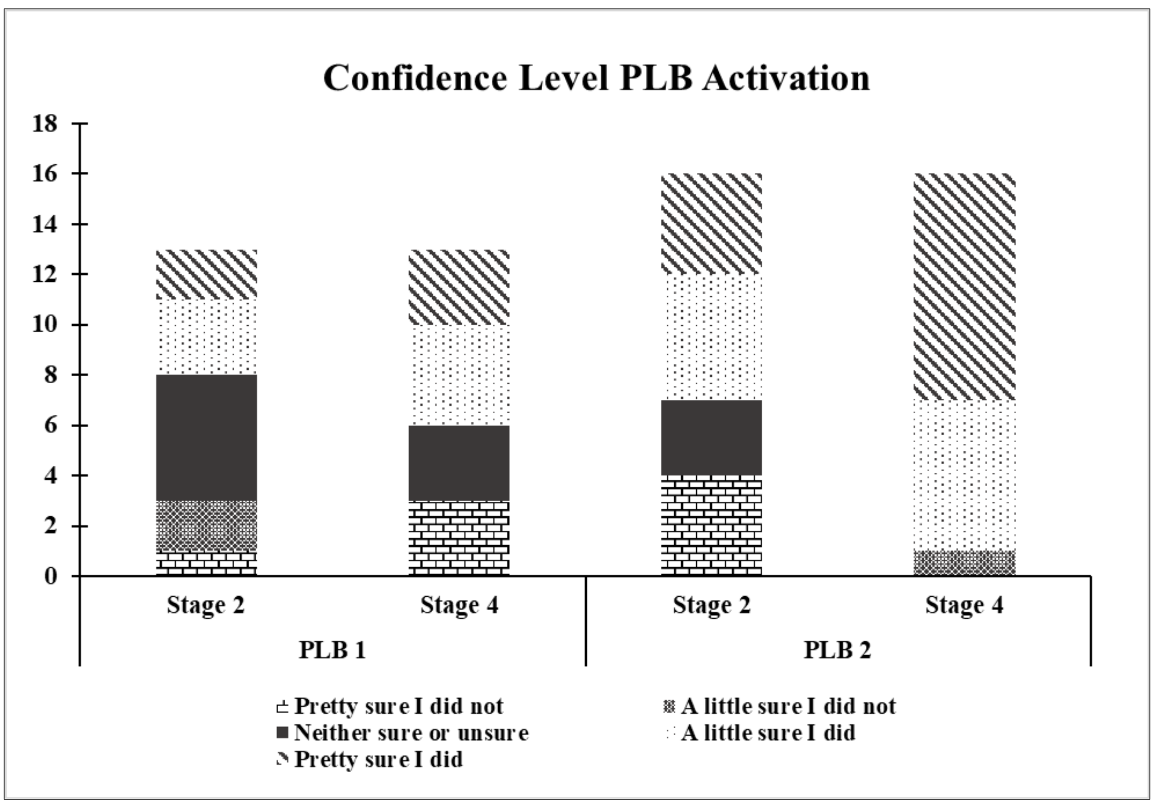


Figure 51: *Participant Confidence PLB Activation Questionnaire Data*

The main finding to be seen from the confidence level PLB activation plot is that more participants felt the most confidence ("pretty sure I did") for the activation of PLB 2 overall. Additionally, for PLB 1 overall more participants were neither sure nor unsure if they had successfully activated it. No participants selected "pretty sure I did not activate the device" in Stage 4 of PLB 2. "A little sure I did not" was selected more often for PLB 1 than for PLB 2. "A little sure I did" was selected more for PLB 2 than PLB 1. For both PLBs, transitioning from Stage 2 to Stage 4 the confidence level percentage increased by Stage 4 ("pretty sure I did"), similarly the case for "a little sure I did".

Table 36: Summary Table Participant Confidence Level PLB Activation

Confidence	PLB 1		PLB 2	
	Stage 2	Stage 4	Stage 2	Stage 4
Pretty sure I did not	8%	23%	25%	0%
A little sure I did not	15%	0%	0%	6%
Neither sure or unsure	38%	23%	19%	0%
A little sure I did	23%	31%	31%	38%
Pretty sure I did	15%	23%	25%	56%

