THE EFFECTS OF TOWING ON HUMAN PERFORMANCE IN A LIFE RAFT

LISE PETRIE

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by

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ABSTRACT

Introduction: Evacuation from a ship or offshore installation is a hazardous undertaking, even in controlled situational and environmental circumstances. Life rafts are used in abandonment situations and are preferred to individual cold water entry. Life rafts can be self-launching and self-inflating and protect the occupants from extreme heat or cold. In high seas or winds, life raft motion could affect the performance of survival tasks, even while being towed. Despite the regulated and required use of life rafts, there is an absence of quantitative knowledge about life rafts and human performance in motion conditions.

Methods: Twenty-four healthy male participants (23.8 ± 3.1 yrs, 177.7 ± 6.9 cm, 78.5 ± 11.4 kg) were given two hours of basic training by survival training experts prior to the data collection sessions. Canopy closure, movement within the life raft, sea anchor deployment and retrieval, paddling, and bailing were all demonstrated during the training session. Participants were asked to repeat these tasks during the data collection sessions whilst in a 16-person life raft that was being towed in either calm sea or controlled sea state 2 conditions in a self-contained tow tank facility.

Results: In movements within the life raft, sea anchor retrieval, paddling, and bailing tasks there was a significant difference between the no wave condition and the wave condition. In canopy closure the quality and speed of completion showed improvement with practice.

Conclusion: Quantitative data and qualitative observations for five tasks showed that motion, experience with the task, life raft design and equipment can all affect performance. Several recommendations to the current sea survival training standards are presented.

Acknowledgements

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Last, but not least, a big thank-you to all the participants for putting up with scheduling changes and delays and long hours in the life raft, and to my two children, Callum and Kendall, for tolerating the long hours I was away from the house during data collection.

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CHAPTER 1 - INTRODUCTION

Evacuation from a ship or offshore installation is a hazardous undertaking even in controlled situational and environmental circumstances (Cross & Feather, 1983). Inflatable life rafts have made an enormous contribution to saving lives at sea since first issued in WWII (Wills, 1982) and have been shown to be more successful in the rescue of human life than lifeboats (Hahne, 1983). They are commonly used world wide as primary or secondary means of evacuation (Joughin, 1990) from oil installations, merchant ships, cruise ships, ferries, military vessels, and small vessels (Mak et al, 2005). The main reason for life raft use in abandonment is to prevent entry into cold water and reduce the potential for cold shock, hypothermia, and drowning (Transport Canada, 2003). Despite their regulated and required use, there is an absence of quantitative knowledge about life rafts and human performance, especially in different weather conditions.

A life raft can be self-launching and self-inflating and protect its occupants from extreme heat and cold ("Survival at Sea", 1976), but is difficult for occupants to manoeuvre and thus it must be towed on-site by a support vessel. A tow patch allows standby vessels or motorized lifeboats to tow the life raft away from sinking ships, fires, or explosions (Mak et al, 2005). It also enables life rafts to be tethered together to facilitate search and rescue (National Marine Safety Committee, 2005) and allows them to be towed, even as a group, when rescue is delayed due to unfavourable conditions, such as high waves or when occupants are too exhausted to self-extract safely from the life raft (Hahne, 1983).

Sea survival training has proven to play an essential role in successful escape and survival. Cross and Feather (1983) noted that in past maritime disasters it was personnel unfamiliar with emergency procedures that made the situation worse, whereas those that were well trained took steps to prevent a dire situation from escalating to a worsened state. Furthermore they feel that casualties are kept to a minimum the more proficient personnel become in carrying out these procedures. Leach (1986) agreed that the more people practice, the more automatic their response would be, even in a stressful emergency situation. As life-saving equipment becomes more sophisticated, higher standards of training are required for its proper use if one is to overcome the threat to life that abandonment in adverse sea or weather conditions can pose (Cross & Feather, 1983; Hahne, 1983).

In high seas or winds, life raft motion could affect the performance of survival tasks, even while being towed. This could result in delayed, extended, or unsuccessful survival and recovery situations. There is little information on human performance in a life raft while being towed, especially in motion conditions. Performance of tasks such as entrance closure, movement within the life raft, deployment and retrieval of the sea anchor, bailing, and paddling are all deemed important to life raft occupant survival

The purpose of this study was to gain a better understanding of the effects that motion due to towing has on the ability to perform the management tasks necessary for life raft occupant survival following the abandonment of a maritime vessel. The following hypothesis was considered: does life raft towing affect the completion time and quality of the performance of life raft management tasks? This information will be invaluable to search and rescue planners, marine evacuation system designers, survival trainers and regulatory bodies governing safety at sea.

CHAPTER 2 - REVIEW OF LITERATURE

2.1 Introduction

Inflatable life rafts were introduced during World War II and in recent years have been carried by most merchant and passenger ships, saving many lives by their use (Wills, 1982). They are also used on oil installations and military vessels as evacuation systems (Mak et al, 2005) and their features of compactness and lightweight have made them a convenient lifesaving appliance for fishing vessels and small pleasure craft (Hahne, 1983; Wills, 1982).

Abandonment into a life raft is just the first of several immediate actions to be taken towards successful sea survival and rescue. Once a life raft is occupied, it may be necessary to tow it away from a hazardous situation such as a fire, explosion, collision, or sinking vessel (Mak et al., 2005). It also may be appropriate to tow a life raft during the rescue phase if circumstances such as adverse environmental conditions or exhaustion of the occupants make immediate evacuation from the scene too hazardous (Hahne, 1983). In these situations towing may occur early in the evacuation process and thus several life raft management tasks may be required to improve the chances for a successful rescue.

2.2 Immediate Actions

Several studies have focussed on the efficiency of evacuation systems (Cross & Feather, 1983), which often end with abandonment by slide or chute into an inflatable life raft, or entry from the water into a life raft (Tikuisis & Keefe, 2005). There are studies of evacuees once on board a life raft that deal with lengthy survival durations while lost at sea in more temperate climates (Callahan, 1983;

Mallory & Bachrach, 1988), although few have examined the immediate life raft management actions that must be taken for initial survival, particularly in colder waters (Cross & Feather, 1983; Joughin, 1987; Joughin, 1990). The vital, initial actions that must follow a successful evacuation are: 1) cut the painter line and get clear of the immediate danger either using the paddles provided or by being towed, 2) look for other survivors, 3) stream the sea anchor, 4) close up canopy entrances, and 5) maintain the life raft in good condition by bailing out any water and sponging the floor dry (Cross & Feather, 1983; Joughin, 1987; Joughin 1990; Wright, 2003, p. 34).

If the vessel or structure is equipped with lifeboats, these are often used to initially tow the life rafts away from danger (Wright, 2003, p. 30). Speed standards for towing life rafts in calm water have been set to test the life raft's stability (International Maritime Organization [IMO] Life-saving Appliance Code [LSA], 2003), but the speed of towing in waves with human occupants on board has not been clearly determined (G. Small, personal communication, 18 January, 2007) and the effects of this motion on human performance of survival and life raft maintenance tasks within are still largely unstudied.

2.3 Motion Effects

Motion due to the environment can affect energetic and biomechanical performance, but has little or no effect on cognitive performance (Haward, 2000; Wertheim, 1998). Motion-induced fatigue (MIF) is a result of increased energy requirements caused by continuous muscular effort to maintain balance, such as when working on a vessel at sea (Wertheim, 1998). Motion-induced interruption (MII) is the name given to a situation where local motions interfere with task performance due to a loss of balance (Crossland & Rich, 2000; Dobie, 2001; Wertheim, 1998). The effects of MII's have been studied to some extent on ships and moving platforms (Dobie, 2001; Haward, 2000; Holmes, 2005; Matthews et al, 2007), but have seldom been applied to tasks performed in a moving life raft. In ship simulator experiments (Haward, 2000), physical aspects of task performance, such as balance and moving, were reported as being most affected by vessel motions. In heavy seas and high winds, MII's can compromise successful completion of the necessary life raft survival tasks and therefore reduce the chances of a successful rescue. Dobie (2001) found that it was more difficult to carry out tasks involving gross motor skills in moving environments compared to static environments, therefore bailing, occupant movement, and paddling performance could all be affected.

2.4 Cold Water Exposure

Water conducts heat 25 times more rapidly than air and the colder the water the greater the thermal stimulation and heat loss (Brooks, 2001). In cold water, even a slight drop in water temperature can cause a much greater cold stimulus than equivalent cold air temperatures (Lee et al, 1997). A major determinant of survival in cold water is the sea state, as a higher state increases the risk of drowning due to immersion of the oro-nasal openings and increases convective cooling (Transport Canada, 2003).

Incapacitation of the hands can occur very shortly after entry into cold water, and grip strength and tactility are reduced just at the critical time when they are most needed to initiate survival actions (Brooks, 2001). Motor function impairment of the arms and hands usually occurs before cognitive impairment and well before the onset of lethal hypothermia (Tikiusis & Keefe, 2001). Finger temperature seems to be the primary determinant of manual performance decrement (Litchfield, 1987). Isolating the occupant from cold-water sources and adequate thermal protection of the hands should be considered important in the abandonment process (Litchfield, 1987; Petrie et al, 2005).

All of the aforementioned cold factors have led to the realization that sudden cold-water immersion in waters less than 15°C is very dangerous and should be avoided if possible. In an emergency situation, the objective should be to evacuate at the last possible moment, directly into a life saving appliance, in order to remain dry (Brooks, 2001; Cross & Feather, 1983; Golden & Tipton, 2002, p.95). The National Marine Safety Committee (NMSC) of Great Britain states that boarding into a life raft instead of floating in the ocean with a life jacket, also facilitates search and rescue (NMSC, 2005). These findings have led to new regulations requiring vessels to carry life rafts in waters with a mean monthly temperature of 15°C or less (NMSC, 2005; Transport Canada, 2003).

Even with successful evacuation into a life raft, cold water and wind may still jeopardize survival. Dry-shod evacuation, although ideal, is not always possible. Evacuation via slide systems can provide speed, but there is minimal protection from the elements and users will get wet before entry into a life raft if heavy seas or high winds prevail (Brindle & Brindle, 1993). Waves and wind may also enter the life raft through the canopy openings during ventilation, paddling, or survivor retrieval, changing a dry situation to a cold/wet one (MacKay, 1972). Occupants should be prepared, if possible, with immersion suits or several layers of warm clothing and a waterproof shell before abandonment (Keatinge, 1976; MacKay, 1972; Wright, 2003, p. 34).

2.5 Training

Kitchen (2000) and Bercha et al (2003) state that appropriate training in survival techniques and equipment enhances human performance in an emergency situation. Hahne (1983) adds that life saving equipment cannot be expected to retain its efficiency when used by inexperienced persons and that general progress in science and technology demand higher standards of training in the handling of such equipment.

The Safety of Life at Sea (SOLAS) convention of 1914 recognised that human life at sea had priority over property (Kopacz et al, 2001) and subsequently initiated the maritime safety system employed today. Sea survival training was introduced in the SOLAS 1974 regulations and improved upon by international amendments by the IMO in 1983. As the petroleum industry gradually expanded their operations from land to the offshore environment, there was a need for new skills to work in the marine environment (Lund & Zambon, 1990). The International Association for Safety and Survival Training (IASST) was founded in 1980 by stakeholders involved in safety training for the North Sea Oil Industry (McDonald, 1987).

In severe conditions such as those off the coast of Norway, the aim of the safety training for the oil industry is to ensure that the instinctive responses of the men when reacting to life threatening emergency situations at sea are based on practical experiences of what to do and how to respond to problems that arise, rather than only reacting to what they see going on around them (Vere, 1987). Vere (1987) reports that historically, in sea disasters, people have too often died unnecessarily due to lack of adequate training pertaining to emergency situations. In the severe conditions of the Norwegian Continental Shelf and the waters of the North Atlantic, petroleum exploration requires highly skilled people who know how to act in an emergency. Off the coast of Newfoundland it is impossible for anyone to obtain employment in the offshore industry unless they have taken a survival training course (Lotz, 1987). These training standards have markedly improved since the Ocean Ranger disaster in 1982 (McDonald, 1987).

Ideally, training should emphasise the avoidance of accidents such as fires and explosions (Vere, 1987), but should include sufficient instructions on the possibility of structure abandonment for whatever reasons.

In the North Atlantic there are two current minimum training standards for the offshore industries. The first of these is a national regime from Transport Canada based on international standards under the IMO and controls the delivery of training that relates to the certification of mariners (Transport Canada, 1998). This course is the Marine Emergency Duty Course (MED-A/B1) and is mainly for fishermen or cruise ship staff (V. March, personal communication, 21 November 2006). The second training standard is specifically for offshore personnel and is required by the Canadian Association of Petroleum Producers (CAPP) for anyone employed on an oil rig (CAPP, 2005). This Basic Survival Training (BST) Course is designed for everyone going offshore to work at, or even visit, oil installations and has a renewal requirement every 3 years (CAPP, 2005). There is strong emphasis on the use of life rafts in these basic courses, as it is very difficult to organise practical inflatable life raft exercises aboard ships (Joughin, 1986). Both courses, like their international counterparts (Hahne, 1983), consist of onshore sessions, including classroom instruction and wet-drills using a life raft in a swimming pool, followed by practical sea exercises offshore.

Vere (1987), considering his extensive experience in Norwegian offshore activities, proposed training recommendations where everyone would have the basic safety training (BST), and people who are dedicated to special duties, such as lifeboat coxswains, would have more specialised training. Those in emergency management would receive even more specialised training in order to organise and lead personnel in complex situations, such as evacuations. Leach (1986) describes in detail the psychological aspects that can affect humans during sea survival and states that when properly briefed, trained, and drilled with a knowledge of what to expect in a survival situation, people will be more effective in dealing with an emergency. He emphasises that training removes the fear that results from lack of knowledge, and that repetition enables humans to function effectively at an automatic level.

2.6 Conclusion

In an emergency situation, successful evacuation into a life raft can mean the difference between life and death. Once in a life raft, an operator must be able to perform essential management tasks in order to survive. Many factors may affect this performance which, if poor, may jeopardise a successful escape.

