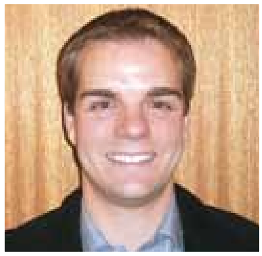
Suits in motion



Steven Mallam

Graham Small

Scott MacKinnon

Mallam, Small and MacKinnon provide important new information about the time it takes to don an immersion suit under simulated real world conditions, as well as the effectiveness and importance of training.

Who should read this paper?

Anyone with an interest in maritime safety – from recreational boaters to Navies and Coast Guards, fishers, offshore oil and gas operators, shipping companies and regulatory bodies charged with the development of legislation covering health and safety in marine operations.

Why is it important?

It is well known that personal flotation and thermal protection provided by 'immersion suits' greatly increase the chances of survival of individuals adrift at sea. Canadian standards state that an immersion suit must be unpacked and properly donned without assistance within two minutes. In safety training facilities students are generally taught to perform donning tasks in a fixed, stable environment. This does not fully reflect the variables of real world marine emergencies. Anecdotal evidence indicates that people are losing their lives because of incomplete or improper immersion suit donning during the abandonment process.

The work reported here examined donning times for two popular types of immersion suits under a variety of conditions. During the trials, test subjects stood on an enclosed motion bed that was programmed to simulate conditions likely to be encountered during an emergency at sea.

The results of this research showed that in total over one quarter of participants took longer than two minutes to don their suits, with error rates of donning tasks as high as fifty percent. Highest error rates were found on tasks involving protection of the face and hands, and significant differences were observed between suit types. It was found that four or more repetitions significantly increased user performance and proficiency with the equipment and led to shorter donning times and greater user confidence.

About the authors

Steven Mallam is a PhD candidate with the Maritime Human Factors Group at Chalmers University of Technology in Göteborg, Sweden. His research interests centre around health and safety in industrial settings through analysis of human physiological, biomechanical and cognitive processes in high stress, dynamic emergency scenarios. Graham Small is an instructor of marine emergency duties and related courses at the Marine Institute Offshore Safety and Survival Centre. Scott MacKinnon is a Professor of Human Factors and Dean of the School of Human Kinetics at Memorial University of Newfoundland.

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 it becomes necessary to abandon a vessel or offshore platform evacuation, personal flotation and thermal protection greatly increase chances of survival for individuals escaping directly into water. Marine abandonment immersion suits, intended to be quickly donned in the case of an emergency, can provide effective protection against dangers of cold shock and prolonged immersion. The ability to locate and correctly don an immersion suit prior to abandoning is critical. Canadian Standard CAN/CGSB-65.16-2005 dictates that an immersion suit must be unpacked and properly donned without assistance within two minutes. Tests are performed on a fixed, stable deck. No empirical investigation has been conducted on time required to don immersion suits in a dynamic environment.

Thirty-two participants, with similar knowledge and training, performed immersion suit donning tasks using two types of suit. Trials were performed on a motion bed that simulated maritime conditions with varying combinations of platform motions and levels of ambient illumination. Participant donning times and donning task errors were recorded for each trial. Across all conditions the mean donning time was 102.7 seconds (SD = 39.6 sec). There was a significant difference between donning time and suit manufacturer ($p < .0001$). Although overall mean donning time was within the two-minute requirement, in total there was a 26.1% failure rate in the completion of full donning tasks within two minutes. Donning task error rates were recorded as high as 56.3% per donning attempt. Results indicate that training standards need to more adequately reflect realistic environmental conditions and demands. Performance-based standards will more likely ensure that all personnel are better educated and prepared to don an abandonment suit successfully within the required time period, and thus increase chances of survival and rescue. Performance-based standards that include reference to donning suits in a dynamic environment will be more likely to lead to the development of suits and training that meet the needs of users in real conditions.

KEY WORDS

Immersion suit; Donning time; Abandonment; Marine safety

INTRODUCTION

Large numbers of people work, live and are transported in marine environments and protection from elements is vital. Prolonged immersion in water below 35°C as a result of marine accidents will eventually lead to hypothermia [Neifer, 2006], while human cold shock responses begin at water temperatures below 25°C [Keatinge, 1969]. Outside of the tropics, the majority of bodies of water on the planet have temperatures below 20°C [Golden and Tipton, 2002]. As much of the world's larger bodies of water are below critical temperature thresholds in which the human body has the ability to maintain homeostasis, this clearly indicates the importance and need for safety and protection against such conditions. In the event that an individual is immersed in cold water, a flotation device and thermal protection greatly increase chances of survival. A marine abandonment immersion suit, in proper working order, appropriately sized and donned correctly, is an effective tool to combat the dangers faced by an individual immersed in colder waters.