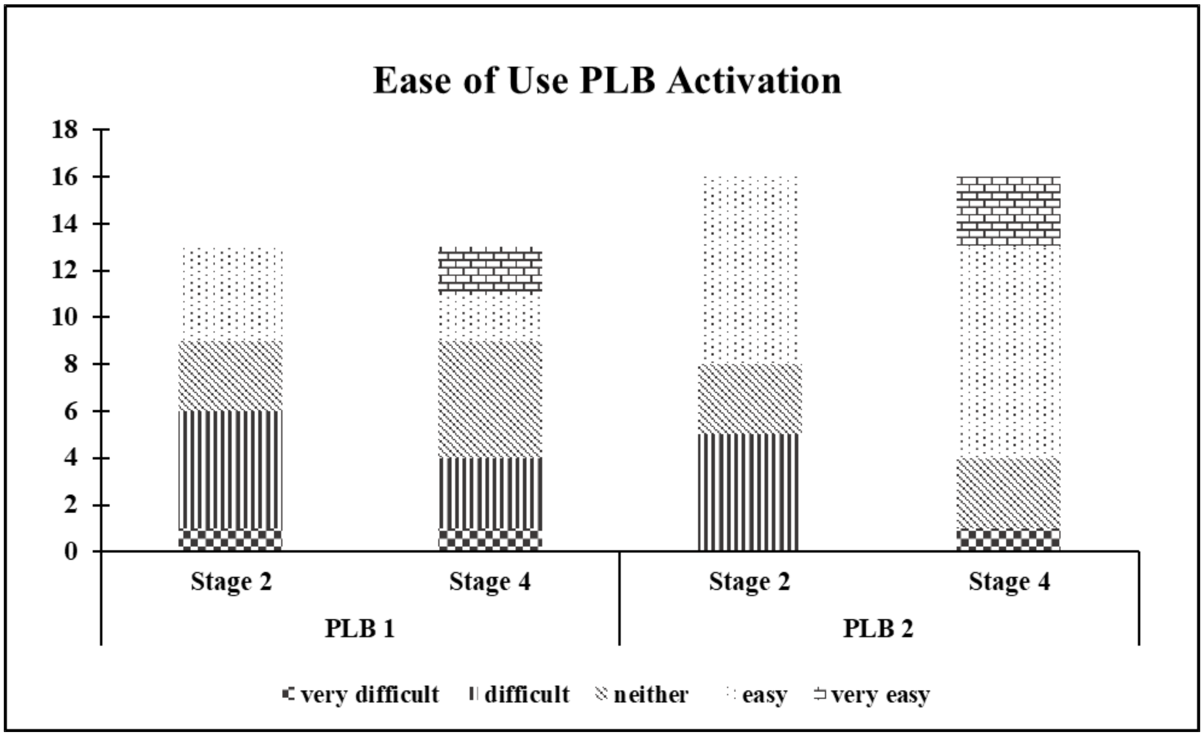


Figure 52: *Participant Ease of Use PLB Activation Questionnaire Data*

Table 37: Summary Table Ease of Use for PLB Activation

Ease of Use	PLB 1		PLB 2	
	Stage 2	Stage 4	Stage 2	Stage 4
very difficult	8%	8%	0%	6%
difficult	38%	23%	31%	0%
neither	23%	38%	19%	19%
easy	31%	15%	50%	56%
very easy	0%	15%	0%	19%

The main finding from the participant ease of use for PLB activation feedback overall is that participants felt PLB 2 was easier to activate, although “very easy” is similar in both devices. More participants felt PLB 1 was both more difficult to activate. The ease-of-use confidence increases for both PLB 1 and PLB 2 from Stage 2 to Stage 4, as well as for very easy for both devices from Stage 2 to Stage 4. Both PLB 1 and PLB 2 were found to be more difficult to use in Stage 2.

Regarding improvements to the design of the PLB to make the devices easier to activate, the following feedback was provided by participants:

- Activation button larger and in the centre of the device (PLB 2)
- Bigger buttons and only one button as the activation button (PLB 1)
- A beep or sound after it is activated would be helpful (vibrating signal) (PLB 2)
- A protruding activation button with a different texture (PLB 1)
- Separate more the side buttons on the device (PLB 1)
- Hearing the click of a button or any sound to know whether its activated (PLB 2)
- A more dextrous button for activation (PLB 2)
- A weaker activation button not so hard to depress (PLB 2)
- A light on the device to see the activation button (PLB 1)
- Hard to know which of the two buttons to activate (PLB 1)

5.7 Button Test Questionnaire

Questionnaire results for the first series of questions about being able to find and press the buttons are shown in **Table 38**.

Table 38: Main Feedback for Button Panel Test for Both Warm and Cold Hands

Buttons easiest to find if hands warm?	Percentage of key terms mentioned by participants
Protruding in shape	30%
Large in size	43%
Recessed in shape	8%
Close to centre of panel	8%
Flat in shape	3%
Texturized buttons	5%
Buttons making a sound	5%
Buttons easiest to depress with warm hands?	**Percentage of key terms mentioned by participants**
Protruding in shape	31%
Large in size	46%
Recessed in shape	8%
Close to centre of panel	8%
Flat in shape	3%
Texturized buttons	0%
Buttons making a sound	5%
Buttons easiest to find with cold hands?	**Percentage of key terms mentioned by participants**
Protruding in shape	31%
Large in size	44%
Recessed in shape	5%
Close to centre of panel	8%
Flat in shape	3%
Texturized buttons	5%
Buttons making a sound	5%
Buttons easiest to depress with cold hands?	**Percentage of key terms mentioned by participants**
Protruding in shape	31%
Large in size	46%
Recessed in shape	8%
Close to centre of panel	8%
Flat in shape	3%
Texturized buttons	0%
Buttons making a sound	5%

It can be seen from **Table 38**, that overall, the responses for both the buttons easiest to find and depress when having a warm wet hand and when having a cold wet hand are very similar. Indicating that the participants felt no difference for both locating and pressing buttons in the warm versus in the cold. This reinforces that temperature was not influential in both finding and depressing buttons. Additionally, across both warm and cold, the large button represented the strongest feedback for ease of locating and depressing a button. This was followed by protruding in shape, recessed in shape and flat in shape. Button texture was barely recognized, highlighting that participants did not notice different button texture (rough vs. smooth).

Participant feedback on their overall performance for the button test in both the warm and cold condition results is shown in **Figure 53**. **Figure 53** displays a series of ranks from Rank 1 (poor) to Rank 5 (very well) in order to represent how the participants felt they performed in the experimental session. It shows that 18 of the participants felt they performed pretty well, 7 participants felt that they performed neither poorly or well, 2 participants felt they performed very well, 2 participants felt they performed a little poorly and none felt poorly. This shows overall that the majority of participants felt confident in their ability to find and press the different buttons. This is especially highlighted by the fact that none of the participants felt they performed poorly.