Research to date has dealt largely with life rafts from engineering and design perspectives, evacuation system models, and the effects of cold on manual performance. Relatively little has been studied on the effects motion and training can have on the ability of an operator to perform essential life raft survival tasks. Even less is known about these effects while the life raft is being towed, either away from a hazard, or towards rescue.

CHAPTER 3 - METHODS

3.1 Life Raft Characteristics

3.1.1 Design

The life raft employed in this study was a new 16 person SOLAS 'A' commercially available inflatable life raft (DBC Marine Safety Systems, Richmond, B.C.). Its eight sides form a symmetrical octagon and are 1.33m each in length. It has one boarding platform and two canopied entrances (see Figure 3.1).

Figure 3.1 SOLAS 'A' 16 person inflatable life raft.

3.1.2 Life Raft Ballasting

The life raft was ballasted to a total of 75% load capacity. Ballasting included 8 heavy duty PVC rescue mannequins (Dacon AS, Norway) filled with approximately 75kg of water (see Figure 3.2), two researchers, and two experimental subjects.

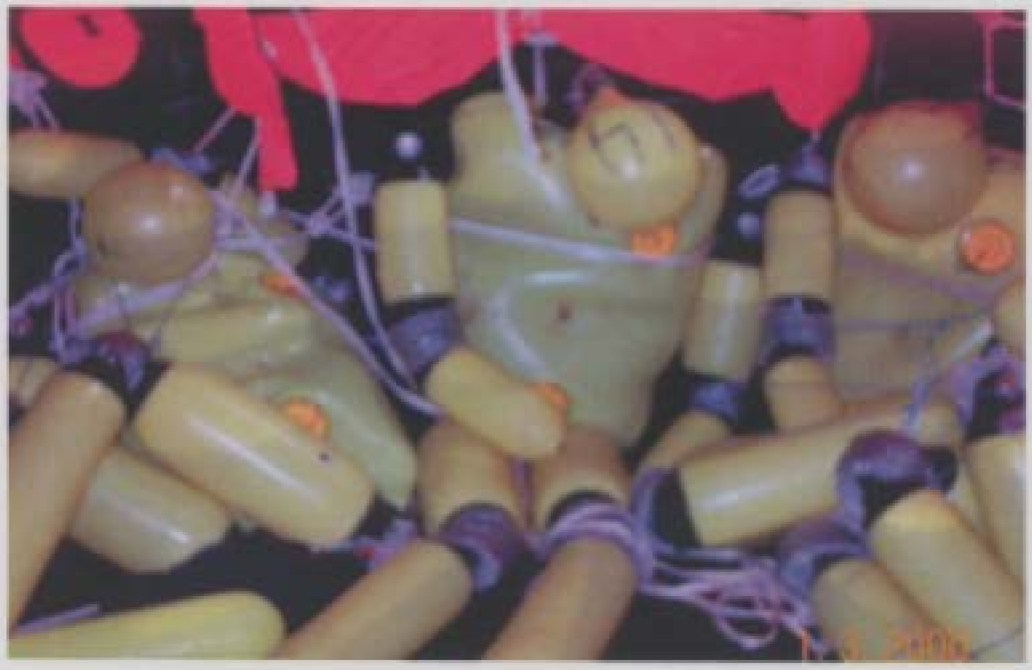


Figure 3.2 PVC water-filled rescue mannequins.

3.2 Towing Tank Characteristics

A towing tank located at the Institute for Ocean Technology, National Research Council (St. John's, Newfoundland and Labrador, Canada) was employed in this study. The towing tank has a total length of 200m with a working area of 120m by 12m and a water depth of 7m (see Figure 3.3).

Figure 3.3 National Research Council towing tank.

3.2.1 Speed of Tow

The life raft was towed at a speed of 1 m/s (1.94 knots) through both still water and mechanically generated waves by a single, manned carriage spanning the 12m width of the tank.

3.2.2 Motion Conditions

Two motion conditions were considered for the towing protocol: no waves and waves. Waves were generated uni-directionally by a dual flap hydraulic wave board using digital computer control. The irregular wave profile had a significant wave height of 0.5m and produced a simulated Sea State 2 condition without wind effects. Motion conditions were presented randomly to the participants for each task. Three wave probes were installed in the tow tank to measure wave conditions produced; one close to the wave maker (upstream wave probe), one at the 60m mark (midstream wave probe), and one on the carriage (encounter wave probe)(see Figure 3.4). Each wave probe sampled the wave state at a rate of 50Hz. A parabolic beach is located at the opposite end of the tow tank to allow for wave power absorption and prevent reflection of waves.

Figure 3.4 Midstream wave probe.

3.3 Life Raft Motion Measurement Instrumentation

Life raft motions were measured using two independent systems: MotionPak – Two BEI MotionPak II (BEI Technologies, Inc., Concord, California) systems were placed in the raft; one attached directly to the floatation tube of the life raft interior, and the other installed in a mannequin inside the raft directly opposite. This device is a fully self-contained motion measurement system that utilises internal power regulation and signal conditioning electronics. It is a "solid-state" Micro-Electro-Mechanical Systems (MEMS) six degree of freedom inertial sensing system used for measuring linear accelerations and angular rates in instrumentation and control applications. The three quartz rate sensors have a measurement range of +/- 75 degrees/second, and the three silicon accelerometers have a range of either ± 1.5g, or ±2.7g (see Figure 3.5).

Figure 3.5 MotionPak in mannequin (left).

One QUALISYS System (IOT, St. John's, NL and Qualisys AB, Gothenburg, Sweden) with six infrared emitters was attached as a "tree" to the front exterior side of the raft (see Figure 3.6). These emitters measured six motions: accelerations in the cardinal X, Y, Z directions and yaw, pitch, and roll angles.

Figure 3.6 QUALISYS tree on exterior (front right) of life raft.

3.4 Data Acquisition

The tow tank is equipped with a virtual memory system (VMS) and Windows-based distributed client/server data acquisition system. Human factors data were collected employing standard temporal synchronization of all data streams. These data were validated by a video recording system. Two time synchronization markers were used to indicate the start and end of each task. Two video cameras were installed inside the life raft at the lower ends of the canopy arch inflation chamber, while 2 other cameras were mounted externally; one on top of the main carriage (in line with the tow point) looking back at the raft and the other one on the connection truss beside the raft. A Polar S610i heart rate monitor (Polar Electro, Finland) was worn by all participants throughout the study and collected heart rate data at 5-second intervals. These data were then downloaded to a personal computer for later analysis following the completion of the data collection trial.

3.5 Participant Demographics

Twenty-four participants completed a medical history questionnaire and gave written consent in accordance with Memorial University's Human Investigation Committee prior to volunteering for this study. All participants received standardized training on how to complete the life raft management tasks. This training was accomplished in a previous training session from an earlier study with any new subjects being re-trained. All participants were male with a mean age of 23.8 ± 3.1 years, mean stature of 177.7 ± 6.9 cm, and mean mass of 78.5 ± 11.4 kg and were required to wear standardized clothing consisting of a long-sleeved t-shirt and long pants.

3.6 Life Raft Management Tasks

This experiment consisted of five different life raft management tasks. All tasks were performed in both motion conditions (no wave and wave) while the life raft was being towed. All participants wore SOLAS approved life jackets while in the life raft.

3.6.1 Canopy Closure

The participant was first required to secure the three loops of the outer flap of the canopy doorway to the three rubber toggles on the outside of the floatation tube (see Figure 3.7), then untie and unroll the inside flap, pulling the drawstring tight and tying it to the tie hanging down from the top of the opening (see Figure 3.8). Time to completion and quality of closure were both recorded. This task was performed twice for each motion condition.

Figure 3.7 Closing external flap of canopy.

Figure 3.8 Closing internal flap of canopy.

3.6.2 Movement

The participant was required to sit facing the interior of the raft with his arms placed through the grab line. Upon the word "go", the subject had to release himself from the grab line and move to the opposite side of the raft as quickly as possible, then turn around, sit down, and re-secure his arms in the grab line at which instant the measurement time was stopped. This task was performed in two directions: with waves (A1) and against waves (A2) alone, then crossing the other participant with the wave direction (C1) and against the wave direction (C2)(See Figure 3.9). These four movements were performed only once for each motion condition.

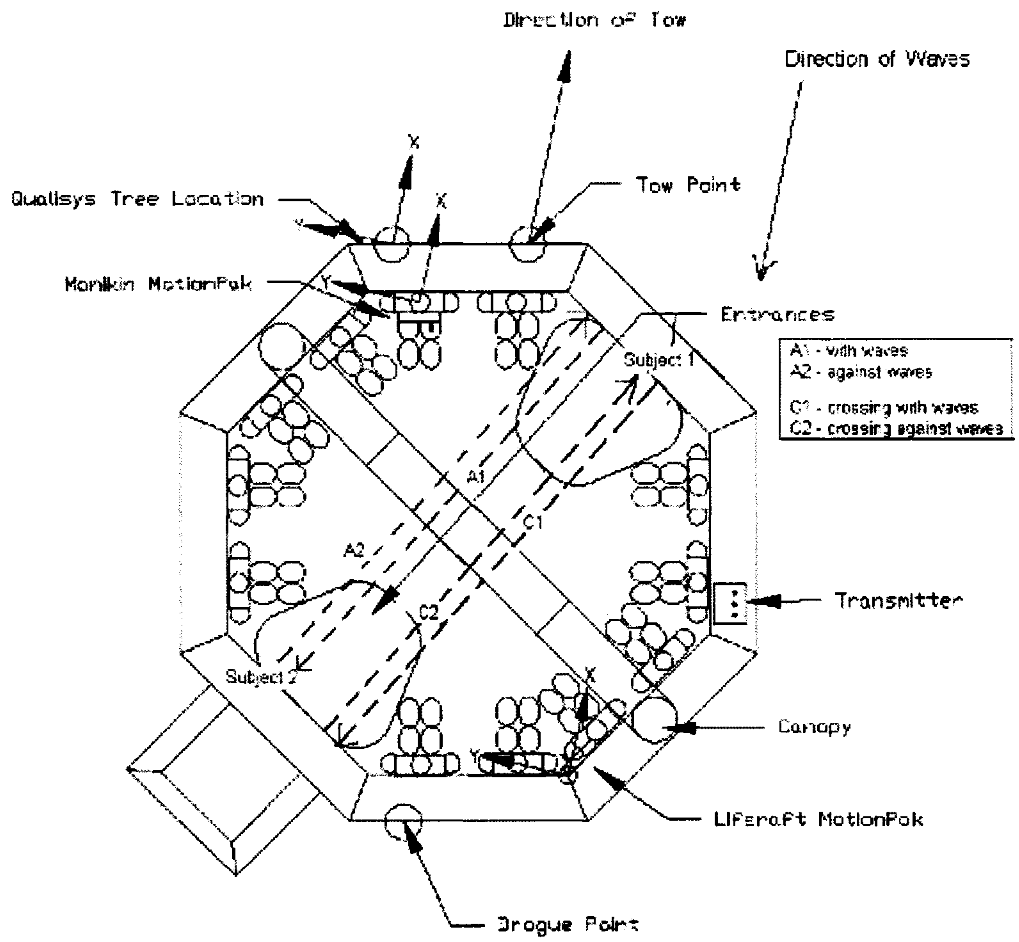


Figure 3.9 Movement directions.

3.6.3 Sea Anchor

The sea anchor employed was an Icelandic type that has a small opening at the aft end and a larger opening at the forward end (see Figure 3.10) and was supplied with the life raft. The participant was required to deploy it to full length (rope length of 20m) and then retrieve it, as fast as possible without compromising the technique demonstrated during the training session. Both time and quality of task were recorded. The participant performed two trials for both towing conditions.

Figure 3.10 Icelandic type sea anchor.

3.6.4 Paddling

The life raft was freed from its towline for this task and the participant was required to lean out of the fore side of the raft and paddle as far as possible in a 5 minute time period using a standard issue plastic life raft paddle (see Figure 3.11). Each subject followed this procedure for two separate trials in both motion conditions. Note that in the wave condition the subject paddled with, rather than against, the waves.

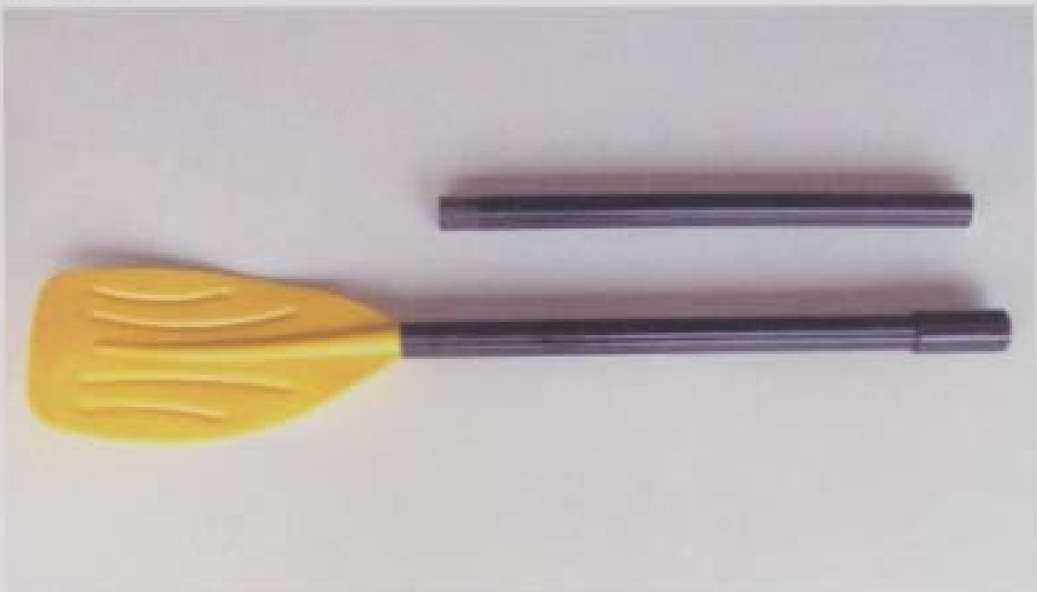


Figure 3.11 Standard issue two-piece life raft paddle.