During marine 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 essential. The reference standard for immersion suit systems states that a suit must be unpacked and donned without assistance within two minutes [CAN/CGSB-65.16-2005]. Testing against this standard is done in a stable, benign environment. This approach may not reflect the realities or demands of dynamic conditions that occur during vessel or offshore platform evacuations at sea.

OBJECTIVES

To the authors' knowledge there is no peer-reviewed research published in the English language on marine abandonment immersion suit donning in dynamic conditions. This study will provide fundamental, quantitative data on time required to don marine abandonment immersion suits in a variety of simulated motion and lighting conditions. The purpose of this study is to determine whether individuals provided with the minimal prescribed training can complete donning tasks under adverse simulated marine environmental conditions within the two-minute donning time required by the reference standard and thereby contribute to the corpus of knowledge that informs users, manufacturers and regulators.

METHODOLOGY

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; Body Mass Index (BMI) 24.9 ± 2.8) were recruited. It was required that participants had no prior experience with marine abandonment immersion suits and had not worked at sea in any capacity. Females who were, or were potentially, pregnant and individuals with underlying heart, respiratory illness and vestibular system problems were not accepted as subjects. The Human Investigation Committee of Memorial University of Newfoundland granted ethical approval for this study.

Immersion Suits

Two models of immersion suits from two manufacturers were used. Both are classified as marine abandonment immersion suits and approved by Transport Canada. Both suit systems are of similar design and retail price and are intended for the same purpose. Both are designed to be rapidly donned, provide flotation and thermal protection for extended periods and thereby increase survival times of individuals immersed in water.

The general design of both immersion suits can be described as full body, watertight dry suits, having liberal size ranges with the ability to fit a wide array of body types. The suits are sealed by a main zipper on the anterior side with hand and face protection intended to be donned after the main zipper is closed. Each suit is stored in an individual carry bag sealed by snap buttons. Participants were randomly assigned an immersion suit model prior to data collection. After anthropometric measurements were collected, an appropriately sized suit was issued, based on the manufacturer size specifications. For the purpose of identification, data tracking, and analysis, suit types were designated as S1 and S2.

Instrumentation

To expose the participant to ship-like motions in a controlled setting, a six degrees of freedom, electric motion platform was used (Series 6DOF2000E Electric Motion Platform, MOOG Inc., East Aurora, New York). It was situated within an indoor laboratory with controlled and constant lighting, noise and air temperature. The motion platform was fitted with a 2 m x 2 m metal platform equipped with 103 cm high railings fully enclosing the area where suit donning took place. A canopy covered three sides and top of the platform at a height of 215 cm in order to eliminate external visual references and to simulate an enclosed space typical of vessels.

Data were recorded via two independent video camera systems and saved for later reduction and analysis. An infrared video camera with a wide angle lens was mounted within the motion platform capable of capturing close up footage of the entire area of the platform in both lit and darkened conditions. The infrared video feed was streamed live to external monitors so that researchers could closely monitor participant activity and safety throughout each trial. A second video camera was mounted outside of the motion platform to record from the opposite viewpoint.

EXPERIMENTAL VARIABLES

Dependant Variables

Timing and success of donning tasks

The video record for each trial was analyzed for both timing and success of completing the individual tasks necessary to fully don an immersion suit. The process of donning an immersion suit was described as a sequence of seven separate tasks within three categories (see Table 1). Times required to complete tasks were analyzed and measured to the nearest second.

Independent Variables

Experimental conditions

Experimental trials consisted of six platform operations and lighting combinations, one of which was repeated making a total of seven donning trials (see Table 2). The baseline condition (“Stable, Light”) was recorded twice and standardized as the first and last condition for each participant in order to scrutinize for learning effects. Conditions 2 through 6 were randomized for each participant.

Category			Donning Tasks
1	Critical Tasks	1	All Limbs Within Suit
		2	Hood On, Zipper Fully Sealed
2	Hand Protection Tasks	3	1st Hand Protection Donned
		4	1st Velcro Wrist Strap Attached
		5	2nd Hand Protection Donned
		6	2nd Velcro Wrist Strap Attached
3	Face Shield	7	Face Shield Attachment

Table 1: Immersion suit donning tasks.

