Donning Time of Marine Abandonment Immersion Suits Under Simulated Evacuation Conditions

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Abstract - **Maritime emergencies often occur rapidly in unpredictable circumstances. In a scenario where vessel or offshore platform evacuation is necessary, personal floatation and thermal protection greatly increases survival chances for individuals immersed in water. Marine abandonment immersion suits, intended to be quickly donned in the case of an emergency, can provide effective protection against these dangers and prolong life. The ability to locate and correctly don an immersion suit before vessel or offshore platform abandonment is critical. Canadian standards dictate that an immersion suit must be unpacked and donned without assistance within 2-minutes. This research investigates whether individuals with common knowledge and training levels could complete donning tasks under simulated adverse maritime conditions, involving varying combinations of motion and lighting. Three of the seven conditions found total mean donning times above the 2-minute donning standard, while all conditions had one or more participants fail to meet the time requirement.**

Keywords
Immersion suit, survival, abandonment, emergency, donning, marine simulation.

INTRODUCTION

With large numbers of people working, living and being transported through maritime environments, protection from its elements is vital to human survival. While prolonged immersion in any water below 35°C will eventually lead to hypothermia (Neifer, 2006), human cold shock responses begin at water temperatures below 25°C (Keatinge, 1969). Outside of the Tropics, the majority of major bodies of water on the planet have temperatures below 20°C (Golden & Tipton, 2002). Thus, much of the world's larger bodies of water are below critical temperature thresholds in which the human body has the ability to maintain body temperature homeostasis. This clearly indicates the importance and need of safety and protection for individuals against such conditions. In the event that an individual is immersed in cold water, a flotation device and thermal protection greatly increases the chances of survival. A marine abandonment immersion suit, in proper working order, appropriately sized and donned correctly, is an effective device to combat against the dangers faced by an individual immersed in colder waters.

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During maritime emergencies time is critical. Anecdotal evidence from reports of incidents in which vessels have sunk rapidly shows that incorporating immersion suit donning into emergency response planning is critical. The current Canadian National Standard for immersion suit systems (CAN/CGSB-65.16-2005) states that the suit must be unpacked and donned without assistance within 2-minutes. Generally, safety training facilities train and test to this standard on land in stable, benign environments. This prescriptive standard and training approach may not reflect the realities or demands of vessel or offshore platform evacuations in dynamic conditions such as those found at sea. The standard makes no mention of the 2-minute donning time being attainable or appropriate in real-world scenarios (see Figure 1).

Figure 1. Fishing vessel in heavy seas.

OBJECTIVES

There is negligible empirical, peer-reviewed research published in the English language on marine abandonment immersion suit donning times.

This study will provide fundamental, quantitative data on the timing of tasks required to don marine abandonment immersion suits in a variety of simulated platform motion and lighting combinations. The purpose of this study is to determine whether individuals provided with minimal training could complete donning tasks under adverse simulated environmental conditions and achieve the 2-minute donning time required by the Canadian Standard. The results and conclusions from this study should be of use to a number of agencies and governing bodies associated with the maritime trade. From regulatory bodies and professional mariners to oil companies and recreational boating enthusiasts, the goal of this research is to better inform and prepare people for maritime emergencies, ultimately with the aim to help save lives.

METHODOGOLY

Participants

Eighteen males and fourteen females (*n*=32; age 22.9±2.0 yrs; stature 173.5±8.6 cm; mass 75.6±12.9 kg) were recruited for participation in the study. It was required that participants had no prior experience with marine abandonment immersion suits and had not worked in a marine industry. Females who were, or possibly were pregnant, individuals with underlying heart, respiratory illness and vestibular system problems were eliminated from participating in the experiment. The Human Investigation Committee (HIC) of Memorial University of Newfoundland granted ethical approval for this study.

Test Clothing

Participants performed experimental trials while wearing standardized attire. A pair of appropriately sized generic, one-piece work coveralls was issued to wear over their clothing. Low-cut, laced athletic shoes, shorts and t-shirts were required to be worn under the issued coveralls. Prior to data collection all jewellery, watches and eyeglasses were removed and long hair was tied back.