3.6.5 Bailing

The raft was filled with approximately 300 litres of water. The participant was required to bail out as much water as possible during the length of one run down the tank (119.23 $\pm$ 1.15 sec) using either the standard issue nylon bailer, or the standard issue nylon equipment bag (see Figure 3.12) for both motion conditions.

Figure 3.12 Bailer (on left) and equipment bag (on right).

The water bailed was pumped up to a 244.55 ℓ barrel. The height (in metres) of the water in the barrel was measured with a bail level probe after each trial and the total volume was subsequently calculated (see Figure 3.13).

Figure 3.13 Bailing set-up.

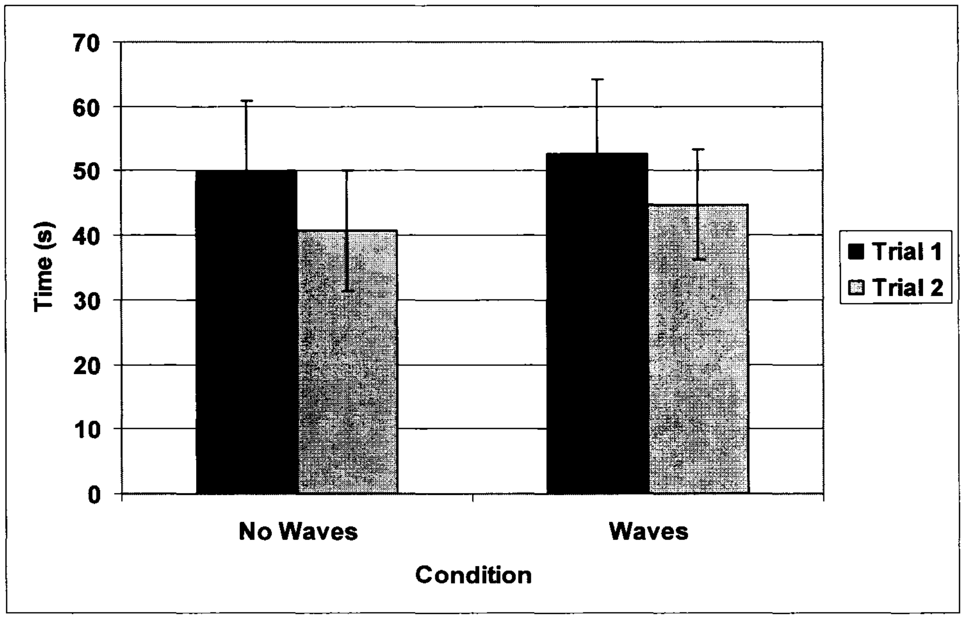
CHAPTER 4 - RESULTS

4.1 Introduction

Participants performed five different life raft survival tasks in two different motion conditions; no waves, and irregular waves while being towed in an inflatable life raft. The five tasks were named (and abbreviated) as follows: canopy closure (CC), movement (MT), sea anchor (SA), paddling (PA), and bailing (BA). Data presented in this section represent values averaged across subjects. Standard deviations are also described in the figure and table data. Individual data can be found in appropriate appendices.

4.2 Canopy Closure

In the no wave condition the mean time taken to complete the canopy closure was 49.9 ± 10.9s for Trial 1 and 40.8 ± 9.3s for Trial 2, while in the wave condition the mean times were 52.6 ± 11.6s for Trial 1 and 44.8 ± 8.7s for Trial 2



(see Figure 4.1). Individual participant data for this task may be found in Appendix A. A repeated measures ANOVA showed no significance (p= 0.101) in the different wave conditions, but a significant difference (p < .001) was found between the first trial and the second trial.

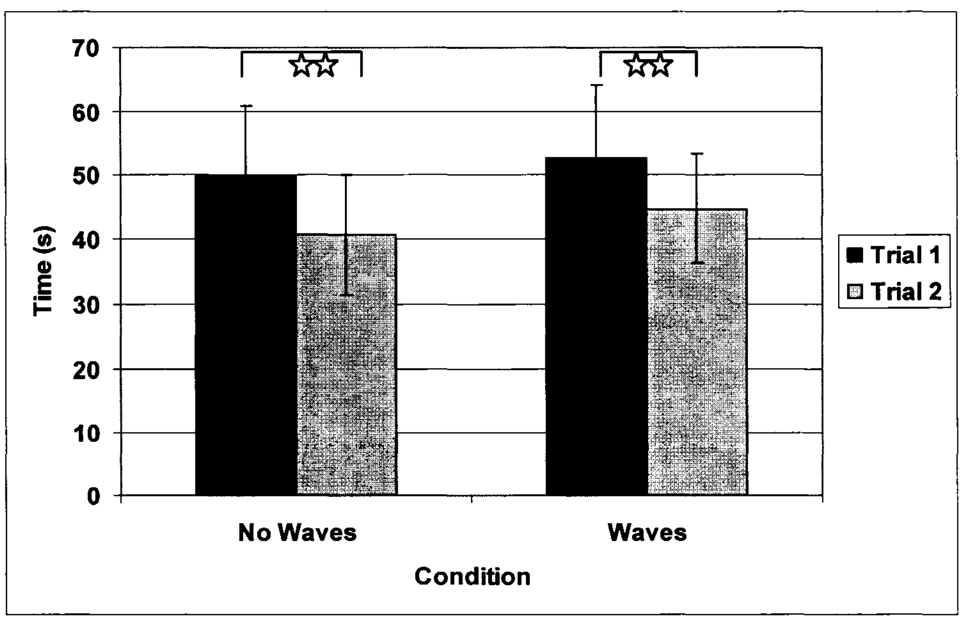


Figure 4.1 Mean canopy closure times (s).
Note:** indicates significant difference at $p < .001$

Qualitative data were also recorded for this task, as the proper closure of the canopy is crucial to survival in a life raft. It was observed that although there was no significant difference in task time completion due to wave condition, there seemed to be an improvement in the quality of the task completion as the exposure to the task increased. Table 4.1 describes, for each subject, the quality of the closure attempt. Note that these data are reported in order of trial completion and not necessarily by the motion condition.

Table 4.1 Qualitative description of each canopy closure attempt by trial order.

Participant	Run 1	Run 2	Run 3	Run 4
1	Good/Came Undone	Good	Good	Good
2	Good	Good	Good	Good
3	Perfect	Good/Came Undone	Missed Untying Tie	Came Undone
4	Sloppy	Perfect	Perfect	Good
5	Missed Untying Tie	Sloppy	Good	Good
6	Bit Loose	Good	Good	Good
7	Sloppy/Came Undone	Good	Missed Middle Mushroom	Good
8	Perfect	Good	Good	Good
9	Good	Good	Good	Good

10	Came Undone	Good	Came Undone	Good
11	Good	Good	Good	Good
12	Sloppy	Came Undone	Came Undone	A Little Sloppy
13	Perfect	Came Undone/Missed Middle Mushroom	Perfect	Perfect
14	Good	Came Undone	Came Undone	Sloppy
15	Missed Untying Tie	Came Undone	Perfect	Came Undone
16	Came Undone	Good	Good	Sloppy
17	Good	Good	Good	Came Undone
18	Sloppy/Knot Instead Of Bow	Good	Good/Came Undone	Good/Used Teeth
19	Good	Good	Good	Good
20	Good	A Little Loose	A Little Sloppy	Good
21	Sloppy/Knot Instead Of Bow	Good	Knot Instead Of Bow	Loose/Knot Instead Of Bow

4.3 Movement

In the no wave condition the mean time for movement A1 was 4.1 ± 1.0s, movement A2 was 4.0 ± 1.4s (see Figure 4.2), movement C1 was 4.3 ± 1.4s, and movement C2 was 4.5 ± 1.4s (see Figure 4.3). The mean times for the wave condition were 4.5 ± 1.2s for movement A1 and 4.4 ± 1.2s for movement A2 (see Figure 4.2) and 4.5 ± 1.3s for movement C1 and 4.6 ± 1.0 s for movement C2 (see Figure 4.3). Data for individual participants in this task may be found in Appendix B. A repeated measures ANOVA indicated that direction of movement did not have any significant difference ($p=0.513$) in the time taken, although there was a trend towards taking longer to complete the movement when having to cross against another participant. There was a significant difference ($p= 0.049$), however, between motion conditions, with the participants talking longer to complete the movements while being towed in waves.

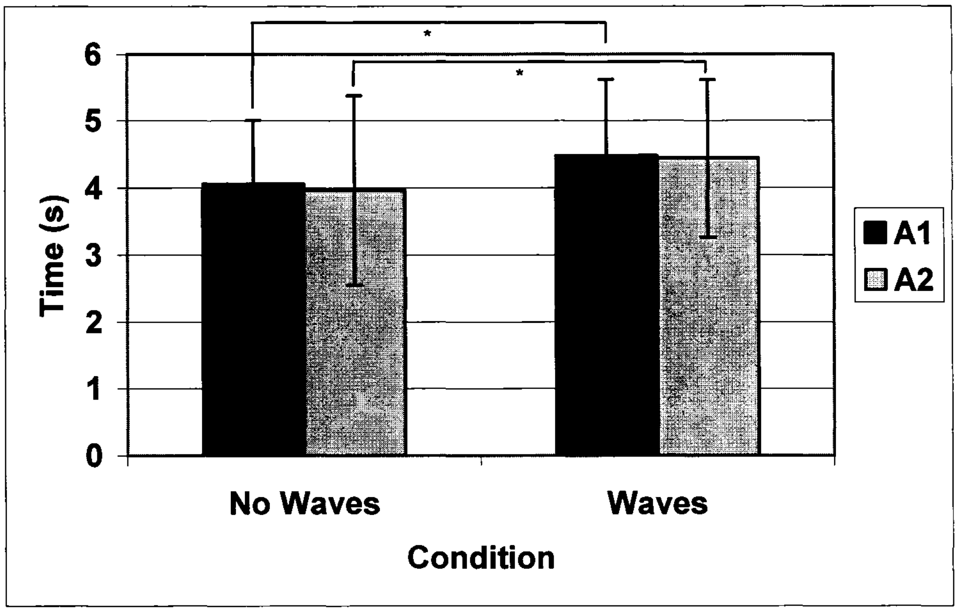


Figure 4.2 Mean time (s) taken to perform Movement A.

Note:* indicates significant difference at $p < .05$

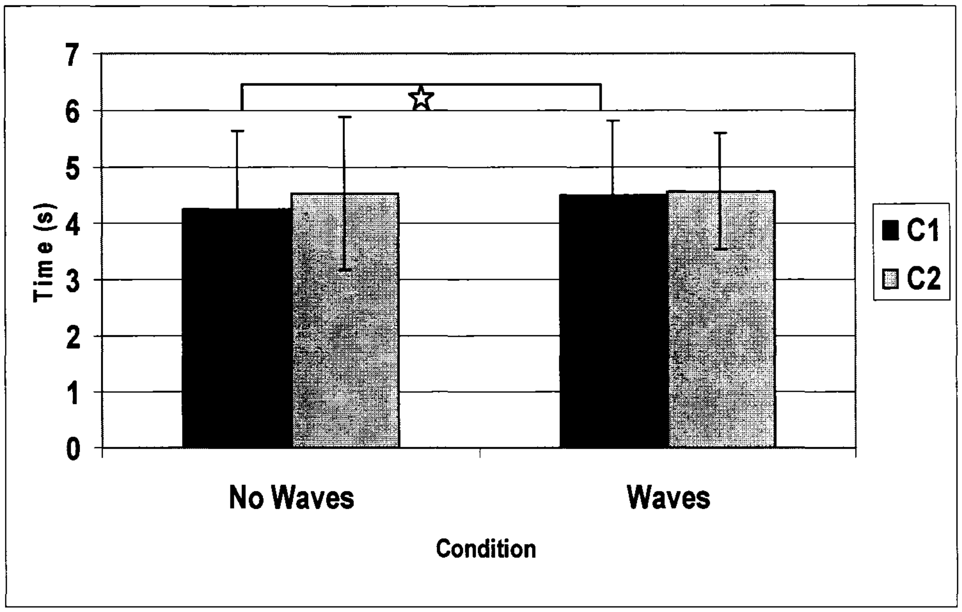


Figure 4.3 Mean time (s) taken to perform Movement C.
Note:* indicates significant difference at $p < .05$

4.4 Sea Anchor

4.4.1 Deployment

In the no wave condition the mean time to deploy the sea anchor was 31.3 ± 7.8s in Trial 1 and 30.5 ± 12.9s in Trial 2. In the wave condition the mean time was 35.2 ± 10.0s in Trial 1 and 31.5 ± 6.3s in Trial 2 (see Figure 4.4). A repeated measures ANOVA showed no difference between the motions (p=0.251), while there was a trend for a difference between the times for Trial 1 and 2 (p=0.085).

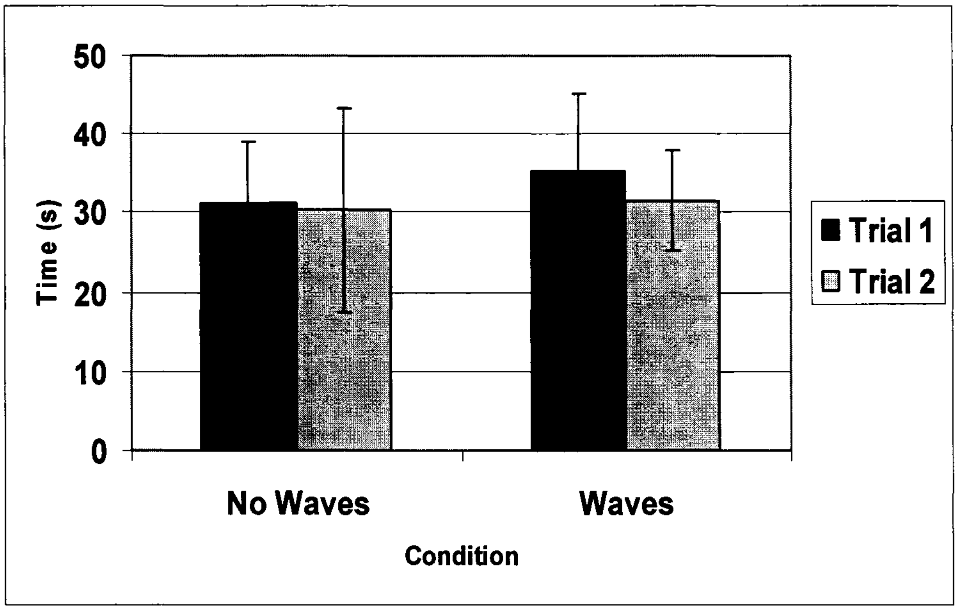


Figure 4.4 Mean time (s) taken to deploy the sea anchor.