Condition	Platform Orientation	Lighting	Abbreviation
1	Stable	On	S-ON-1
2	List	On	L-ON
3	Motion	On	M-ON
4	Stable	Off	S-OFF
5	List	Off	L-OFF
6	Motion	Off	M-OFF
7	Stable	On	S-ON-2

Table 2: Experimental conditions.

Platform motions

Three motion conditions were established: "Stable," "List," and "Motion." The platform orientation in the "Stable" condition remained horizontal and static. "List" conditions had the platform inclined at an angle of 15 degrees and remained static for the duration of the trial. "Motion" conditions used six degrees of freedom to simulate a fishing vessel deck motion collected during previous sea trials unrelated to this study. Maximum platform kinematics ranged from +/- 30 deg/s for pitch, roll, and yaw and +/- 0.5 g for heave, surge and sway.

Lighting

Two lighting conditions were used: "Light" and "Dark." 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 black-out environment.

EXPERIMENTAL PROCEDURE

Pre-Trial Procedure

Volunteers for the study were instructed to bring personal, low-cut athletic footwear, shorts and a t-shirt. After a brief introduction to the laboratory, each participant completed consent forms and a series of anthropometric measurements were taken, including stature and body mass. The information was used to select clothing and an immersion suit of appropriate size.Standardized test clothing (coveralls) was then issued, prohibited items such as jewellery, watches and eyeglasses were removed, long hair was tied back and a discrete chest heart rate monitor was affixed around the torso directly to the skin. Each participant's baseline heart rate was then measured over a period of ten minutes using the wireless heart rate monitoring system as a basis for determining length of rest periods.

Each participant was then given a sheet of written, point form, immersion suit donning instructions to study over a period of five minutes. The generic text instructions were based on general content and layout issued by the suit manufacturers, pertinent to both immersion suits. Participants were given standardized verbal instructions regarding the construction and donning procedure of the immersion suit. Participants were instructed that they could signal for the termination of the trial at any point they felt necessary. A brief description was given of the real-world scenario that the experiment was intended to simulate: the participant is on 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. Three 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.

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

Trial Acclimation Period
Prior to the start of each donning attempt, a standardized acclimation period was implemented in order to initially expose participants to the motion and lighting condition combinations. This allowed participants to become briefly accustomed to the environment and prepare themselves for suit donning in an effort to contribute to realism, comfort and safety. Between all trials, including the pre-trial procedure, the laboratory lights were on (the identical lighting as used for the "Light" condition). During "Dark" conditions, laboratory lights were turned off immediately before beginning the acclimation period.

Once a trial condition was initiated, the participant was asked if he/she were ready to continue. Upon receiving a positive response, the researcher then indicated that the acclimation period was commencing and the start signal would be implemented momentarily by speaking the standardized phrase "anytime within the next two minutes the trial will begin."

Participant Donning Trials
Upon completion of the respective acclimation period, the researcher 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
After each trial the platform and lighting were returned to baseline. The participant remained

on the platform and with the help of the researcher doffed the immersion suit then donned and fully tied their footwear. A chair was placed on the platform for the participant to sit and rest, and water was provided for hydration. If required, talcum powder was applied to the participant's hands and suit cuffs to eliminate any presence of sweat. Donning instructions were provided for reference if the participant wished to review them. The researcher took the immersion suit out of sight of the participant, inspected it for damage, folded and placed it in the carry bag for the next trial.

The inter-donning trial rest period was not defined as a predetermined, set period of time, but as the point at which the participant had reached his/her individual physiological recovery threshold (RT). A participant's RT was defined as 60% of his/her age predicted maximum heart rate measured in beats per minute (BPM) [Larson and Potteiger, 1997]:

RT (BPM) = 220 – Participant Age x 0.60

Once the heart rate had dropped, and stabilized below his/her calculated RT heart rate value, the participant was deemed to be sufficiently recovered. The chair, donning instructions and bottled water were then removed from the platform and the participant was instructed to assume the starting position in preparation for the next trial.

RESULTS

The two immersion suit models were assigned equally among thirty-two participants. Each participant completed seven donning trials exclusively using one immersion suit model. A total of 224 donning trials were conducted and 95.98% of the data were available for analysis, due to nine trials having incomplete and/or improperly saved video data. A mixed design two-factor repeated measures ANOVA was used to examine both immersion suits and experimental condition effects on timing. All statistically significant primary effects were scrutinized using Fisher's Least Significant Difference post-hoc analyses. Each donning attempt was also scrutinized for correct, incorrect or incomplete task completion and was quantified and categorized accordingly. Data were not used in the statistical analysis where participants purposely stopped a trial due to comfort or personal safety reasons.