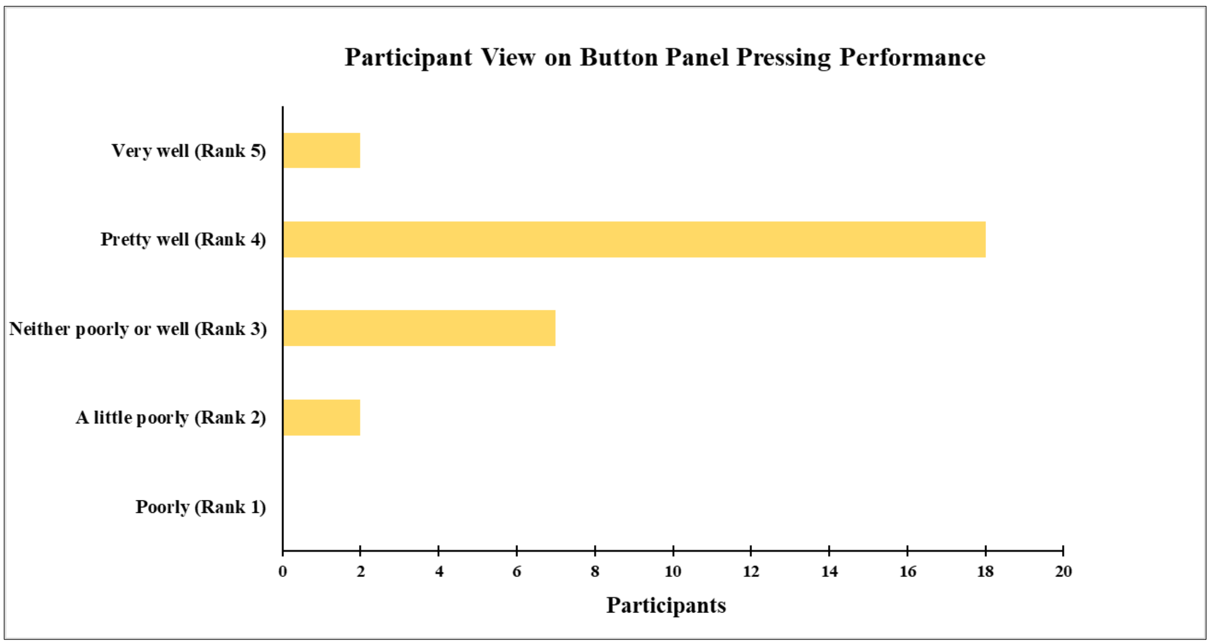


Figure 53: *Participant Feedback on their Performance for the Button Panel Test*

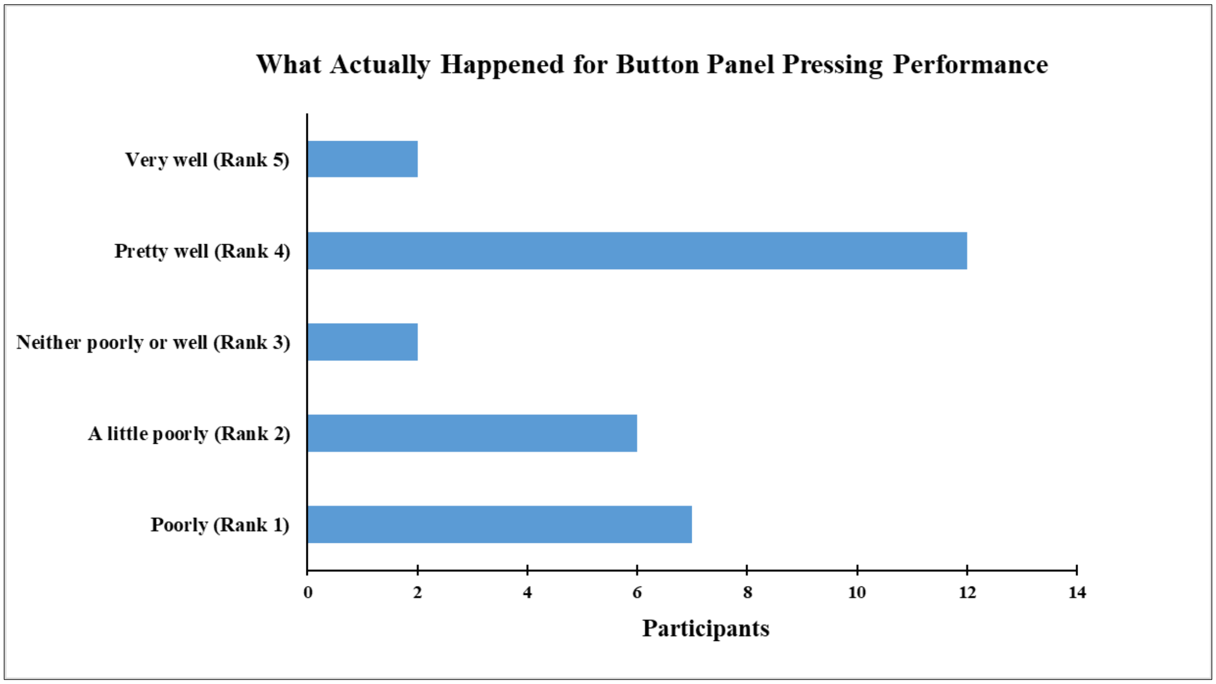


Figure 54: *What Actually Happened for the Participant Performance of the Button Panel Test*

Shown in **Figure 54** is a representation of how the participants *actually* performed in the button panel test. These results were obtained by setting criteria for the participants for each of the ranks and matching their performance outcomes based on the findings of their performance for a) pressing the greatest variety of different button designs in combination with b) pressing and finding the most small button designs. Rank 5 (very well) was based on finding all small buttons and all of the 12 different button designs, where Rank 1 (poorly) was based on the participants finding no small button types and less then 33 percent of all 12 button types. The mean of the sample and percentage intervals which best matched the ranking outcomes were selected for each individual participant. In comparison with how the participants felt they had performed overall between what they thought and what actually happened, "pretty well" is still the majority between both cases. However, more participants performed a little poorly (6 participants), and poorly (7 participants) in reality. In the context of PLB use in practice, this seems a reasonable finding since the devices do help save thousands of lives at sea each year, however, the small proportion of people who thought they performed well but did not, there is cause for some concern.

6.0 Summary Discussion of Results & Recommendations

6.1 PLB Test Comparison

The main findings of the PLB test (Stage 2 and Stage 4) indicate that when not considering the effects of temperature, PLB 2 was activated more often than PLB 1, though the difference is most apparent in Stage 2 where PLB 1 is 23% correctly activated and PLB 2 is 38% correctly activated. For PLB 1 the test button was pressed most commonly in the warm condition, and in the cold condition the device was activated more often than in the warm. Additionally, PLB 1 was activated more often in Stage 2 and Stage 4 cold than warm. For PLB 2 the test button was pressed more in the warm than in the cold, and in the cold for PLB 2 the most common of the outcomes was no buttons pressed. However, the activation rate was similar between cold and warm for successful activation. Overall, PLB 2 was activated more than PLB 1 in the warm. When looking at both PLBs, there is not much difference between successful cold activation versus successful warm activation. This supports the conclusion that temperature does not significantly influence the activation rate of the PLBs and should be considered a positive outcome for people in distress at sea. However, of some concern is the proportion of people who were unable to properly activate the devices, suggesting there was some confusion about which button was the right button to press for activation. This requires further research to better understand the issue.

With respect to the questionnaire, more participants felt strongly that they had successfully activated PLB 2 than PLB 1. PLB 1 had more participants which felt neither sure nor unsure of its activation. This is supported by the findings that more people pressed the test button for PLB 1 which had buttons located on the side. PLB 2 was rated easier to activate by participants, and PLB 1 as more difficult.