4.4.2 Retrieval

In the no wave condition the mean sea anchor retrieval time was 26.5 ± 7.0s in Trial 1, and 27.8 ± 6.2s in Trial 2. The wave condition showed a mean time of 30.7 ± 7.6s in Trial 1 and 30.2 ± 7.1s in Trial 2 (see Figure 4.5). A repeated measures ANOVA revealed a significant difference between conditions (p=0.015), but no significance between Trials 1 and 2 (p=0.634). Individual participant data for both parts of this task can be found in Appendix C.

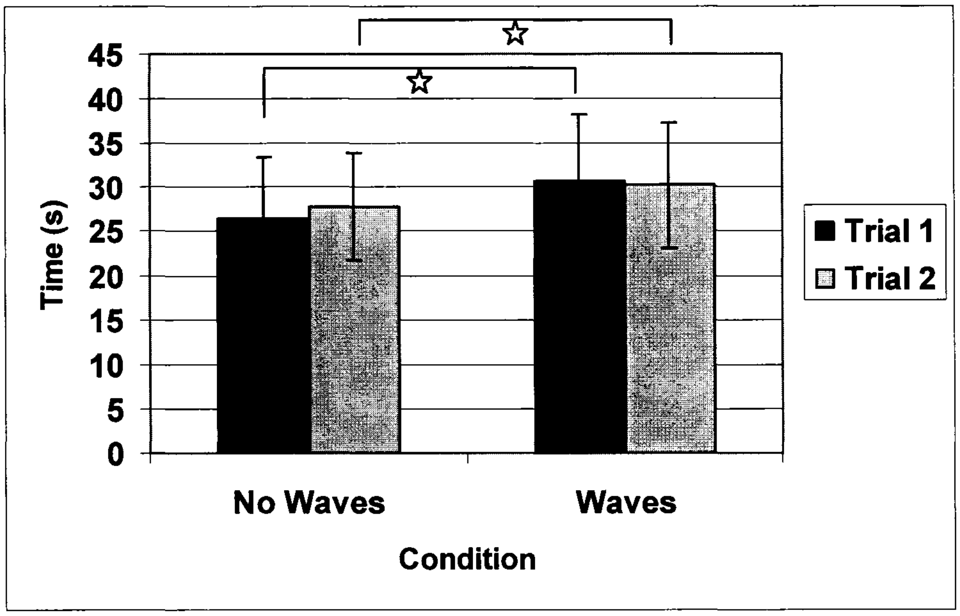


Figure 4.5 Time (s) taken to retrieve the sea anchor.
Note:* indicates significant difference at $p < .05$

4.5 Paddling

The distance paddled was calculated by recording the difference in the carriage position from the start to the finish after a timed 5-minute trial. The wave tank operator manually held the carriage position constant with the raft position. The mean distance paddled in the no wave condition was 23.7 ± 7.7m while the mean distance paddled in the wave condition was 47.1 ± 3.7m (see

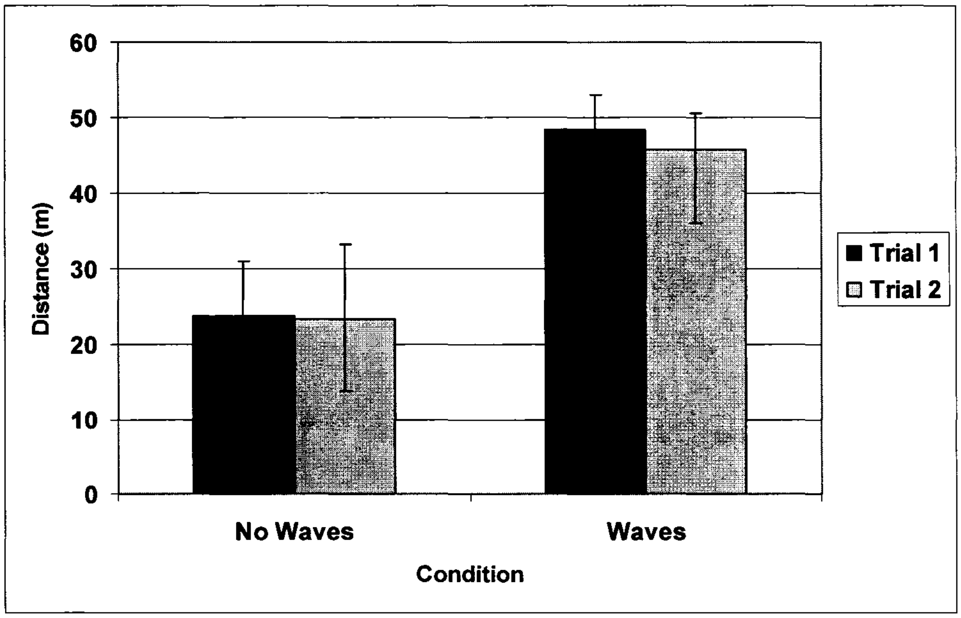


Figure 4.6). Individual participant data for this task can be found in Appendix D. A repeated measures t-test indicated a significant difference (p=0.018) between the mean distances travelled in the two wave conditions.

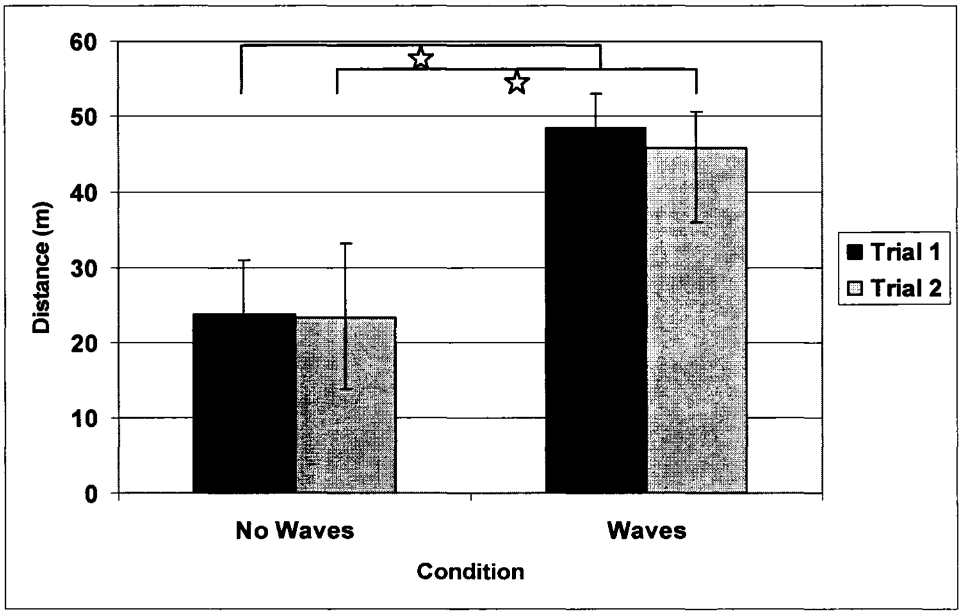


Figure 4.6 Mean distance (m) paddled during a five-minute period.
Note:* indicates significant difference at p < .05

Heart rate values were analysed for the paddling task. The mean and maximum heart rates for paddling in the no wave condition were 145.2 ± 22.1beats·min^{-1} and 157.7 ± 21.0beats·min^{-1} respectively. In the wave condition the mean heart rate was 138.8 ± 15.4beats·min^{-1} and the maximum 152.5 ± 14.2beats·min^{-1} (see Figure 4.7).

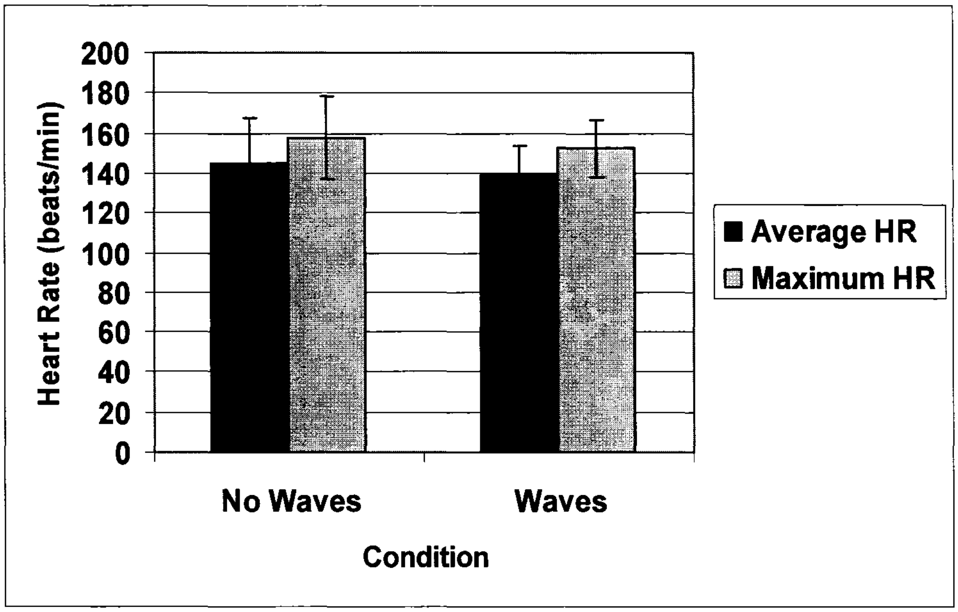


Figure 4.7 Mean and maximum heart rates (beats·min^{-1}) while paddling.

Note that paddling heart rate comparisons were based on 10 participants, as the awkward paddling position interfered with data transmission in some individuals and data loss occurred. A repeated measures t-test for the mean paddling heart rates showed there was no significant difference (p=0.095) between motion conditions. There was also no significant difference (p=0.120) between motion conditions for the maximum paddling heart rates. Individual participant heart rate data for this task may be found in Appendix E.

4.6 Bailing

Bailing consisted of using two different apparatus: a bailer supplied with the life raft and an equipment bag in which the bailer is typically stored in the life raft. The trial duration for both the no wave and wave conditions are reported in Table 4.2. Bailing times were analysed using a repeated measures ANOVA and a maximum difference of 1.0s was found between no waves and waves. This was not a practical difference, as in the wave condition the participants had to wait until the pump was started and the waves had reached the raft before the towing procedure began.

	No Waves		**Waves**	
	Bailer	*Bag*	*Bailer*	*Bag*
Mean	118.7s	118.2s	118.9s	119.6s
SD	0.8	1.6	1.4	0.7

Table 4.2 Mean trial durations (s) for the bailing tasks.

The mean volume using the bailer was 132.4 ± 24.1ℓ for the no wave condition and 121.7 ± 29.4ℓ for the wave condition, while the mean volumes obtained using the equipment bag were 89.6 ± 34.5ℓ in the no wave condition and 78.6 ± 34.5ℓ in the wave condition (see Figure 4.8). Individual participant data for this task can be found in Appendix F. A repeated measures ANOVA revealed a significant difference in the bailing volume ($p=.027$) between no waves and waves, as well as a significant difference ($p <.001$) between bailer and equipment bag.

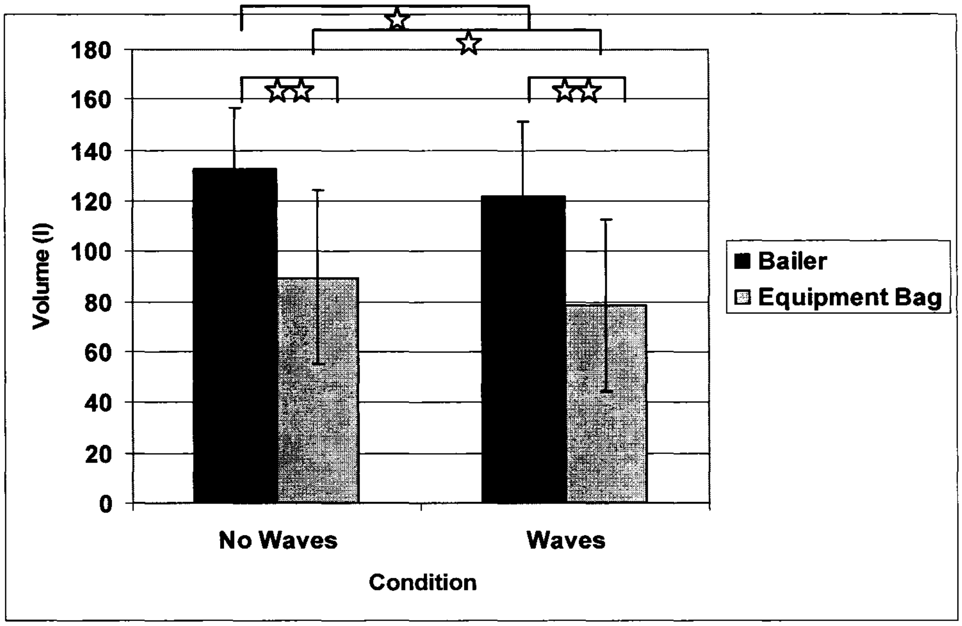


Figure 4.8 Mean volume (ℓ) of water bailed using two different bailing devices. Note:* indicates significant difference at $p < .05$ and ** indicates significant difference at $p < .001$

The mean bailing rate for the bailer in the no wave condition was $66.9 \pm 12.3ℓ \cdot min^{-1}$ and in the wave condition was $61.4 \pm 14.8ℓ \cdot min^{-1}$. Using the equipment bag, the mean bailing rate was $45.5 \pm 17.6ℓ \cdot min^{-1}$ in the no wave condition and $39.4 \pm 17.2ℓ \cdot min^{-1}$ in the wave condition (see Figure 4.9).