Total Suit Donning Time

Figure 1 summarizes immersion suit donning times. The mean time required to perform all donning tasks across all conditions was 102.7 seconds (SD = 39.6 sec). Analysis showed a significant difference in the time taken to don a suit across the experimental conditions ($F = 7.1$; $p < .0001$). Post-hoc analysis revealed that there were significant differences between Condition 1: baseline "Stable – Light On 1" and Condition 2: "List – Light On" ($p = .002$) and Condition 7: "Stable – Light On 2" ($p < .0001$). In comparing the identical environmental conditions of the first and last trial a significant difference was found. However, the only other significant difference of a condition compared to the baseline was Condition 2: "List – Light On." These observations suggest that neither darkness nor motion had a significant impact upon donning times. No significant interaction effects were observed ($p = .632$).

Figure 2 summarizes total mean times by condition. "Motion – Light Off" produced the longest donning time of 125.6 seconds (SD = 40.2 sec) and was the only condition having a mean time over the two-minute time requirement. Mean time for first trials was calculated to be 116.4 seconds, while the seventh trial, in the identical environment, produced a mean time of 76.7 seconds, a reduction of 39.7 seconds or 34.1%. This suggests significant learning effect. It must be noted, however, that although mean donning times were generally below the two-minute regulation time, in each condition at least one participant failed to meet the two-minute donning requirement. The maximum recorded time was 299.0 seconds, nearly two and a half times more than the required time set out by the reference standard.

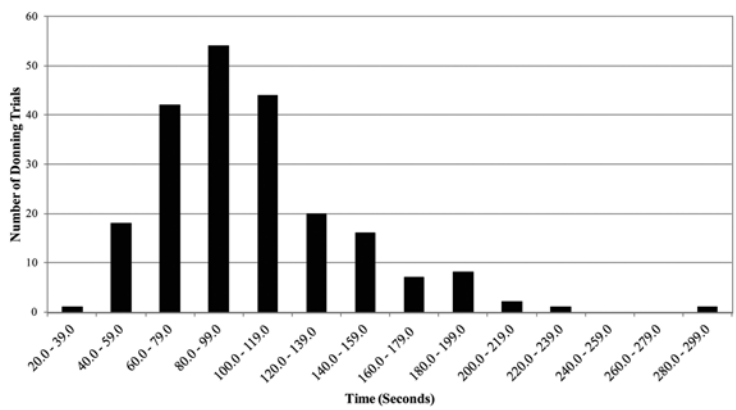

Figure 1: Total participant donning trial task times.

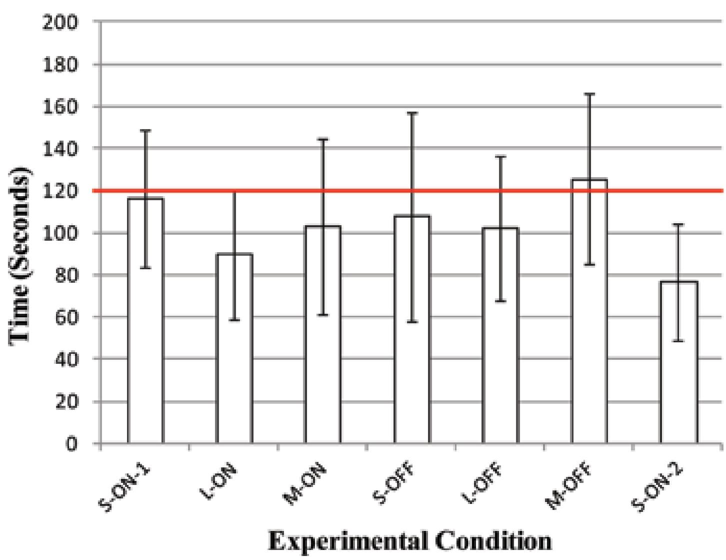

Figure 2: Total mean times of all immersion suit donning tasks.

Total Participant Donning Times: Comparing Suits

Mean donning times for both suit types were below two minutes over all conditions (S1 = 115.9 sec; S2 = 90.1 sec). A significant difference ($F = 31.4$; $p < .0001$) was found between the total donning time for the two suit types. Overall, S2 took 26.7 seconds less than the S1 to completely don across all conditions. Figure 3 compares both suits' donning times for all participant donning trials.