Feedback from the participants suggested improvements to make the PLBs easier to activate. For PLB 1 (test button and activation button on the side) it was suggested by the participants to have bigger buttons and to separate the buttons more on the side as it was hard to know which of the two buttons was the activation button. For PLB 2 the main suggestions were regarding a weaker activation button to press more easily and in this case the participant was referring to the test button and thought it the activation button and found it hard to depress. Additionally, it was suggested that PLB 2 should have a more dextrous activation button. From this input in order to improve the design for PLB 1 the test and activation button on the side should not be close to one another which confuses which one to activate. In such an activation button on the front and the test button on the side would be better for the design as the test button would have been more distinguishable from the activation button. For PLB 2, if the activation button was larger then the test button, it would be easier to locate and activate then the test button. Additionally, for PLB 1 if the buttons were larger could also enable easier activation. One drawback to making activation buttons easier to use is that it may also increase the rate of false or accidental activations, which is a known problem for search and rescue authorities. These competing needs of the user and the system efficiency make this a challenging design problem for engineers.

6.2 Button Test

For the button apparatus tests, button size was the most significant factor, followed by button shape for both the warm and cold conditions. Additionally, for both the warm and cold immersion conditions, texture was not significant and the button design which was most often pressed was the same – protruding, large and smooth. The button which was pressed the least was also the same for the two temperature conditions – small, recessed and rough. The button optimization performed in Design Expert software for both the warm and cold condition supported the same button design being pressed the most and least. Additionally, for both large and small buttons, the order of most to least pressed was protruding, flat and recessed. From the analysis it was also demonstrated that there was no significant difference between warm and cold performance. Interestingly, in the cold condition all the button types were found by two participants, whereas in the warm condition only 11 button types were found. As performance does not seem to be influenced by immersion temperature, it is evident that button size is the most influential parameter for both finding and depressing any button. Texture was not significant and that could mean that when the hands are wet maybe the texture is not perceived as strongly as the size and shape of the button. As the protruding shape was the most pressed, in terms of button design, maybe this could contribute to accidental activation of a PLB. So perhaps a flat and large button would be a good compromise for the design.

From the participant feedback, the main comments made were about large buttons and ones which were sticking out from the board (protruding). This is supported by the findings of the experiment that those were indeed the parameters which lead to a higher activation rate of the buttons in both temperature conditions. Texture was barely mentioned by the participants which also reinforces that texture was not a significant parameter in both finding and depressing a button. Interestingly, recessed in shape was mentioned more frequently than flat in shape, which leads to the recessed being felt and noticed but being too hard to be fully pressed.

The findings from the button panel portion of the experiments can be applied to the findings of the PLB portion of the experiment as they are both in agreement with respect to larger buttons. PLB 2 (which had a larger activation button) was activated more often than PLB 1. This suggests that across both the PLB test (Stage 2 and Stage 4) and the button apparatus test (Stage 3), button size was truly the most influential parameter and not temperature. As temperature was also not playing a role for both PLB 1 and PLB 2 in the sense activation rates were comparable between warm and cold for both devices. Regarding button shape, PLB 2 had a slightly protruding shape and PLB 1 more of a flat button shape. So, in this case, the PLB test is in accordance with the findings of the button panel test. With respect to the research hypothesis, it was correct that protruding buttons were the most depressed, however based on the experimental findings there was no difference in a rough button texture versus a smooth button texture. It was hypothesized that rough buttons would be easier to depress, however this ended up not being the case. Additionally, the research hypothesis was that participants would perform more poorly after having their hands cold and wet, however through the main findings of both the PLB tests and the button panel test there wasn't much of a difference in their overall performance among the thermoneutral wet condition and the cold wet condition.

7.0 Conclusions

This thesis investigated how human research participants interact with push buttons after exposure to cold and warm water. The research was focussed specifically on the use of push buttons found on personal locator beacons used to alert search and rescue authorities of an emergency. Four stages of testing was carried out: Stage 1 demonstrated that the research participants were representative of typical members of the population where manual dexterity is concerned. Stage 2 and Stage 4 involved the use of two commercially available PLBs and Stage 3 involved the use of a specially designed push button apparatus to determine which button characteristics were most important for ensuring successful activation. The main findings demonstrated that participant performance when having cold wet hands was comparable to the participant performance having warm wet hands for push button activation of both the PLBs and the test button panel apparatus. Additionally, it was found that the most significant factor affecting successful activation was button size (large), followed by the button shape (protruding), and that button texture was not a significant factor. The large protruding and smooth button was the most used (independent of temperature), and the small recessed and rough button was the least used (independent of temperature). Regarding the activation of the PLBs, the PLB with the test and activation button on the front was more frequently activated overall than the PLB with both the test and activation button located on the side. It was also found that after a basic training session, only about one third of participants were able to properly activate the PLBs, despite most feeling confident that they had successfully done so. In most of these cases, participants had actually pressed the test button which does not alert the search and rescue system. From these findings, it is recommended to design buttons larger than 0.5 cm in diameter. It is also recommended that since test buttons are only meant to be used in controlled situations to confirm the device is in good working order, it would be worth considering making them smaller and positioning them where they cannot be confused with the activation button, however, this requires further research. The findings of the PLB tests emphasize that being familiar with the devices before getting into an emergency situation is very important. Also, even with a minimum amount of training they prove to be difficult to correctly activate. Future research should also include button activation with the use of gloves.

Additionally, for future research it would be beneficial to study the effect of high winds, waves, a combination of both cold and wet on the activation rate of PLB's in order to depict the extra constraints which come from a real-life scenario at sea.