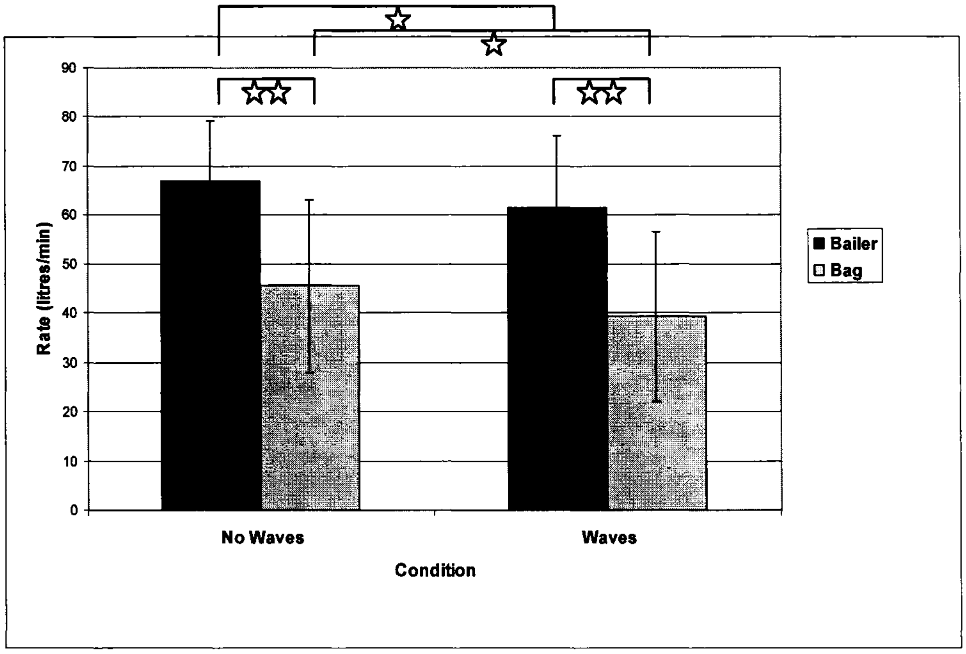


Figure 4.9 Mean bailing rates (ℓ·min^{-1}) using two different bailing devices. Note:* indicates significant difference at p < .05 and ** indicates significant difference at p < .001

A repeated measures ANOVA revealed a significant difference (p=0.017) for bailing rate (ℓ·min^{-1}) between wave conditions, as well as between devices used (p<0.001).

The mean maximum heart rates for bailing in the no wave condition were 150.1 ± 21.9beats·min^{-1} using the bailer and 129.5 ± 26.9beats·min^{-1} using the equipment bag. In the wave condition these were 143.9 ± 25.6beats·min^{-1} using the bailer and 134.1 ± 24.0beats·min^{-1} using the equipment bag (see Figure 4.10). A repeated measures ANOVA performed on the maximum heart rate data showed that there was no significant difference between wave conditions (p=0.726), yet there was a significant difference between the device used (p=0.001). Individual participant heart rate data for this task may be found in Appendix G.

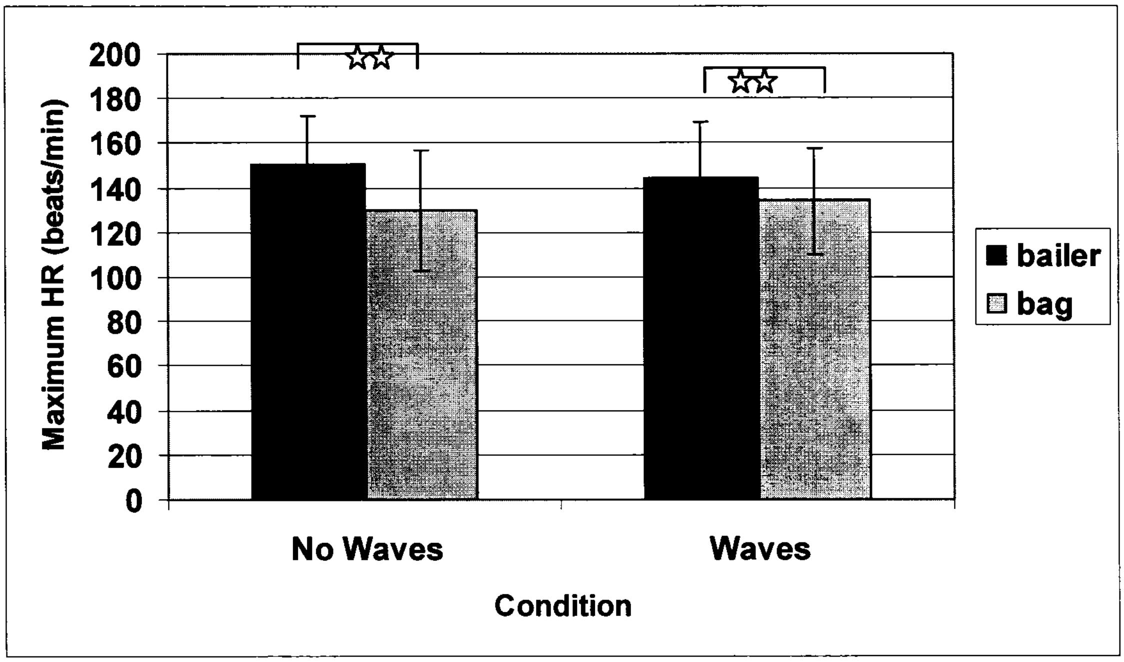


Figure 4.10 Maximum heart rates (beats·min^{-1}) during bailing using two bailing devices.

Note: ** indicates significant difference at $p < .001$

4.7 Wave profiles

Although the participants were oriented in different positions in the life raft, took different lengths of time to complete a task, and each task may have started at slightly different times, the average wave energy is fairly constant within a run. Figure 4.11 through Figure 4.13 illustrate the wave profiles over time across several subjects for repeated measures of the canopy closure-movement-sea anchor (Figure 4.11), paddling (Figure 4.12) and bailing (Figure 4.13) tasks. Between runs the wave generation was re-initiated. The repeatability in the generation of wave profiles is evident and shows that there was little inter-day variability. There would be some intraday variability in four of the five tasks depending on when the participants started and how long they took to complete the task. This did not have as much impact on bailing, as the task was completed over a full run (full wave profile) of the tank each time. Bailing was also the most consistent task because the participants all started and ended the task in the same position in the raft.

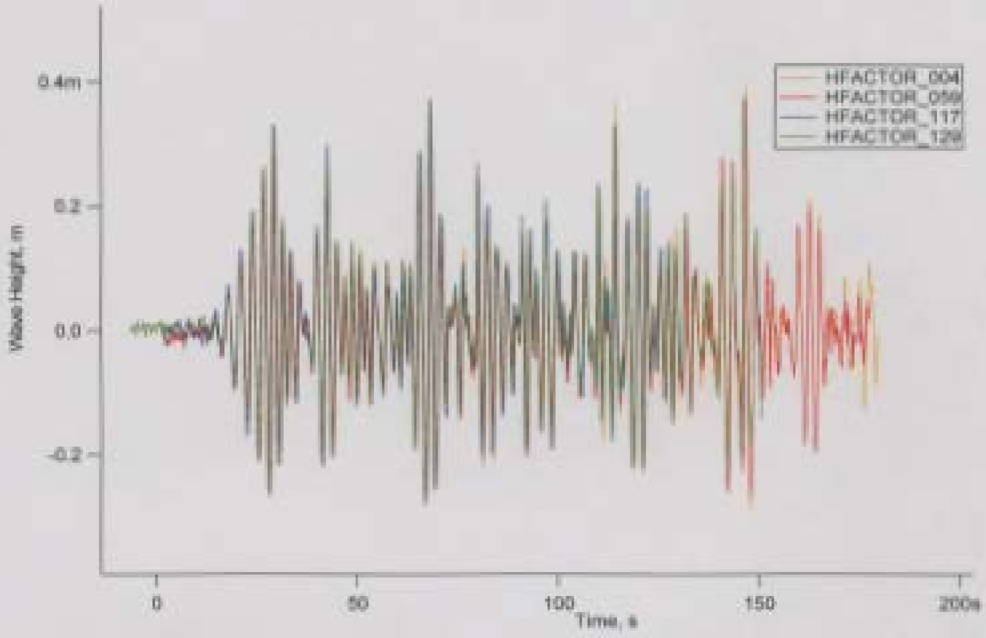


Figure 4.11 Wave profiles over time from canopy closure-movement-sea anchor tasks from every 4th run/day of wave testing over a four-day period.

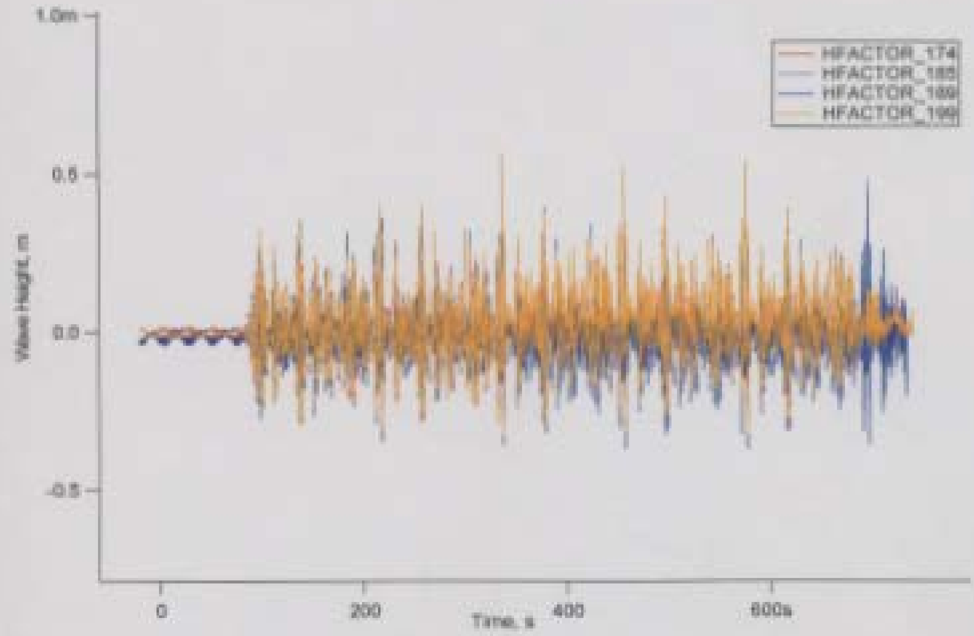


Figure 4.12 Wave profiles over time from paddling tasks every 4th run over one day.

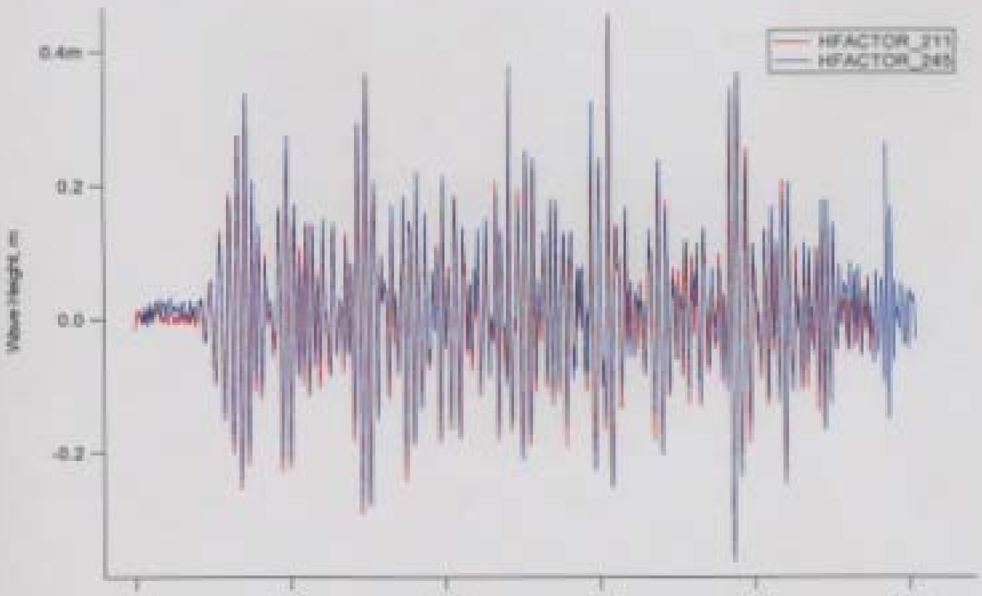


Figure 4.13 Wave profiles over time from bailing tasks every 4th run over two days.

CHAPTER 5 - DISCUSSION

5.1 Introduction

There has been limited research undertaken which considers human performance in a life raft following vessel abandonment at sea. To date the focus of life raft research has been from an engineering and design perspective where the criteria established by marine safety authorities concerns itself with life raft design almost void of how humans survive and perform survival tasks within the structure. There has been some work related to the responses of humans in abandonment conditions (Petrie et al., 2005; Keefe, 2005), but these studies were conducted in calm water environments with a focus mainly on life raft entry or rescue. Evaluation of the efficiency of essential tasks immediately after life raft boarding and performed by occupants with little or no previous training has not been studied. Such research could provide the knowledge necessary for more appropriate training procedures, as well as valuable insight into human survival at sea.

At present there are two training standards for life raft operation under escape, evacuation, and survival situations. One is a Canadian national standard from Transport Canada (Transport Canada, 1998). This standard reflects the international training standards for mariners published under the International Maritime Organization (IMO, 2003). The second training standard has a different focus and relates to the training of offshore personnel and is set out in a document developed by the Canadian Association of Petroleum Producers (CAPP) (CAPP, 2005). Currently many of these training tasks are taught at a familiarisation/group participation level, rather than at the individual skill mastery level, without time for each person to demonstrate proficiency in each task (G. Small, personal communication, 12 October, 2006). Clearly there is a need for more research-informed policy to guide regulators and safety trainers in the development of better training standards.