When the two suits were analyzed separately across all conditions, "Motion – Light Off" produced the largest mean times (S1 = 139.2 sec; S2 = 114.6 sec). S1 mean time was over two minutes in three conditions: "Stable – Light On 1," "Stable – Light Off" and "Motion – Light Off." S2 mean time was below two minutes for all seven conditions. S1 had maximum times well over the two-minute time allotment in each condition, ranging from 184.0 seconds to 299.0 seconds. S2 donning times were above the required donning time in five of the seven conditions,

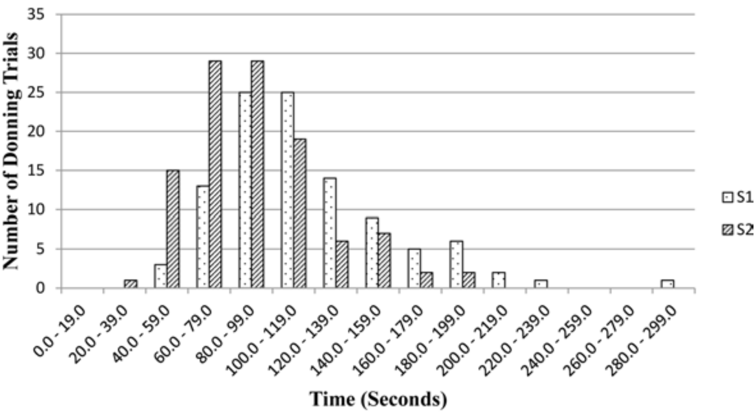

Figure 3: Total participant donning times: comparing suits.

difference was found between the suit type and the time it took to complete these tasks (F = 2.7; p <.101). S2 mean time was 56.6 seconds, while S1 took slightly over four seconds longer, at 60.9 seconds.These results suggest that, if a person can access his/her immersion suit quickly, then in approximately one minute he/she should be able to complete minimal tasks required to achieve effective flotation, watertight integrity and thermal protection for the majority of the body. However, even though mean completion times of critical tasks were within two minutes, there was a large time range of 21.0 seconds to 152.0 seconds, with eight occurrences where participants failed to complete the critical tasks within the two-minute time requirement.

ranging from 127.0 seconds to 191.0 seconds. Two S2 conditions, "List – Light On" and "Stable – Light On 2," yielded maximum times below the two-minute time requirement (113.0 sec and 97.0 sec, respectively).

Critical Tasks

Critical donning tasks are defined as the bare minimum, essential tasks which need to be carried out if the suit is to provide minimal protection in cold water. Completion of these tasks will provide watertight protection to the majority of one's body, a level of thermal protection, and effective flotation in water. Critical tasks identified were: locating and unpacking the suit from its carry bag, removing footwear, getting all of the limbs within the suit, donning the hood, and fully sealing the zipper. By completing these tasks an individual has sealed the suit, and provided thermal protection for the majority of the body with only the hands and portions of the face remaining exposed. Although having exposed hands is not ideal, the critical tasks represent the most important tasks with the largest benefits in terms of thermal protection and safety when completed correctly.

Critical donning tasks took a total mean time of 58.7 seconds (SD = 24.4 sec). No significant

Donning Task Errors

Figure 4 presents the percentage of total errors made over all conditions for each donning task. Donning task errors are identified if a participant failed to attempt a donning task or attempted but failed to complete a task. Tasks which had the majority of errors were those requiring fine motor skills involving hand and face protection. Attaching the face shield resulted in the highest percentage of errors at 19.5% across all conditions and suits. This was followed by errors in securing the second and first Velcro wrist straps of the gloves at 18.1% and 12.1% error rates, respectively. In comparison the larger, gross movement tasks involving unpacking, getting oneself within the suit, fully closing the zipper and initially donning hand protection had smaller error rates than the

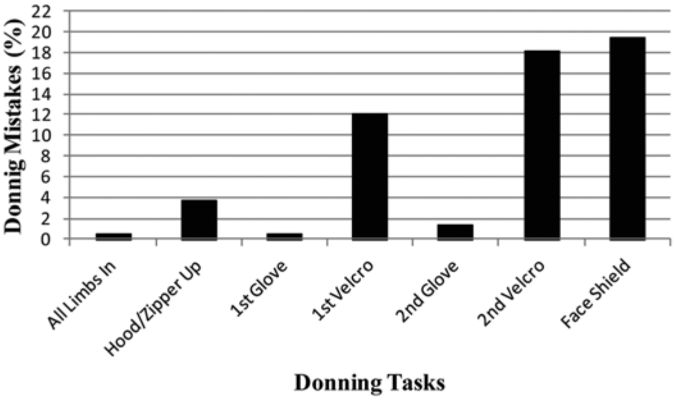

Figure 4: Percentage of total mean donning task errors.

finer motor tasks needing greater dexterity which include securing the Velcro wrist straps and attaching the face shield.