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Appendices

Appendix A: Standardized Tests Boxplots

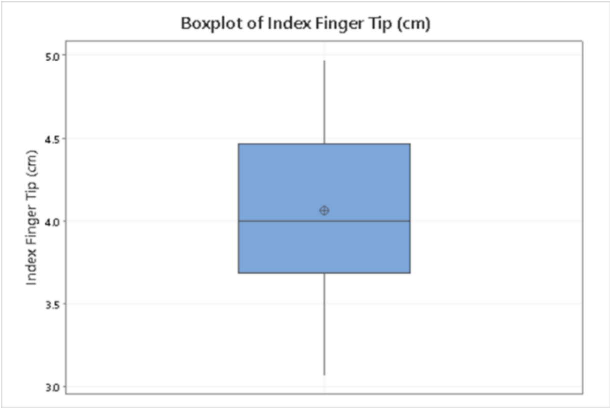

Figure 55: *Boxplot Index Fingertip Measurement (cm)*

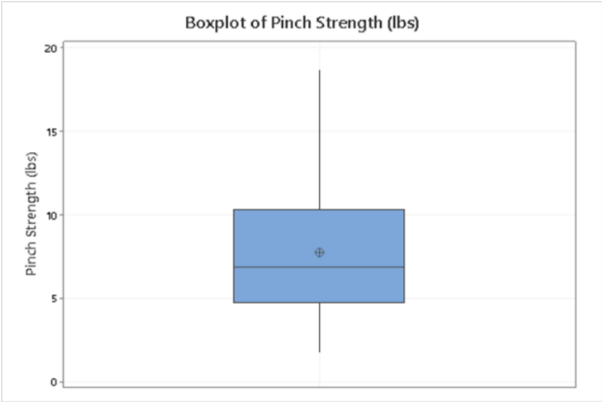

Figure 56: *Boxplot of Pinch Strength (lbs)*

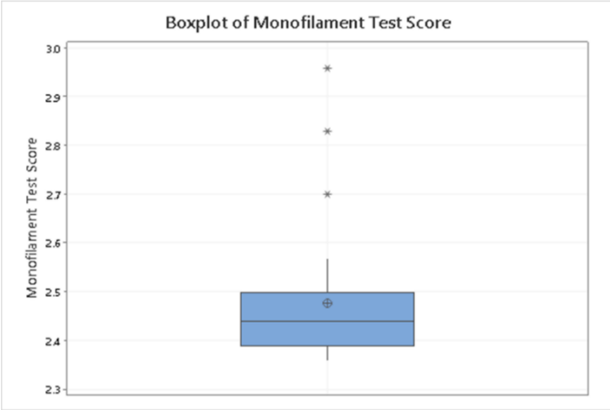

Figure 57: *Boxplot of Monofilament Test Score*

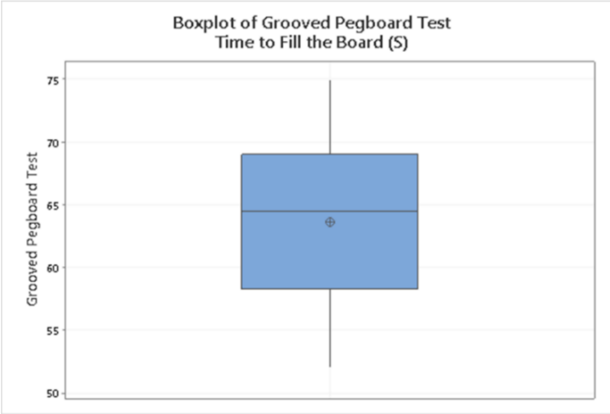

Figure 58: *Boxplot of Grooved Pegboard Score*

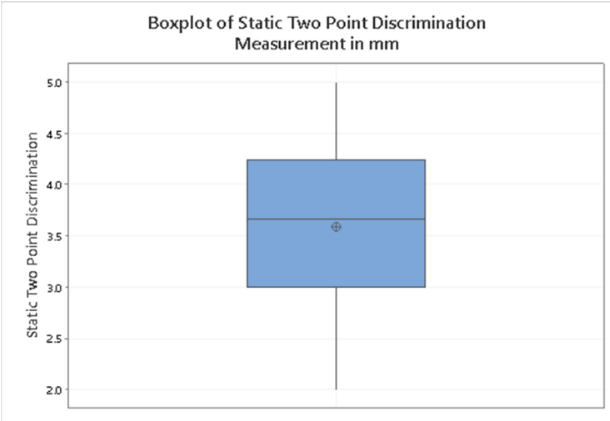

Figure 59: *Boxplot of Static Two Point Discrimination (mm)*

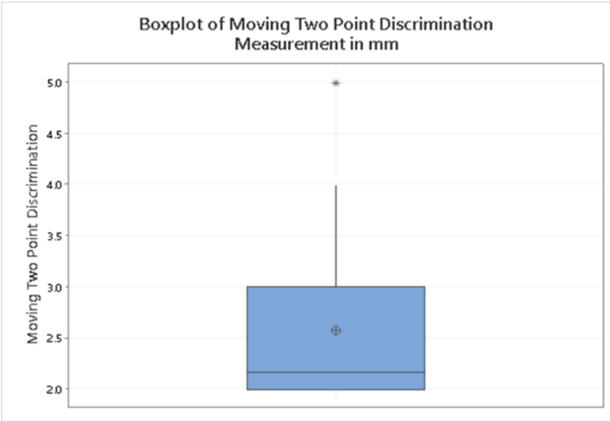

Figure 60: *Boxplot of Moving Two Point Discrimination (mm)*

Appendix B: Design Expert Diagnostic Plots for Warm Temperature Condition

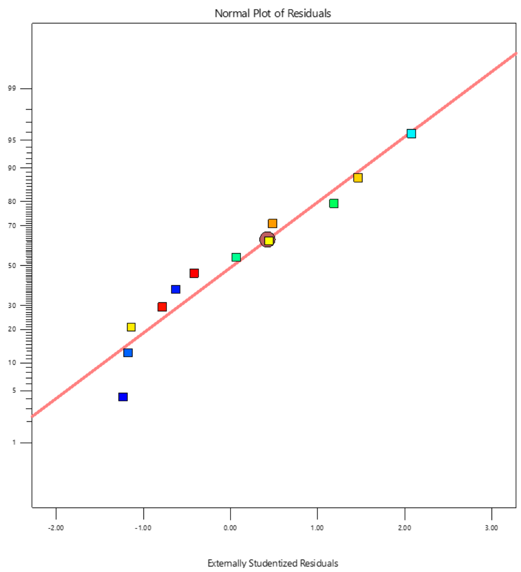

Figure 61: *Normal Plot of Residuals Warm*

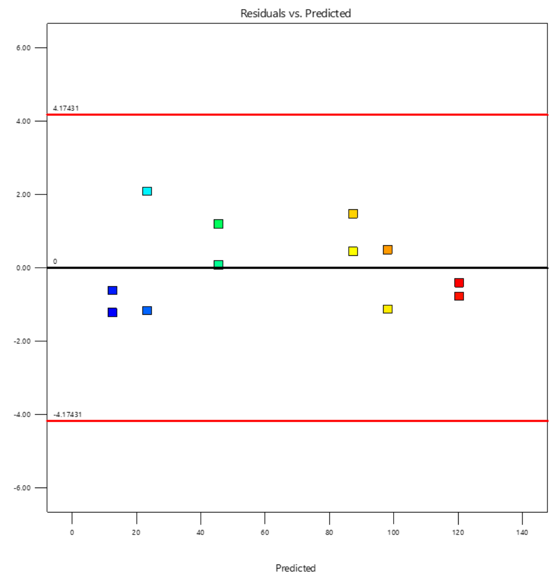

Figure 62: *Residuals vs. Predicted Warm*

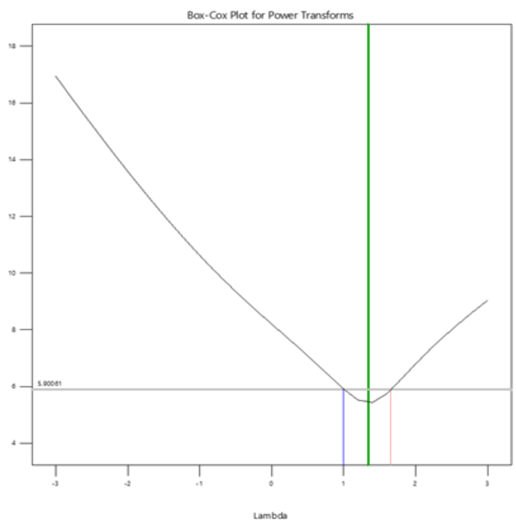

Figure 63: *Box-Cox Plot Warm*

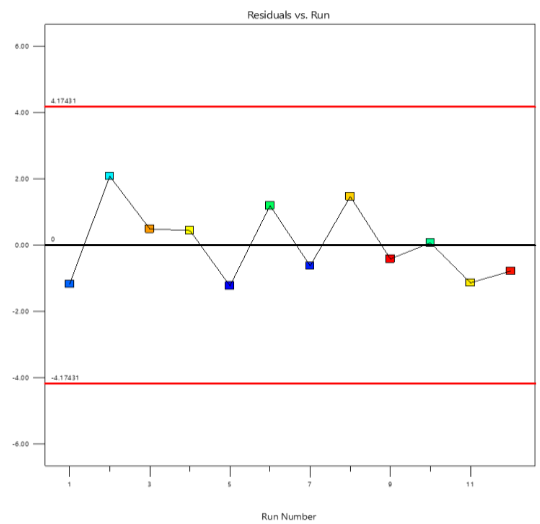

Figure 64: *Residuals vs. Run Order Warm*

Appendix C: Design Expert Diagnostic Plots for Cold Temperature Condition

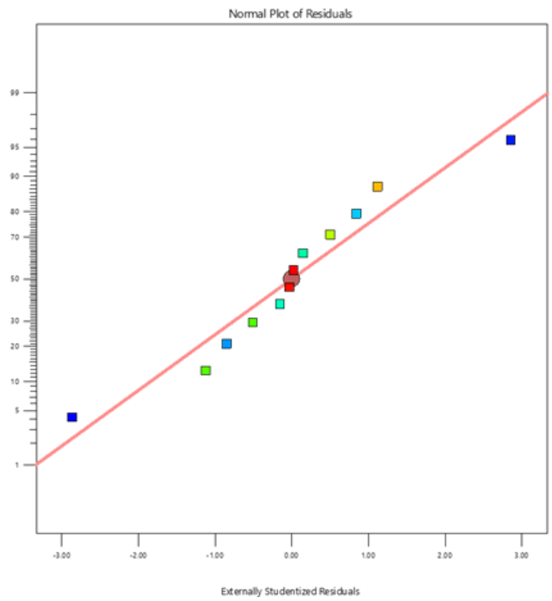

Figure 65: *Normal Plot of Residuals Cold*

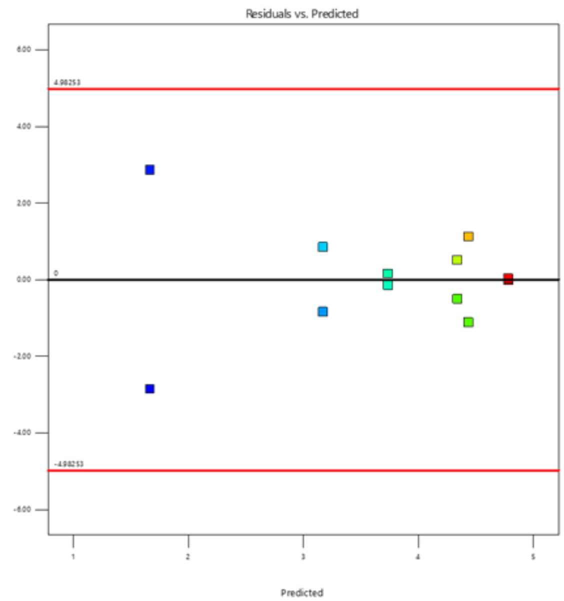

Figure 66: *Residuals vs. Predicted Cold*

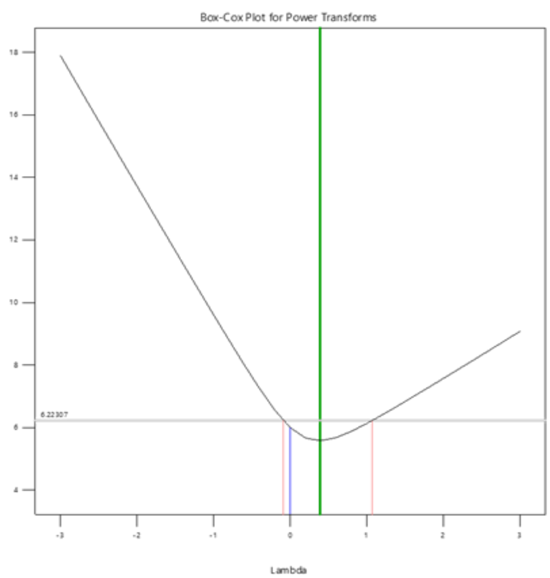

Figure 67: *Box Cox Plot Cold*

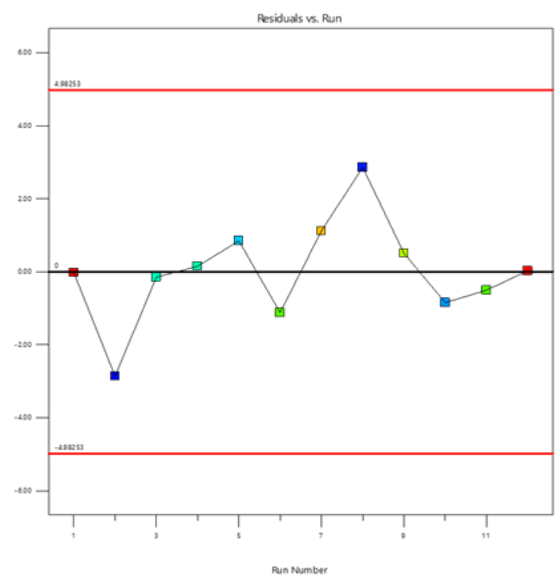