The purpose of this study was to evaluate human performance during life raft management tasks under simulated towing conditions. An enclosed tow tank facility provides opportunity to work in a controlled and repeatable environment. While wave conditions may be relatively benign compared to those typical of northern Atlantic waters, the systematically reproduced wave spectrum and towing velocity allows for intra-trial repeated measures and inter-subject comparisons. This approach allows for a better understanding of within and between subject variability in task performances.

5.2 Canopy Closure

5.2.1 Discussion

Immediately after complete boarding of the life raft, action should be taken to secure the canopied entrances of the survival craft to ensure protection against wind chill and water ingress. These immediate actions can prevent or delay the onset of hypothermia especially for those occupants who entered the life raft from the water (Cross and Feather, 1983). Proper canopy closure will prevent the wind from getting in under the canopy, causing it to bellow upwards and lift the life raft off the ocean surface (McKeag, 1982). A current study (L. Mak, personal communication, December 5, 2006) has shown that the opening and closing of the canopy is necessary for ventilation of carbon dioxide even during towing and Wright (2003, p. 34) states that if the life raft is not ventilated every half hour asphyxia may occur. These findings emphasize that canopy closure would be a frequent occurrence throughout the survival and rescue phase.

The results for this task (see

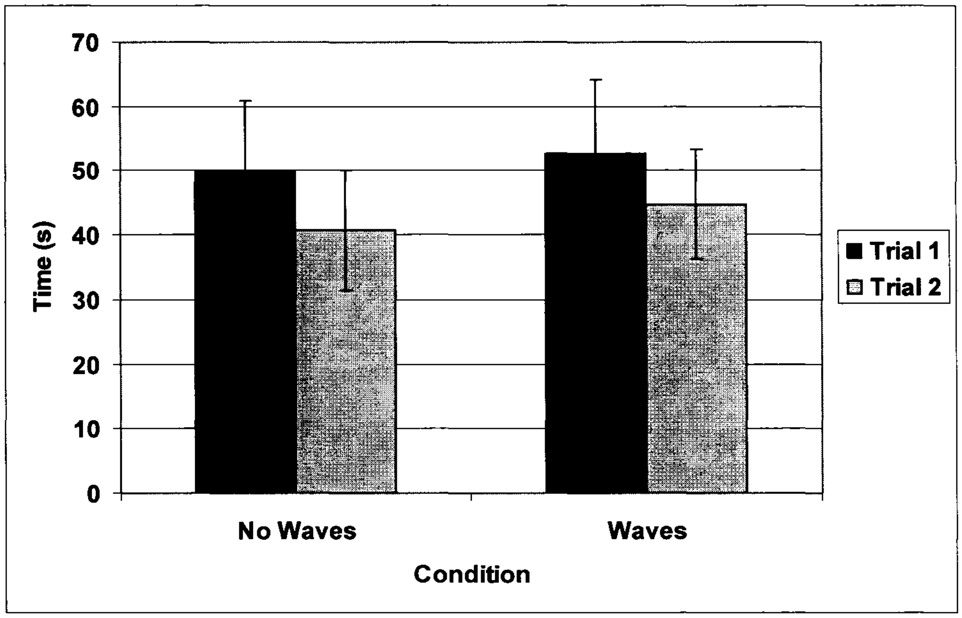


Figure 4.1) revealed that there was no difference in canopy closure performance while being towed in either wave conditions. However the participants performed the canopy closure significantly faster in the second trial for both conditions. This indicated that learning might have occurred with practice. When the task execution was considered from a qualitative perspective (see Table 4.1) any inaccuracies noted could be due to fatigue, cold, or as a result of competition amongst participants to finish faster than the subject participating in the same trial. Manual dexterity deterioration can occur in the first few minutes of exposure to cold water (Cheung et al., 2003) with gross manual dexterity deterioration occurring between 30 and 120s and fine manual dexterity occurring between 30 and 300s of exposure. The participants' hands were exposed to water in three of the five tasks indicating that future studies should consider the effects of cold exposure on dexterity and task performance.

5.2.2 Recommendations

Participants had trouble untying the looped knots on the outer canopy and it was often difficult to tie the inside looped knot with the one long, thin drawstring cord and the shorter, wider ribbon. A recommendation would be to increase the number of times trainees complete a canopy closure so the occupants become proficient and efficient at this task. A second recommendation would be to make tying materials more consistent within the life raft, i.e. all made out of thin cord, or all made out of wider, shorter ribbon. It was also observed that the long drawstring often got caught on the participant (16 times out of 84 trials, or 19.1 % of the time) and often came undone when they turned and sat down upon closure completion. A third recommendation would be to shorten the length of the drawstring.

Another difficulty was finding the exterior securing points quickly and participants sometimes missed them altogether. A suggestion was made to have large white indicator arrows on the outside of the floatation tube pointing to the three securing points. Another problem was that these protrude externally from the floatation tube and are therefore prone to being rubbed off. One of these broke off during the study and also during project-related sea trials (Phillips, 2005).

All of the aforementioned situations would impede the canopy's ability to keep water out of the life raft. In this study the occupants were exposed to some water, and therefore may have experienced cold to the hands, slowing down their fine motor ability in as little as 30 seconds (Cheung et al., 2003). Further studies could include whether the task could be completed more efficiently while wearing protective gloves, as cold and wet exposure would be inevitable in a North Atlantic survival situation.

5.3 Movement

5.3.1 Discussion

The positioning of occupants in the life raft is important when at sea, especially when loaded below capacity, yet a controversy exists in the literature as to which positions would be beneficial in certain situations. It has been found that most occupants tend to huddle together for warmth on the downwind side of the life raft (Wills, 1982), which can be detrimental in a free floating situation, creating the potential to over turn on the crest of a wave with a strong wind current (McKeag, 1982). It has therefore been recommended, by both McKeag (1982) and Wills (1982), that in this circumstance, the occupants should always gather together at the bow, or upwind side of the life raft. Wright (2003), however, recommends when in heavy seas in a free floating life raft, one should position the majority of occupants to the side of the raft where the sea anchor is attached to prevent the raft capsizing. In a towed life raft it has been observed that the bow of the life raft submerges at higher towing speeds (Hahne, 1983 and Simões-Ré, personal communication, October, 2006), allowing the life raft to take on water. During project-related sea trials employing uneven, water-filled bag ballasting, Simões-Ré (personal communication, October, 2006) found that this bow submergence was alleviated somewhat when ballast was shifted away from the bow. It may therefore be necessary to move the occupants back towards the stern while being towed to counteract this and prevent water from being shipped into the life raft.

In this study there was a trend to take longer in both wave conditions when crossing against another participant (movement C), which could be due to lack of manoeuvring room within the life raft. Participants required extra time to avoid colliding with a crossing participant. The time taken to move against waves or tow direction (A2 and C2) (see Figure 3.9) was no different than moving with the waves or away from direction towed (A1 and C1) (see Figure 4.2 and Figure 4.3). It did, however, take longer to complete both movements A and C in the wave condition versus the no wave condition (see Figure 4.2 and Figure 4.3) as motion induced interruptions were observed. Anecdotally, it was noted that the participants also had a difficult time getting their arms back into the grab lines at the completion of the movement.

5.3.2 Recommendations

Movement of the occupants should only be carried out if necessary, as collisions could occur. It has been observed (Cross and Feather, 1983) that, in a life raft, stressful circumstances, combined with cold conditions, can have a serious effect on the reasoning ability of the occupants and could lead to dangerous apathy. In training sessions, it would therefore be beneficial for those managing the life raft escape to instruct participants to move one at a time when possible.

The standard life jacket keeps the occupant's body further away from the life raft's floatation tube causing the lines to be tight on their arms. A design recommendation would be to have a looser fitting grab line so it won't cut into the occupants' arms and would make it easier to insert the arms. Participants suggested that it would be more comfortable if these grab lines were made of wider, flatter cord to reduce further the restrictions against the arms.

5.4 Sea Anchor

5.4.1 Overview

Sea anchor use has been found to be important to the stability of the life raft in wind and waves (McKeag 1982, Joughlin 1987) as well as controlling the rate of drift (Joughlin, 1987). There is some controversy, however, as to whether the sea anchor should be streamed or not while the life raft is being towed. The life raft manufacturer's user's guide (Zodiac, 2001) and others (Wright, 2003, p. 30) state that the sea anchor should be stowed while towing, whereas the Testing and Evaluation of Life-Saving Appliances (IMO, 2003) indicates that, for testing purposes, the sea anchor should be streamed when the life raft is towed. Project-related sea trials conducted with the same 16 person life raft reported that while under tow without the sea anchor the life raft moved severely from side to side (Simões-Ré, personal communication, June, 2005). In addition, while towing at higher speeds, the bow of the life raft tends to submerge forcing water onto the canopy and subsequently into the life raft (Hahne, 1983, Simões-Ré, personal communication, October, 2006, McKenna and Paulin, 1997). It was found that deployment of the sea anchor slowed or reduced the amount of water shipped into the life raft (McKenna and Paulin, 1997).

5.4.2 Deployment

5.4.2.1 Discussion

The deployment times in this study were not statistically different between the two wave conditions, but there was a trend towards a longer time for Trial 2 (see Figure 4.4) It was observed that the deployment technique is very important in the prevention of rope entanglement. It is for this reason that the technique for each trial was noted as a pass or fail. In total there was only one failure reported out of 84 runs, although it should be noted that four trials were aborted due to a knotted sea anchor line and not included in the statistical analysis. It was anecdotally noted that participants took more care in deployment at the advice of the testers after the aborted runs. Deployment may be a necessary step, either before being towed or at the onset of towing, and must therefore be carried out quickly and with care as to get the full length of line out for the best raft stability.

5.4.2.2 Recommendations

Training protocols should advise participants to stream the sea anchor slowly and steadily taking care not to allow the uncoiling line to become knotted. Trainees should also be advised to deploy the sea anchor before being towed.

5.4.3 Retrieval

5.4.3.1 Discussion

Retrieval of the sea anchor took longer in the wave condition (see Figure 4.5). The increased time in the wave conditions would be expected for two reasons. The irregular wave actions created inconsistent tension on the sea anchor line; so more time was needed to manage the changes in tension. Furthermore, wave actions cause the operator to become more unstable, so physical and mental effort would have to be exerted to maintain balance and would divert attention from the task at hand.

5.4.3.2 Recommendations

The participants were barehanded and complained of sore hands and slippery rope conditions, so gloves would be practical, not only for protection against the cold, but for enhanced grip and protection against friction (see Figure 5.1).

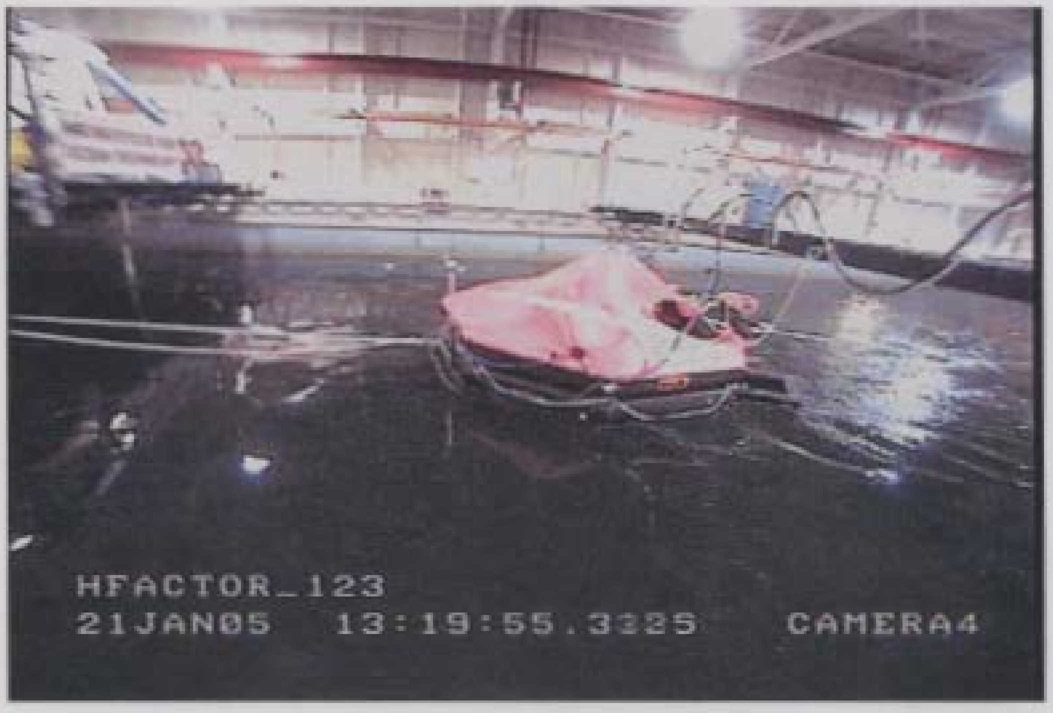
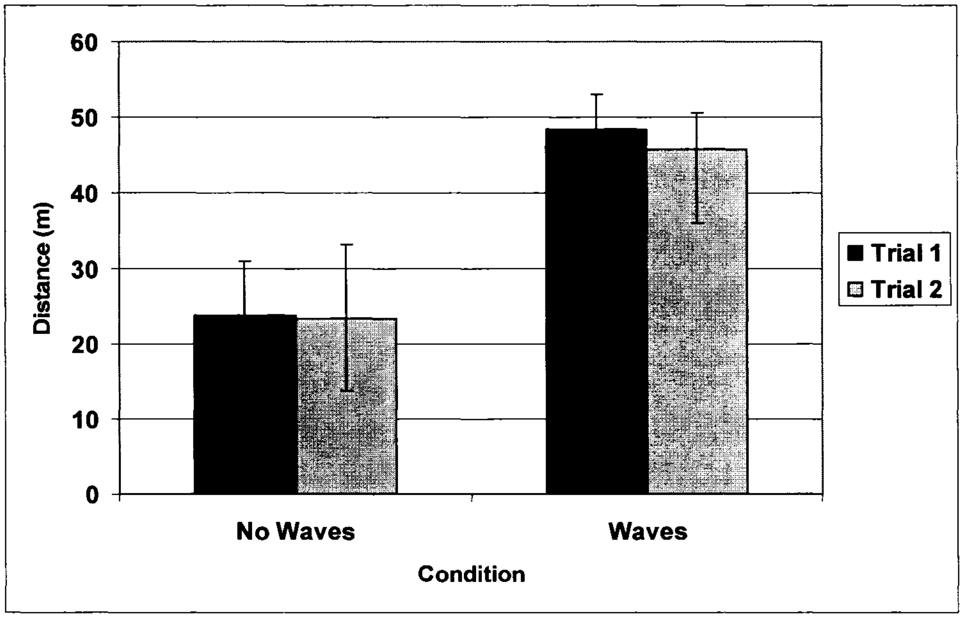


Figure 5.1 Sea anchor retrieval.