The mean error rate values ranged from 5.1% to 12.5% with individual error rates recorded as high as 56.3%. Interestingly, "Stable – Light On 1" recorded the highest task error rate across all conditions. This indicates that initial exposure to a suit in benign conditions recorded higher error frequency than that of all motion and darkness condition combinations.

Order Effect of Donning Trials

Post-hoc analyses examined donning conditions and order effects to determine to what extent participants "learned" over the course of the experiment. Figure 5 presents mean total donning times of participants in the order in which they completed each trial. In general, donning times were reduced with each successive donning trial, independent of the condition motion and lighting variables. A significant difference in the trial ordering and total time to don an immersion suit was observed ($F = 6.3$; $p < .0001$).

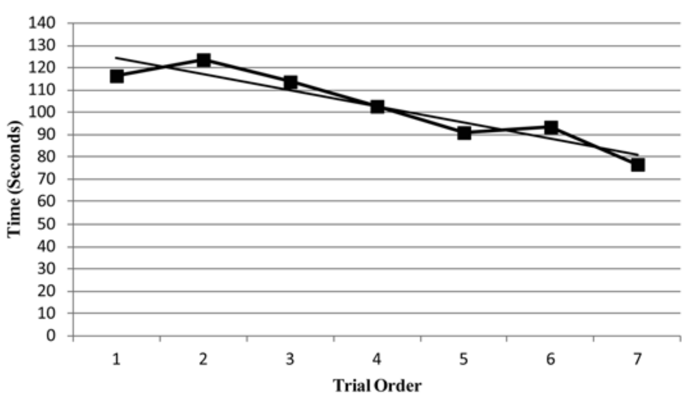

Figure 5: Mean donning times of participant trials in sequential order.

Post-hoc analysis revealed that there was a statistical difference between the first donning trial and the fifth ($p = .018$), sixth ($p = .016$), and seventh ($p < .0001$) trials. These findings suggest that an effective way to optimize initial immersion suit donning training would be to perform five consecutive donning trials (with adequate rest periods) within a training session for significant participant learning to occur.

DISCUSSION

Overall, mean donning times were 102.7 seconds, which is 17.3 seconds less than the two minutes specified in the reference. However, more comprehensive analysis of the data reveals otherwise. Most prominent is that donning time in 56 of the total 215 donning trials was above the required two-minute criteria, representing a 26.1% failure rate. Combine these findings with the fact that high task completion error rates occurred in certain donning tasks and it becomes clear that suit design and construction does not adequately fulfill requirements of real-world applications. While design and construction can always be improved, particularly as new technologies emerge, barriers to obtaining the desired donning time reflect gaps in guidance, requirements, and specification in the standards and their interpretation. Guidance and regulations for immersion suits construction have evolved since first draft to encompass more and more of the variables associated with the complex environmental conditions, training and emergency scenarios, equipment and people. As data from these trials indicate, gross donning of suits in the time specified and overall protection of the majority of users may be adequately addressed in the standard and implementation by manufacturers.

The Importance of Recognizing Hierarchy in Donning Tasks

While it is important to regard an immersion suit as a complete system, it is necessary to examine components and donning tasks to determine relative importance in terms of the larger scope of escape and survival. The reference standard regards immersion suits as a whole, with minimal attention to the functionality of individual suit components. Variation among current immersion suit designs attests to the flexibility of interpretation by manufacturers of the overall requirements. Future innovation should be guided by more specific performance requirements that account for escape and survival demands. Identifying and recognizing critical tasks will contribute to greater initial overall protection that will facilitate completing secondary tasks that may not be vital to immediate survival but will enhance probability of longer term survival. Results show that secondary tasks (donning gloves and face shield attachment) take a large percentage of total donning time (see Figure 6) and also lead to a proportionally large number of donning errors. Bulky hand protection of current immersion suit designs hinders performing vital abandonment tasks and procedures by reducing hand dexterity and function [Brooks, 2003]. Ultimately escape and survival hinges on weighing the benefits and drawbacks of a particular scenario. In terms of immersion suit donning the importance of establishing a hierarchy of tasks and stressing the importance of performing critical tasks in a timely manner cannot be over-emphasized.