Figure 68: *Residuals vs. Run Order Cold*

Appendix D: Design Expert Diagnostic Plots for Combined Temperature Condition

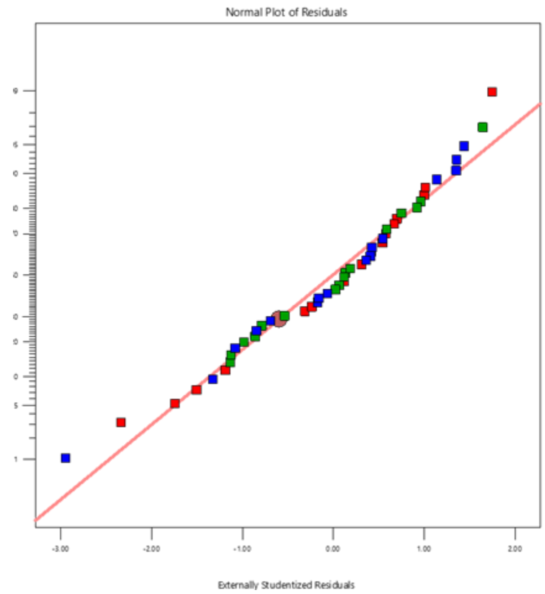

Figure 69: *Normal Plot of Residuals Combined*

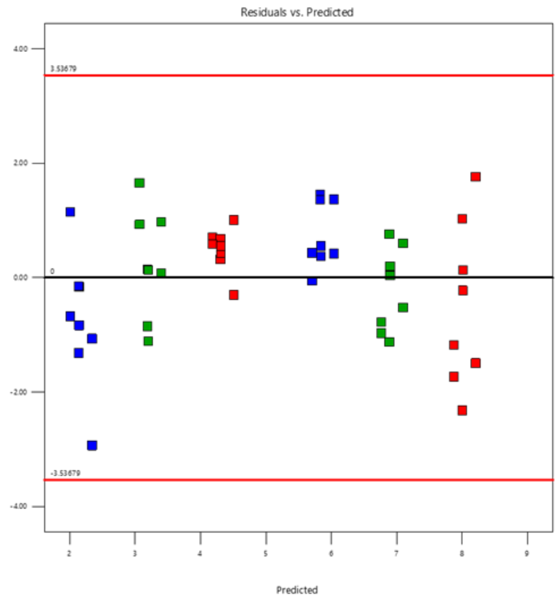

Figure 70: *Residuals vs. Predicted Combined*

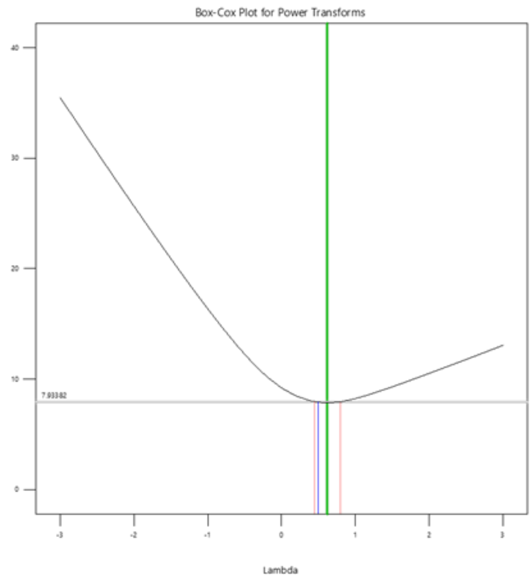

Figure 71: *Box Cox Plot Combined*

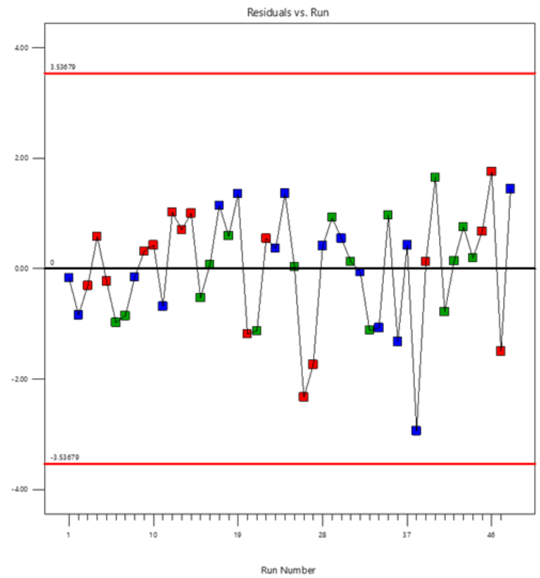

Figure 72: *Residuals vs. Run Order Combined*

Appendix E: Project Background Sample Sheet

Project Background

My name is Alexandria Major and I'm a Master's student in Engineering at MUN. Thanks for volunteering for this experiment. Firstly, I will give you a quick overview of what we would like you to do today. Then I will ask you to you review this consent form and ask whether you have questions about your participation in the study. If you agree to participate, please tick the appropriate boxes, sign, and date the last page. The study will take no more than 1 hour to complete and in return and we will give you a $10 gift card from Tim Horton's. Your participation in the study is voluntary and even if you sign the consent form, you can still withdraw from the study at any point without negative consequences. When you're ready, we'll begin with the overview.

This study will investigate dexterity of your hand after it has been immersed in cold water. We are trying to understand if having cold hands affects your ability to use the push buttons on emergency devices such as personal locator beacons. The experiment has four stages:

First we will perform baseline tests to evaluate your hand dexterity when your hands are warm and dry. This will allow us to compare your results with other published research.

Next we will give you basic training about how to use a personal locator beacon and then ask you to activate one. For this test, we will let you know if your hands need to be cold or if they can remain warm.

For the third stage, we will ask you to immerse your dominant hand in cold water for two minutes. After this, we will measure your skin temperature and then guide your hand to an apparatus which you will not be able to see. The apparatus has a variety of buttons in different locations on the surface. We would like you to only use the index finger of your dominant hand to find and press as many buttons as you can in a 2-minute period. Don’t worry about pressing the same button twice – if you find a button, please press it.

For the last stage of testing, we will ask you to re-activate the PLB that you used in Stage 2. Your hand temperature will be the same as it was for Stage 2.

After testing, we will ask you to fill-out a couple of short questionnaires. Also, we will need you to sign a form indicating that you have received your gift card. Your data will remain anonymous and only the researchers (my supervisors and I) will know you participated.