5.5 Paddling

5.5.1 Discussion

Paddling may be necessary to clear the life raft from the evacuated structure (Transport Canada, 1998) or for attempts to recover nearby survivors. In this study a significant difference was found between paddling in the no wave condition versus paddling in the direction of the waves during the wave condition



(see Figure 4.6). Wave condition distances were higher than distances paddled in the no wave condition, so a wave drift correction was calculated. This equalled 34.2m, which showed that the wave action alone saved the occupants a considerable amount of energy. The participants only had to paddle 12.9m in waves versus 23 m in the no wave condition yet travelled twice the distance.

Some participants found the paddling position to be awkward in general (15.6%), hurting their backs (12.5%), putting pressure on their stomachs (31.3%), and sometimes resulting in nausea (12.5%). This position also inhibited heart rate data collection in 38% of the participants due to the location of the monitor across the chest and the pressure of the lifejacket against their body while leaning over the floatation tube of the raft to reach the water with the paddle blade.

The mean heart rates recorded for the paddling task showed a trend towards the no wave heart rates being higher than the wave heart rates (145 beats.min^{-1} vs. 138 beats.min^{-1}) (see Figure 4.7). This was possibly due to the more consistent paddling, i.e. more paddle strokes were possible per five-minute no wave trial than in the wave condition, as it was observed that the paddle could equally reach the water with every stroke. There was also a higher standard deviation in the no waves condition, which could be attributed to differences in physical fitness of the participants, fatigue effects (due to the consistent paddling mentioned above), backaches, and position-induced nausea.

The maximum heart rates showed no significant difference, yet showed a higher standard deviation in the no wave condition (see Figure 4.7) which could possibly be explained by the fact that there may not have been as much fatigue in the wave condition because the participants did not need to exert as much effort for distance travelled.

Only two paddles are issued per 16-person life raft and in this study the standard issue paddle broke 5 times out of 66 trials, or 7.6% failure rate (see Figure 5.2).

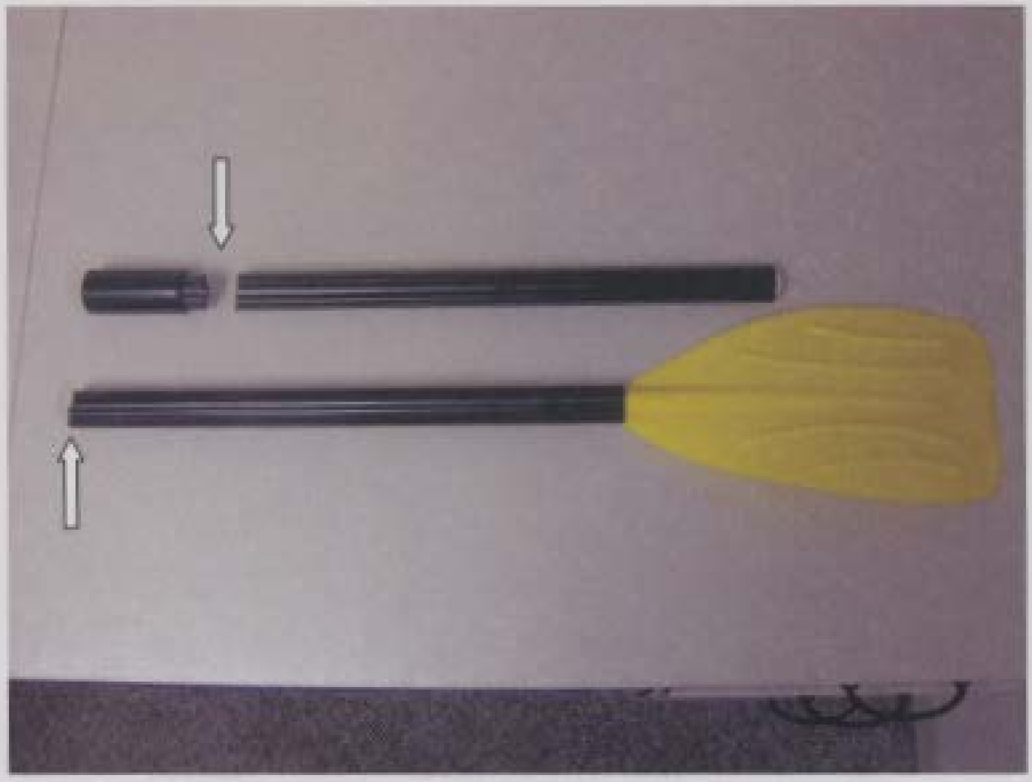


Figure 5.2 Paddle breakage points.

This interrupted the participant's paddling rhythm and concentration, and may have reduced the total distance travelled. In an evacuation or rescue situation, this could have detrimental effects on clearing the hazard area or reaching a free floating survivor, even when paddling with the waves.

The IMO testing and evaluation code (IMO, 2003) states that the fully loaded life raft should be capable of being propelled at least 25m in calm conditions with the paddles provided. In this study, young, healthy, unstressed participants were only able to paddle the life raft at 75% of capacity in the calm water condition a mean of 23.7 ± 7.7m in a time of five minutes. These participants reported being "exhausted" at the end of the trial. It seems, therefore, that any attempt at survivor retrieval by paddling should only be considered if the survivor is within close range and leeward from the life raft.

5.5.2 Recommendations

In an evacuation participants should be advised during training to find the leeward direction if trying to either get clear of a ship or pick up a survivor, and paddle with the waves to get there faster and expend less energy. The training regime should therefore emphasize the importance of this fact and teach participants how to paddle with the drift/current. Training often requires that the persons paddling away from the vessel proceed in an oblique direction relative to the downwind trajectory to avoid potential exposure to smoke and airborne contaminants emitted from the abandoned structure (J. Boone, personal communication, October 2006). Under these circumstances it is even more important to be aware of current and wind directions. If it is expected that the paddling will occur over an extended period of time, a process of substituting paddlers should be considered.

Participants had to lean out of the life raft to reach the water (see Figure 5.3), especially in the wave condition, and it is recommended that another occupant be assigned to hold the paddlers' feet.

Figure 5.3 Paddling position.

The standard issue paddle can vary greatly within the same make and model of life raft (V. March, personal communication, 21 November 2006). It can be a two-piece plastic handle with a plastic blade (such as that used in this study), a small one piece wooden canoe paddle, a two-piece aluminium handle with a plastic blade, a wooden dowel with a square board nailed onto the bottom of it, or a one piece shorter aluminium handle with a plastic blade (such as the types often employed under training circumstances). If the occupants are wearing SOLAS approved life jackets, a shorter paddle will not likely reach the water (V. March, personal communication, 21 November 2006), yet will if the occupants are wearing immersion suits and no lifejackets. For training purposes it is often the most durable paddle that is employed, rather than what actually might come with the life raft. A recommendation would therefore be to standardize the paddle within the life raft manufacturer and with the personal evacuation equipment supplied.

5.6 Bailing

5.6.1 Discussion

One of the immediate actions after abandonment is to bail any water that has collected inside the life raft using the bailer and to sponge the floor dry (Joughin, 1987; Zodiac International, 2001; Wright, 2003). This would prevent the occupants from getting or staying wet and cold. The life raft operators manual also suggests using the supplied paddles to scoop out the water if need be.

There was a significant difference in the volume of water bailed (p= .027) and the rate of bailing (p=. 017) (see Figure 4.8 and Figure 4.9 respectively). A significant difference (p< .001) was found between the bailer and the equipment bag. The bailer allowed higher volumes despite it holding only 3 litres of water compared to the 20 litres of water the equipment bag was capable of holding. This resulted in volume increases of 32% and 35% in water bailed with the bailer in the no wave condition and in the wave condition respectively.

It was observed during data collection that the participants were able to use the bailer more efficiently through physical strength or fitness without a lot of emphasis on technique. One participant did create a specific technique that improved his bailing results. The participant held the bailer with one hand with his thumb and ring finger through the two loops, scooped up the water, then pushed it out from the bottom side of the bailer with his other hand (see Figure 5.4).

In the wave condition it was observed that the participants endured more motion-induced interruptions, reducing the number of bailing strokes, losing water out of the bailer, and actually falling down into the shipped water. This resulted in wetter, and therefore colder, participants. Using the equipment bag was observed to be more difficult in waves, as it appeared harder to manoeuvre the sloshing water into the equipment bag.

Figure 5.4 Improved bailing technique steps 1 and 2.

Maximum heart rates (see Figure 4.10) were generally higher when using the bailer versus using the equipment bag. This coincided with the fact that the bailing volumes were also generally higher when employing the bailer. Bailer technique was observed to allow more bailing strokes per trial and therefore more activity compared to when using the equipment bag. These heart rates also showed a trend to be higher in the no wave condition, where participants had higher bailing volumes and rates. This indicates that these participants were working faster and accomplishing more bailing strokes resulting in an increased heart rate.

5.6.2 Recommendations

Training should emphasize using the bailer rather than the equipment bag, as it was easier to use and generally produced higher expressed water volumes.

Motion induced interruptions would occur in a real life situation, so falling and getting wet while bailing is a possibility.

CHAPTER 6 - CONCLUSIONS

This study is one of the first to evaluate human performance of initial survival actions in a life raft while being towed in wave conditions. These results identify the factors and challenges related to the successful management of a life raft during important phases of the evacuation and escape of a maritime vessel in distress. Quantitative data and qualitative observations showed that motion, practice, life raft design and equipment factors can all affect performance of the studied life raft management tasks. With respect to the experimental hypothesis, there were significant differences between wave conditions in four of the five management tasks, which showed that task completion time was increased with the introduction of motion. In the remaining task, canopy closure, there was a significant difference between the first trial and the second trial, which supports the notion that there may be improvement with practice and training.

As a result of this study, several recommendations that may be of value to regulators, manufacturers and trainers are made. These consist of critical life raft design issues for both manufacturers and regulators, and show the need for more research informed policy to guide safety trainers and regulators in the development of better training standards.

A suggestion for future research would be to look at the effect wearing protective gloves has on the time and ability to complete these same management tasks. In canopy closure, for example, the difference between dexterity impairment due to the cold, versus the ability to successfully perform the task while wearing gloves would be of great interest. In the sea anchor retrieval task, gloves may prove to increase the grip on the rope and therefore decrease the time taken for retrieval. In bailing, gloves may be beneficial to protect against the cold caused by remaining wet for an extended period of time, yet may inhibit techniques due to the relatively small handle size on the bailing apparatus. Another valuable research possibility would be to monitor the skin temperatures on the forearms and hands of the participants to get a quantitative measure of how cold one becomes while executing some of these wetter tasks.

Future research should consider the adequacy of current training standards. Currently, training is based largely on demonstration and group participation. Individual participation across all tasks would be beneficial with course completion based on a level of achieved competency.

It is hoped that these recommendations, combined with a modified training regime, will further prepare people if evacuation to a life raft is necessary and improve chances of survival and successful rescue at sea.

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Appendix A:

Canopy closure data for no wave and wave conditions.

No Waves

Alias	Securing Canopy		
	Trial 1	Trial 2	Average
1	53.78	38.82	46.3
2	37.06	35.26	36.16
3	38.52	40.82	39.67
4	47.92	37.16	42.54
5	56.26	48.4	52.33
6	49.14	47.12	48.13
7	51.32	45.54	48.43
8	38.84	34.78	36.81
9	60.82	52.82	56.82
10	34.54	33.06	33.8
11	41.98	35.08	38.53
12	47.72	32.82	33.66
13	39.46	32.8	36.13
14	39.22	34.62	36.92
15	57.52	36.08	46.8
16	56	42.3	49.15
17	56	37.7	46.85
18	76.92	43.42	60.17
19	41.2	37.24	39.22
20	62.48	37.08	49.78
21	61.84	73.34	67.59
22			
23			
24			

Waves

Alias	Securing Canopy		
	Trial 1	Trial 2	Average
1	54.12	41.32	47.72
2	55.42	37.3	46.36
3	48.8	56.86	52.83
4	59.52	48.82	54.17
5	49.42	38.02	43.72
6	56.12	43.38	49.75
7	79.7	42.46	61.08
8	43.46	41.4	42.43
9	72.16	56.02	64.09
10	75.48	32.84	54.16
11	45.3	48.72	47.01
12	53.52	49	51.26
13	45.5	55.52	50.51
14	34.5	35.82	35.16
15	50.06	39.12	44.59
16	53.02	46.54	49.78
17	42.8	38.5	40.65
18	55.94	49.86	52.9
19	36.88	35.7	36.29
20	43.34	37.74	40.54
21	49.44	66.46	57.95
22			
23			
24			

Appendix B:

Movement A and movement C times (seconds).