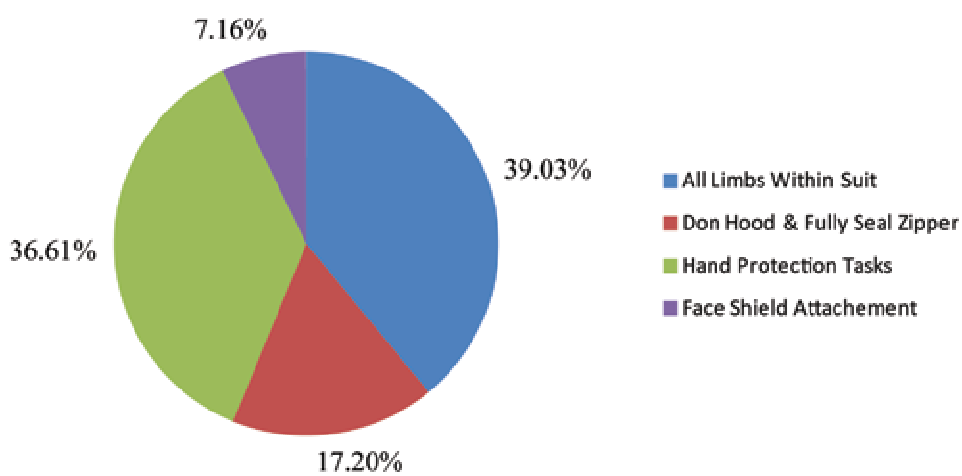

Figure 6: Combined suit sub-task donning time percentages.

To quantify a time value, results of this research indicate that 60 seconds is an appropriate time limit to complete critical tasks, based on averaging across all motion and lighting conditions. However, it must be noted that this value does not include time to locate and retrieve a suit, which would add time to the overall escape process. Based on experimental data across all conditions the majority of participants managed to fully don an immersion suit in 200 seconds or less.

Approved Immersion Suits are Not Created Equal

Even though mean donning times for both suits met the reference standard, a significant difference was found in total donning time between the two suits. This suggests that variations in suit construction and design may have contributed to donning efficiency. Interestingly, there was no significant difference between the suits' critical tasks, while a difference was found in the secondary tasks, suggesting variations in suit construction had greater impact upon the ability to perform tasks that require finer movement and dexterity.

Skill Acquisition and Learning

Over the course of the experiment and donning trials participants became more familiar with the immersion suit and donning procedures. Results show that, regardless of environmental condition or combination of motion and lighting variables, participants generally achieved quicker donning times between the first and last trial, with a 34.1% time reduction. Interestingly, there was no significant difference found between the initial exposure to baseline conditions ("No Motion," "Light") and any of the motion or darkness combinations. These findings suggest that familiarity with suits and proficiency in donning procedures is more important, in terms of quicker donning than exposure to environments rich in motion and darkness. It is also noteworthy that not all immersion suits are created equal. Even though both suits are approved by Transport Canada and have very similar general design and components, significant differences were found in both donning times, and donning task error rates. The significant difference was found only in total donning time, but not in time required to complete critical donning tasks. This suggests that the main effect of suit design is on time required for task related to protecting hand and face. Observations suggest that design features have significant effect on total donning time rate and success of task completion; it is important, therefore, that users have a detailed knowledge and understanding of their equipment.

Results suggest that at least four donning trials were required before best donning performance time was approached. It would be of value for marine survival training schools to consider this when designing and implementing courses for novice students. This is also of significance for vessel masters when deciding the frequency at which suit donning is practiced aboard. Increased donning frequency and repetition increases user familiarity and proficiency with equipment and leads to shorter donning times and greater user confidence.

Not a Worst-Case Scenario, or Even Close

It is important to put the experimental data into perspective in relation to potential real-life situations. A number of factors might greatly affect donning times, error rates, abandonment procedures and success, as well as suit effectiveness. Although the experimental design attempted to create realistic motions, other environmental demands were benign compared to the realities of marine abandonment, which are much more difficult to create under laboratory settings. The experimental protocol had several favourable variables that may have contributed to shorter donning times than can be achieved in the real-world.