If you need to take a break at any point during testing, please let me know. We will video record your hands throughout testing today but at no time will we be able to see your face. This will be used only for data collection purposes. Any identifiable features of your hands will be blurred in video or photo stills we use in publications/presentations. Do you have any questions?

PLB Training Instructions

- Here are two different PLBs.
- We will ask you to activate one of these devices today.
- There are two buttons on each device.
- Pressing one button *activates* the device and alerts search and rescue authorities.
- The other button allows you to perform system test of the device *without* activating it.
- Here is the activation button for this device (pick one PLB to show).
- Here is the activation button for this device (show the other PLB).
- To activate these devices, you need to press and hold the activation button for about 3 seconds.
- When you think you have activated the device, please lay it on the table.

→ *If anyone asks if they will actually alert SAR but turning this on, reassure them that these are test units only and they will not activate SAR.*

Appendix F: Sample Data Collection Sheet

Stage 1: Standardized Testing (Baseline - Dry Thermoneutral)

1. **Index Finger Measurements:**

Dominant hand: Left / Right Index Finger Starting Temp (C): ________________

Circumference (cm): ______________ _ ___________ ______________

t1 t2 t3

NOTES: ____

____

____

2. **Pinch strength (reset marker AND gage to zero):**

Force (lbs / kg) _____________ _____________ ______________

t1 t2 t3

NOTES: ____

____

____

3. **Monofilament Test (index finger, dominant hand, eyes closed, 3 presses, start small):**

Force (g): _____________ ______________ ______________

t1 t2 t3

NOTES: ____

____

____

4. Two Point Discrimination Test (2 to 8 mm, index finger):

Spacing (mm):	____________	____________	____________
	t1	t2	t3

NOTES: ____

1. Grooved Pegboard Test:

Time to complete (s) ____________ (If not completed, number of pegs at end __________)

NOTES: ____

____

____

Stage 2: Activation of PLB

→ Remember to present second script before starting here!

Room Temperature (C): ________________ Water Temperature (C): ________________

Condition: Thermoneutral / Cold PLB Used: ______________

Starting Finger Temp. (C): ____________ Temp. after 2 mins exposure (C): ______________

Finger wrinkly Y / N Finger used: L / R & T I M R P

PLB Properly Activated? Y / N ---If so--- Activation time (s): _____________

Test button pressed? Y / N ---If so--- Time Pressed (s): _____________

NOTES: ____

____

____

____

____

____

Stage 3: Generalized Button Testing

-------------------- Test #1 --------------------

Room Temperature (C): _________________ Water Temperature (C): _________________

Condition: Thermoneutral / Cold

Starting Finger Temp. (C): _____________ Temp. after re-exposure (C): _______________

Finger wrinkly Y / N Finger used: L / R & T I M R P

Panel Orientation (circle): North East South West

Number of Buttons activated in period: ____________ Test duration (s): _______________

Which Buttons were depressed (tally):

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

NOTES: _________________Temp:____

____

-------------------- Test #2 --------------------

Room Temperature (C): _________________ Water Temperature (C): _________________

Condition: Thermoneutral / Cold

Starting Finger Temp. (C): _____________ Temp. after re-exposure (C): _______________

Finger wrinkly Y / N Finger used: L / R & T I M R P

Panel Orientation (circle): North East South West

Number of Buttons activated in period: ____________ Test duration (s): _______________

Which Buttons were depressed (tally):

1	2	3	4	5	6	7	8	9	10	11	12

NOTES:

Stage 4: Repeat Activation of PLBs

→ Remember – don't provide any reminders or training here!

Room Temperature (C): _________________ Water Temperature (C): _________________

Starting Finger Temp. (C): ____________ Temp. after 2 mins exposure (C): ______________

Finger wrinkly Y / N Finger used: L / R & T I M R P

PLB Properly Activated? Y / N ---If so--- Activation time (s): _____________

Test button pressed? Y / N ---If so--- Time Pressed (s): _____________

NOTES: ____

____

____

____

____

Appendix G: Sample Experiment Questionnaire

1. Age in years ________

2. Gender
    a. Female
    b. Male
    c. Other ________________
    d. Prefer Not to Answer

3. Are you Left-handed or Right-handed (circle one)?

4. Occupation ________________________________

5. Do you have a condition that affects your hand dexterity? __________

6. Do you have a condition that affects your hand sensitivity? __________

7. Are you regularly required to perform tasks while your hands are cold? Y / N

8. How much to you know about personal locator beacons (PLB)?
    a. Nothing
    b. Very little
    c. Some
    d. A lot

9. Have you ever handled or used a PLB before today? Y / N

   If yes, how often? Weekly / Monthly / Annually

Testing Stage 2 & Stage 4: PLB Testing:

1. How easy was it to activate the PLB in stage 2? (circle one):
    a. very difficult
    b. difficult
    c. neither
    d. easy
    e. very easy

2. How easy was it to activate the PLB in Stage 4? (circle one):
    a. very difficult
    b. difficult
    c. neither
    d. easy
    e. very easy

3. How confident are you that you correctly activated the PLB ?:

    a. PLB Activation Stage 2 (first session):
        i. Pretty sure I did
        ii. A little sure I did
        iii. Neither sure or unsure
        iv. A little sure I did not
        v. Pretty sure I did not

    b. PLB Activation Stage 4 (second session):
        i. Pretty sure I did
        ii. A little sure I did
        iii. Neither sure or unsure
        iv. A little sure I did not
        v. Pretty sure I did not

4. **In Stage 2** which finger and which hand did you use to activate the device? (circle one)

Finger: Thumb / Index / Middle / Ring / Pinkie

Hand: Left / Right

5. **In Stage 4** which finger and which hand did you use to activate the device? (circle one)

Finger: Thumb / Index / Middle / Ring / Pinkie
Hand: Left / Right

5. Do you have any suggestions for making these devices easier to activate?

___

___

___

___

___

Testing Part 2: Button Panel Apparatus

1. When your hands were WARM:
    a. Describe the buttons that were easiest to find:

    b. Describe the buttons that were easiest to depress:

2. When your hands were COLD:
    a. Describe the buttons that were easiest to find:

b. Describe the buttons that were easiest to depress:

3. How well do you think you performed overall?
    a. Poorly – I struggled to find any buttons
    b. A little poorly – I only found and pressed a few buttons
    c. Neither poorly or well
    d. Pretty well – I found and pressed a lot of buttons
    e. Very well – I found and pressed all the buttons