Immersion Suits

Two models of immersion suits from two manufacturers were used, both of which are approved by Transport Canada. Fundamentally, both suit systems have similar designs and are intended for the same purpose. They are classified as marine abandonment immersion suits, intended for rapid donning and are designed to provide flotation and thermal protection for extended periods, lengthening survival times of individuals immersed in water. The immersion suits are full body watertight dry suits, enclosed by a main zipper on the anterior side. They are designed with liberal size ranges, intended to fit a wide array of body types and are stored within carry bags. Upon successful donning of one's limbs and torso within the suit and closing the zipper, the individual has only their hands and part of their face exposed. The two suit types provide tethered hand protection stored in arm pockets, as well as a face shield designed to cover the cheeks and mouth. Both features are intended to be donned after enclosing the body within the suit. Participants were randomly assigned an immersion suit model prior to data collection. After anthropometric measurements were taken an appropriately sized suit was issued, based on the manufactures size specifications.

Instrumentation

Data Collection Facility

Data collection occurred within an indoor laboratory which was a windowless, dry space with controlled and constant, lighting, noise and air temperature (approximately 22°C).

Six Degrees of Freedom Electric Motion Platform

To expose the participant to ship-like motions in a controlled setting, a six degrees of freedom electric motion platform (Series 6DOF2000E Electric Motion Platform, MOOG Inc., East Aurora, New York) was fitted with a 2m x 2m square metal platform. The platform perimeter was equipped with 103 centimeter high railings which fully enclosed the area where trials took place. A canopy covered three sides and the roof of the platform at a height of 215 centimeters (see Figure 2).

Figure 2. Motion platform.

Video Cameras

Each experimental trial was recorded and saved for further data reduction and analysis via two video camera systems. An infrared video camera with a wide angle lens was mounted within the motion platform and was capable of capturing the entire area of the platform in both “Light” and “Dark” conditions. The infrared camera was streamed with a live feed to external monitors so the researchers could closely monitor participant activities throughout each trial. A second video camera was mounted outside of the motion platform covering the entire area of the motion platform from the opposite side of the infrared camera.

EXPERIMENTAL VARIABLES

Dependant Variables

Timing and Success of Donning Tasks

The video record for each trial was analysed for both the timing and success of completing tasks necessary to fully don an immersion suit. The sequence of donning an immersion suit was broken down into seven separate tasks which were analysed and measured to the nearest second. The seven tasks for a successfully donned immersion suit are as follows:

- All limbs in suit (defined as both feet in the suit shoes and hands through wrist cuffs)
- Hood on with zipper fully sealed
- First glove donned
- First glove Velcro attached
- Second glove donned
- Second glove Velcro attached
- Face shield attached

Maximum Heart Rate

Heart rate data were collected for the duration of the experiment, each trial was analyzed for the maximum heart rate attained by the participant during each trial of the protocol.

Independent Variables

Experimental Conditions

Experimental trials consisted of six different platform orientation and lighting combinations, which made up a total of seven donning trials (see Table 1). “Stable, Light” (Baseline) was recorded twice and standardized as the first and last condition for each participant. Conditions 2 through 6 were randomized.

Platform Orientation

Three motion conditions were established for the research protocol. The platform orientation in the “Stable” condition remained flat and static. The “List” condition had the platform moved to an angle of 15° and remained static for the duration of the trial. The “Motion” condition used all six degrees of freedom, simulating constant motion of a vessel at sea.

Condition	Platform Orientation	Lighting Condition
1	Stable	Light
2	List	Light
3	Motion	Light
4	Stable	Dark
5	List	Dark
6	Motion	Dark
7	Stable	Light

Table 1. Experimental conditions.

Lighting

Two lighting conditions were used in the experimental protocol, “Light” and “Dark”. In both cases identical lighting conditions within the laboratory as well as the surrounding area were set consistently throughout the data collection process. The “Light” condition was defined as normal, ambient room lighting with all lights in the laboratory turned on. The “Dark” condition had all laboratory lights turned off and monitor screens shielded, creating a near total black-out setting.

EXPERIMENTAL PROCEDURE

Pre-Trial Procedure

Anthropometric Measurements

A series of anthropometric measurements were taken prior to the experimental trials including stature, body mass as well as neck, wrist, waist and hip circumferences. Shoulder and waist breadth were measured using a pair of anthropometric callipers (Anthropometer Model 01290, Lafayette Instrument Company Lafayette, Indiana). Breadth measurements, as well as the waist and hip circumferences were taken over test clothing due to its presence and interaction while donning an immersion.