1. The experimental environment had ideal surroundings compared to many areas and conditions on a vessel or offshore installation.

    a. The platform area where participants performed donning tasks was relatively large, measuring 2 m x 2 m, giving the participant ample space to move around and sit or lie down without being obstructed during the duration of donning.

    b. The platform was enclosed with railings suitable for holding onto for stabilization during motions and dry. Open deck areas with no handholds, crowded, confined, wet spaces and more forceful deck accelerations would hinder donning.

2. Immersion suits were in new condition and in perfect working order.

    a. During the testing period, suits were regularly brought to qualified refurbishing and maintenance facilities for professional inspection and repair.

    b. Generally, a single suit was not used for more than two participants, or a total of fourteen donning trials.

    c. Each suit was correctly folded and packed, as per manufacturers' instructions, had adequately lubricated zippers, correctly installed liners and unbroken seals and fabric.

    d. Flaws, disrepair, or incorrect sizing in immersion suits might add to donning times, as well as degrade the suits' effectiveness once the individual is in water.

3. The size of suit given each participant was based upon body morphology and manufacturer sizing specifications.

    a. In reality, a suit might not be of an appropriate size for the individual.

4. Immersion suits in carry bags were placed in front of the participant prior to the beginning of each trial. Participants were standing erect, clothed, awake and aware of their surroundings.

    a. Donning times collected measure only the amount of time it takes a participant to unpack and don an immersion suit.

    b. In applying this to an emergency scenario, the time it takes to prepare (e.g., get out of bed, become orientated to the situation, etc.), locate and retrieve the immersion suit would further increase the length of time to don the suit.

5. The majority of participants were in their twenties and generally in good physical health and reported no severe injuries or major fatigue prior to or during data collection.

    a. In real conditions users of suits may be in less than optimal physical condition.

6. All participants started as novices and were only exposed to written donning instructions prior to starting data collection.

    a. Over the course of the experiment participants gained experience, became practiced and learned donning procedures.

    b. Learning effect was accounted for by randomized trials but, due to the number of repetitions in such a short period of time, it is possible that analytical techniques did not eliminate all learning effect and results may be more optimistic than if only novices were used in all iterations.

7. Participant clothing was ideal for donning a suit.

    a. Participants were required to wear typical athletic clothing (t-shirt, shorts, cotton socks and low-topped athletic sneakers).

    b. Prior to donning trials an appropriately sized pair of one-piece work coveralls was provided.

    c. All jewelry and accessories were removed in the pre-trial procedure to ensure that no negative interaction or damage would affect suit integrity or donning times.

8. Participants were required to have good vison.

    a. Immersion suit donning is generally inhibited by eyewear and anyone forced to don and abandon with uncorrected vision may require extra time to complete the tasks.

9. Potential negative effects of hair were minimized.

    a. Long hair was tied back and out of the way to prevent it obstructing participant vision and to facilitate donning the head piece and sealing the zipper of a suit.

    b. No participants had beards.

10. Differing work boot designs predominantly found at sea may or may not take longer to remove in comparison to low-topped laced athletic footwear used in this experiment.

    a. Many participants removed shoes by stepping on the heel and slipping out of them without untying laces. Rubber work boots or laced boots would most likely take longer to remove.

11. Mean participant BMI was calculated as 24.9. This classifies the study population to be within a “normal weight” range based on height and weight ratios. It can be hypothesized that overweight and obese individuals with poorer physical fitness and excessive body weight would result in increased donning times compared to this data set.

12. The study dealt with suit donning only, and did not investigate the consequences of water entry and manoeuvring in a suit that is of poor fit or is incompletely or incorrectly donned.

CONCLUSION

This is the first empirical research to investigate whether it is possible to don a marine abandonment immersion suit in a dynamic environment within the two-minute time allowance referenced in marine abandonment suit standards. Data from this study indicates that although mean donning times were less than two minutes across all experimental conditions, the standard was not met in 26.1% of the trials. Nearly every participant made one or more donning errors over the course of the trials. Given the favourable conditions under which the study was done, the results suggest that current design and manufacture must be improved if the standard is to be met in real conditions; there also is need to revisit the suitability of the current immersion standard with respect to donning suits in a dynamic environment and with respect to specifying design and manufacturing criteria that will lead to suits that are less subject to user error.

Results of the study indicate that training standards and delivery should adequately reflect realistic environmental conditions and should identify to trainees the importance of identifying, prioritizing and performing critical immersion suit donning tasks. The study also demonstrates that research methodologies can be beneficially applied to create defensible, research-informed, performance-based standards that will more likely ensure that all personnel can successfully don an abandonment suit within the required time period, and thus increase chances of successful survival and rescue.

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