Baseline Heart Rate

The participant was instructed to sit in a comfortable chair, rest their arms on the chair arms provided, place feet flat on the ground and remain as relaxed and as motionless as possible for a period of ten minutes.

Immersion Suit Donning Instructions

While the participant remained seated they were given a sheet of written, point form immersion suit donning instructions to study for a period of five minutes. The pictureless instructions were generated by the research team. They included the same general layout based on information from the manufacturers’ issued instructions, which relate to both suit designs used in the experiment. The investigator gave minimal, standardized verbal instructions with regards to the construction and donning procedure of the immersion suit. A brief description of the real–world scenario the experiment was intended to recreate was given: the participant is on board a vessel in peril and has been ordered to fully don an immersion suit with the intention of abandoning the vessel directly into the water. Two main points were stated:

1. Fully don the suit as quickly as possible.
2. The criteria for a fully donned suit are defined by completion of the tasks listed on the printed instructions.

Donning tasks did not necessarily have to be completed in the order in which they appeared on the instruction sheet however, all tasks must have been completed correctly for the immersion suit to be considered fully donned.

Trial Acclimation Period

Each experimental condition had a standardized acclimatization period to allow for the participants to acclimate to the combinations of the motion and lighting conditions. Participants were not briefed on the length of trial acclimation periods, but were only told a time range in which the trial would begin. “Stable” and “List” conditions had an acclimation period of thirty seconds while “Motion” had an acclimation period of sixty seconds. “Stable” and “List” conditions were given a shorter acclimation period in relation to “Motion” due to the absence of platform movement. Both the “Light” and “Dark” variables followed the same acclimation period as the corresponding motion condition. Between all trials, including the pre-trial procedure the laboratory lights were on, the same lighting as used for the experiments “Light” condition. During “Dark” conditions laboratory lights were turned out immediately before implementing the motion acclimation period.

Once a trial condition was initiated, the participant was asked if they were ready to continue. Upon receiving a positive response the investigator then gave the standardized verbal signal acknowledging the acclimation period had begun and the start signal would be implemented momentarily: “anytime within the next two minutes the trial will begin”. Upon completion of the respective acclimation period the investigator initiated the starting signal and the participant began to don the immersion suit. A trial was deemed complete after either:

1. The participant had met the donning criteria.
2. The experimenter had signalled the end of the trial.
3. The participant had stopped and/or given the signal to end the trial.

Rest Periods

Between trials during rest periods participants were returned to the baseline condition “Stable, Light”. While remaining on the platform the participant doffed the suit with the help of the investigator, donned and fully tied their sneakers. A chair was placed on the motion platform for the participant to rest on while they were given bottled water and the donning instructions for reference. Talcum powder was applied to the participant’s hands and suit cuffs to eliminate sweat residue, if required.

The rest period was defined as the duration of time from the conclusion of each successful suit donning to the time when the participant had reached their recovery threshold (RT), defined as 60% of their age predicted maximum heart rate measured in beats per minute (BPM) (Larson et al., 1997):

$$RT\ (BPM) = 220 - \text{Participant Age} \times 0.60$$

Once heart rate had dropped, and stabilized below their recovery threshold heart rate value, the participant was deemed recovered. The chair, donning instructions and bottled water were removed from the platform while the participant was instructed to assume the starting position and the following trial was implemented.

RESULTS

Table 2 shows the mean total times of the 7 suit donning tasks in each condition, all numbers are reported in seconds.

Condition		Mean	SD	Max.	Min.
Stable	Light: 1st	125.6	33.5	198.0	67.0
	Light: 2nd	88.8	30.7	184.0	36.0
	Dark	131.9	59.3	229.0	51.0
List	Light	104.5	30.0	185.0	48.0
	Dark	116.2	38.2	217.0	59.0
Motion	Light	110.1	46.5	191.0	47.0
	Dark	139.2	40.9	235.0	66.0

Table 2. Total donning times.

Table 3 reports mean donning times of 2 donning tasks: “All limbs in suit” and “hood on with zipper fully sealed”, together defined as “critical donning tasks”. All numbers are reported in seconds.

Condition		Mean	SD	Max.	Min.
Stable	Light: 1st	63.5	21.6	124.0	32.0
	Light: 2nd	43.5	16.2	118.0	21.0
	Dark	55.5	20.7	137.0	30.0
List	Light	50.1	16.2	97.0	28.0
	Dark	57.0	23.5	152.0	29.0
Motion	Light	64.7	25.1	126.0	24.0
	Dark	78.3	28.6	150.0	36.0

Table 3. Critical donning task times.

Table 4 compares "Total Tasks" and "Critical Tasks" the percentage of total donning task mistakes participants made in each condition.

Condition		Total Tasks	Critical Tasks
Stable	Light: 1st	12.5	6.3
	Light: 2nd	6.9	0.0
	Dark	6.3	1.6
List	Light	4.6	1.6
	Dark	6.7	1.6
Motion	Light	6.4	0.0
	Dark	10.1	3.1

Table 4. Percentage of donning task mistakes.

DISCUSSION

Immersion Suit Total Donning Times

3of the 7 trials found total mean donning times over the 2-minute donning standard (see Table 2). "Stable, Light: 1st" resulted in a mean time greater than the 2-minute standard. This condition was the participants initial exposure to the suit, however, even with ample lighting and a flat, stable platform donning times still averaged over the 2-minute requirement. "Stable, Light: 1st" also had the highest number of mistakes of any other condition (see Table 4).

"Stable, Dark" and "Motion, Dark" also had mean times above the 2-minute standard. Interestingly, "Motion, Light" resulted in a mean donning time below 2-minutes. These results suggest that vision obstruction potentially plays as great a role in donning times as motion. Both list conditions ("List, Light" and "List, Dark") found mean donning times to be under 2-minutes. The stable 15° list platform condition did not appear to have detrimental effects on donning times with regards to the other motion conditions.

The first and last trials were standardized baseline conditions ("Stable, Light"), intended to examine the learning effect present within the experiment. There was a mean decrease of 29.3% (36.8 seconds) in total mean donning times when comparing the first trial and seventh trials, suggesting a considerable learning effect. This provides evidence of the value of regular immersion suit donning practice as suggested by regulatory bodies, training facilities and coast guards. These experimental results demonstrate the considerable increase of proficiency and success attributed to immersion suit donning practice. When examining the data, it is important to consider that for each condition, including the final trial "Stable, Light: 2nd", one or more participants failed to successfully complete all tasks, as well as failed to meet the 2-minute donning standard. The majority of participants were in their twenties and generally in good physical health, suggesting that the donning tasks themselves and not the experimental conditions have proved to be challenging. Even after the familiarization with written instruction and practical donning experience, there were still participants who failed to meet the donning time criteria, even during the most benign of environments.

Critical Donning Tasks Times

The ability to successfully complete the initial two donning tasks: "All limbs in suit" and "Hood on with zipper fully sealed" ensures that the majority of the individual's body, including all vital organs, have a form of protection against cold water as well as providing secure floatation when the suit is in good condition, properly sized and correctly donned. After the completion of these two initial donning tasks the only directly exposed areas of the body are the hands and part of the face (see Figure 4).

Figure 4. Completion of critical donning tasks.

Although important, thermal protection of the hands is not essential to survival, providing hand function is maintained for critical tasks (Brooks, 2003). Gloves and mittens provide thermal protection, however traditional immersion suit designs are often bulky and greatly reduce hand and finger function, potentially hindering the ability to carry out survival tasks. Successful completion of enclosing one's limbs, torso and head within an immersion suit and sealing the zipper represents the most important stages of donning. These major, gross movement tasks should be the focus of regulations and training. The subsequent tasks of securing hand protection and the face piece, although important, require fine motor tasks and movements, have a higher rate of failure and ultimately are not as crucial in an emergency scenario when compared to the critical tasks which provide the majority of the body with thermal insulation and floatation properties.

CONCLUSION

This research presents empirical data and analyses of the donning times of marine abandonment immersion suits. Not only does it examine donning in benign environments but also under more realistic, dynamic conditions representative of typical maritime realities. Regulatory bodies and training facilities need to consider more performance based training standards intended for specific goals and objectives rather than the traditional prescriptive, non-applicable approach. With regards to marine environments it is imperative that performance based methodologies are established and tailored to adequately reflect real-world environmental conditions individuals are likely to encounter and experience. Immersion suit donning standards must focus on the most important tasks, which yielded the highest benefits for individuals in maritime emergencies.

ACKNOWLEDGMENTS

The authors would like to thank the Offshore Safety and Survival Centre of Memorial University's Marine Institute for their financial and practical assistance throughout the research project.

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