No Waves

Alias	Movement in Raft					
	A1	A2	Average	C1	C2	Average
1	4.18	5.3	4.74	7.58	6.4	6.99
2	3.38	2.8	3.09	3.26	2.72	2.99
3	4.58	3.24	3.91	4.24	6.48	6.72
4	3.04	4.46	3.75	3.06	3.92	3.49
5	3.9	4.5	4.2	4.94	5.56	4.94
6	3.92	3.32	4.31	5.24	3.78	4.51
7	5.12	4.78	4.95	4.46	4.02	4.24
8	3.4	2.94	3.17	2.82	4.18	3.5
9	3.16	2.86	3.01	2.64	2.56	2.6
10	4.8	2.96	3.88	4.12	5.94	5.03
11	2.68	2.8	2.74	2.3	2.66	2.48
12	2.96	2.44	2.7	3.32	3.6	3.46
13	3.52	2.7	3.11	2.88	3.12	3
14	3.36	3.18	3.27	3.4	4.02	3.71
15	4.2	5.42	4.81	4.7	4.52	4.61
16	5.14	4.52	4.83	5.88	5.92	5.9
17	5.98	8.18	7.08	6.88	7.16	7.02
18	4.04	3.56	3.8	4.84	5.6	5.22
19	3.64	3.74	3.69	4.78	4.46	4.62
20	4.08	3.38	3.73	3.34	3.5	3.42
21	6.14	6.16	6.15	4.7	5.22	4.96
22						
23						
24						

Waves

Alias	Movement in Raft					
	A1	A2	Average	C1	C2	Average
1	5.28	6.28	5.78	4.74	4.82	4.78
2	1.68	4.12	2.9	3.62	3.54	3.58
3	4.74	4.84	4.79	5.3	6.28	5.79
4	4.9	4.06	4.48	4.96	4.28	4.62
5	5.22	4.16	4.69	3.12	3.34	3.23
6	6.66	5.76	6.21	4.26	4.72	4.49
7	5.74	6.26	6	4.58	4.18	4.18
8	3.4	2.88	3.14	2.84	3.04	2.94
9	4.8	5.52	5.16	3.6	3.1	3.35
10	3.46	3	3.23	4.1	5.84	4.97
11	2.68	2.74	2.71	4.5	3.92	4.21
12	4.68	3.26	3.97	3.82	3.68	3.75
13	4.18	3	3.59	3.18	3.36	3.27
14	3.16	2.82	2.99	3.26	4.22	3.74
15	4.02	5.78	4.9	4.5	5.9	5.2
16	4.62	5.34	4.98	5.76	5.94	5.85
17	6.16	5.24	5.7	8.96	5.38	7.17
18	4.5	3.74	4.12	5.64	5.06	5.35
19	4.76	4.86	4.81	4.74	4.34	4.54
20	4.4	5.02	4.71	3.58	4.9	4.24
21	4.94	4.6	4.77	5.26	6.08	5.67
22						
23						
24						

Appendix C:

Sea anchor deployment and retrieval times (seconds) for no `wave condition and wave condition trials.

No Waves

Alias	Sea Anchor Deployment/Retrieval					
	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
	Deploy	Deploy		Retrieve	Retrieve	
1	23.16	23.72	23.44	29.48	29.94	29.71
2	40.16	37.16	38.66	26.62	29.04	27.83
3	31.66	31.24	31.45	26.66	27.94	27.3
4	31.34	24.5	27.92	20.14	22.1	21.12
5	29.48	24.16	26.82	28.2	26.32	27.26
6	30.08	24.2	27.14	32.64	34.06	33.35
7	32.18	30.88	31.53	27	28.12	27.56
8	22.18	21.9	22.04	20.6	22.74	21.67
9	25.84	28.06	26.95	23.7	27.02	25.36
10	32.22	27.04	29.63	35.36	40.64	38
11	30.26	21.6	25.93	24.92	19.44	22.18
12	30.9	27.24	29.07	28.1	34.56	31.33
13	22.68	21.22	21.95	21.4	21.7	21.55
14	46.5	29.8	38.15	30.8	28.4	29.6
15	32.36	41.92	37.14	26.76	37.86	32.31
16	31.72	27.14	29.43	25.3	29.38	27.34
17	30	30.52	30.26	46.18	36.08	41.13
18	25.72	30.08	27.9	15.42	23.7	19.56
19	32.18	38.34	35.26	12.06	22.78	17.42
20	21.94	19	20.47	26.2	23.62	24.91
21	54.32	80.68	67.5	27.84	17.7	22.77
22						
23						
24						

Waves

Alias	Sea Anchor Deployment/Retrieval					
	Trial 1	Trial 2		Trial 1	Trial 2	
	Deploy	Deploy	Average	Retrieve	Retrieve	Average
1	43.58	39.74	41.66	31.86	48.74	40.3
2	48.14	31.22	37.26	26.38	27.74	27.06
3	35.32	34.62	34.97	48.74	43.44	46.09
4	50.88	45	47.94	26.14	22.18	24.16
5	27.08	30.08	28.58	36.2	34.04	35.12
6	28.24	38.4	33.32	42.3	33.5	37.9
7	27.16	26.24	26.7	27.36	26.26	26.81
8	37.72	25.34	31.53	16.58	29.54	23.06
9	25.16	25.36	25.26	28.4	31.32	29.86
10	33.36	27.84	30.6	40.88	33.68	37.28
11	26.32	24.86	25.59	25.22	24.52	24.87
12	36.84	32.84	34.84	37.6	37.3	37.45
13	29.66	21.02	25.34	30.6	23.8	27.2
14	29.86	37.18	33.52	24.86	24.96	24.91
15	24.52	26.38	25.45	30.1	27.44	28.77
16	44.3	31.86	38.08	38.04	32.82	35.43
17	56.08	24.58	43.66	31.24	35.7	33.47
18	28.44	29.9	29.17	21.92	19.88	20.9
19	36.5	41.06	38.78	23.46	24.74	24.1
20	20.46	31.58	26.02	27.3	24.02	25.66
21	49.4	36.2	42.8	29.54	28.7	29.12
22						
23						
24						

Appendix D:

Paddling distances (m) for no wave and wave conditions.

No Waves

Alias	Paddling (distance - m)		
	Trial 1	Trial 2	Average
1	25.95		25
2	25.02	16.24	20.63
3			
4	15.75	8.88	12.315
5			
6	25.27		24
7	19.24	20.92	20.08
8	23.62	14.91	19.265
9	29.83	32.2	31.015
10			
11			
12	13.41	19.12	16.265
13	20.04	23.31	21.675
14	11.47	15.46	13.465
15			
16	32.13	31.18	31.655
17	32.19	46.75	39.47
18	24.95	24.36	24.655
19			
20			
21			
22	32.02	30.38	31.2
23	33.65	28.21	30.93
24	14.72	16.28	15.5

Waves

Alias	Paddling (distance - m)		
	Trial 1	Trial 2	Average
1	55.68	47.43	51.555
2	54.31	42.39	48.35
3			
4	41.99	36.79	39.39
5			
6	47.35	41.24	44.295
7	41.69	49.6	45.645
8	48.5	39.32	43.91
9	54.51	49.53	52.02
10			
11			
12	50.34	42.57	46.455
13	46.22	42.62	44.42
14	47.03	54.31	50.67
15			
16	43.63	48.29	45.96
17	54.83	51.97	53.4
18	43.7	44.88	44.29
19			
20			
21			
22	49.87	50.76	50.315
23	49.28	46.77	48.025
24	46.99	43.93	45.46

Appendix E:

Individual heart rates for paddling task in beats·min^{-1}.

Alias	CalmMean	CalmMax	Wavemean	WaveMax
1	113.5335	130	115.14015	132
2	159.27535	171.5	149.08635	157.5
3	145.377	152	161.03005	173
4	166.8889	177	123.26175	137.5
5	126.2982	143	134.6079	143.5
6	159.2559	171.5	146.17315	156.5
7	154.75815	167	154.7869	167
8	175.9354	188	144.61675	163
9	111.95765	123.5	119.70605	136
10	138.7969	153	139.655	158.5

Appendix F:

Bailing rate (ℓ·sec^{-1} and ℓ·min^{-1}) and volume (ℓ) for both equipment bag and bailer in no wave and wave conditions.

Bailing rate (ℓ·sec^{-1} and ℓ·min^{-1}) and volume (ℓ) for equipment bag in the no wave condition

Condition	Bail/Bag	Alias	time_1	time_2	Total_time	Total_Vol	Rate, lt/min	Rate, lt/s
No Waves	Bag	1	29.68	144.86	115.18	77.0409	40.13244	0.668874
No Waves	Bag	2	61.82	179.8	117.98	77.8752	39.60426	0.660071
No Waves	Bag	3	61.84	180.5	118.66	78.4854	39.68586	0.661431
No Waves	Bag	4	61.56	180.16	118.6	79.58	40.2597	0.670995
No Waves	Bag	5	61.06	180.46	119.4	96.7969	48.64164	0.810694
No Waves	Bag	6	60.4	180.4	120	66.0361	33.01806	0.550301
No Waves	Bag	7	60.16	180.08	119.92	54.6016	27.31902	0.455317
No Waves	Bag	8	60.1	179.18	119.08	155.994	78.5994	1.30999
No Waves	Bag	9	62.48	179.84	117.36	96.9422	49.56144	0.826024
No Waves	Bag	10	61.06	179.18	118.12	155.2	78.8352	1.31392
No Waves	Bag	11	63.92	178.02	114.1	103.744	54.55416	0.909236
No Waves	Bag	12	60.1	177.94	117.84	98.9585	50.3862	0.83977
No Waves	Bag	13	62.28	179.86	117.58	123.47	63.0054	1.05009
No Waves	Bag	14	60.9	180.24	119.34	41.8826	21.05712	0.350952
No Waves	Bag	15	60.42	180.18	119.58	34.9957	17.5593	0.292655
No Waves	Bag	16	61.02	179.74	118.72	91.9818	46.48674	0.774779
						89.59906		

Bailing rate ($\ell \cdot sec^{-1}$ and $\ell \cdot min^{-1}$) and volume (ℓ) for the bailer in the no wave condition

Condition	Bail/Bag	Alias	time_1	time_2	Total_time	Total_Vol	Rate, lt/min	Rate, lt/s
No Waves	Bailer	1	62.96	181.08	118.12	97.173	49.35984	0.822664
No Waves	Bailer	2	61.08	179.96	118.88	102.483	51.7245	0.862075
No Waves	Bailer	3	60.34	179.82	119.48	150.619	75.6372	1.26062
No Waves	Bailer	4	60.78	179.76	118.98	122.268	61.6584	1.02764
No Waves	Bailer	5	61.76	181.06	119.3	123.272	61.9974	1.03329
No Waves	Bailer	6	60.82	179.6	118.78	145.834	73.6662	1.22777
No Waves	Bailer	7	61.2	179.44	118.24	140.84	71.4678	1.19113
No Waves	Bailer	8	60.6	179.46	118.86	163.447	82.5072	1.37512
No Waves	Bailer	9	61.48	179.74	118.26	148.648	75.4176	1.25696
No Waves	Bailer	10	60.6	179.44	118.84	143.169	72.2832	1.20472
No Waves	Bailer	11	60.54	177.38	116.84	154.131	79.1502	1.31917
No Waves	Bailer	12	60.68	179.06	118.38	152.606	77.3472	1.28912
No Waves	Bailer	13	60.46	179.28	118.82	157.787	79.677	1.32795
No Waves	Bailer	14	61.34	179.1	117.76	115.847	59.02512	0.983752
No Waves	Bailer	15	58.54	180.34	120.08	115.993	57.95808	0.965968
No Waves	Bailer	16	60.38	179.46	119.08	83.4184	42.03144	0.700524
						132.346		

Bailing rate (ℓ·sec^{-1} and ℓ·min^{-1}) and volume (ℓ) for the equipment bag in the wave condition

Condition	Bail/Bag	Alias	time_1	time_2	Total_time	Total_Vol	Rate, lt/min	Rate, lt/s
Waves	Bag	1	60.26	180.46	120.2	88.203	44.02812	0.733802
Waves	Bag	2	60.18	179.64	119.46	67.8765	34.0917	0.568195
Waves	Bag	3	59.94	180.52	120.58	62.8661	31.28184	0.521364
Waves	Bag	4	60.36	180.18	119.82	63.383	31.7391	0.528985
Waves	Bag	5	59.96	179.64	119.68	36.9001	18.49938	0.308323
Waves	Bag	6	60.3	179.06	118.76	50.8498	25.69038	0.428173
Waves	Bag	7	60	179.64	119.64	52.9608	26.56008	0.442668
Waves	Bag	8	60.26	179.36	119.1	141.889	71.4804	1.19134
Waves	Bag	9	59.58	180.14	120.56	134.616	66.9954	1.11659
Waves	Bag	10	61	180.48	119.48	121.829	61.1796	1.01966
Waves	Bag	11	60.74	179.64	118.9	106.049	53.51484	0.891914
Waves	Bag	12	59.88	178.4	118.52	68.7826	34.82076	0.580346
Waves	Bag	13	59.18	179.58	120.4	110.106	54.87006	0.914501
Waves	Bag	14	60.94	179.68	118.74	35.9794	18.1806	0.30301
Waves	Bag	15	60.96	179.66	118.7	43.4795	21.97782	0.366297
Waves	Bag	16	59.52	179.7	120.18	71.3055	35.59932	0.593322
						78.56721		

Bailing rate (ℓ·sec^{-1} and ℓ·min^{-1}) and volume (ℓ) for the bailer in the wave condition

Condition	Bail/Bag	Alias	time_1	time_2	Total_time	Total_Vol	Rate, lt/min	Rate, lt/s
Waves	Bailer	1	60.48	179.9	119.42	98.9104	49.69542	0.828257
Waves	Bailer	2	60.86	179.98	119.12	144.213	72.639	1.21065
Waves	Bailer	3	60.76	182.48	121.72	149.527	73.707	1.22845
Waves	Bailer	4	60.38	180.06	119.68	117.856	59.08554	0.984759
Waves	Bailer	5	61.08	179.94	118.86	48.8211	24.64464	0.410744
Waves	Bailer	6	59.82	179.36	119.54	128.698	64.5966	1.07661
Waves	Bailer	7	61.42	179.8	118.38	107.42	54.44526	0.907421
Waves	Bailer	8	60.52	178.98	118.46	141.922	71.8836	1.19806
Waves	Bailer	9	61.38	179.82	118.44	110.831	56.1453	0.935755
Waves	Bailer	10	63.88	179.32	115.44	146.713	76.2546	1.27091
Waves	Bailer	11	60.12	179.52	119.4	152.557	76.6614	1.27769
Waves	Bailer	12	62.72	180.5	117.78	148.145	75.4686	1.25781
Waves	Bailer	13	59.78	179.66	119.88	153.501	76.827	1.28045
Waves	Bailer	14	60	180	120	105.639	52.81944	0.880324
Waves	Bailer	15	60.2	179.96	119.76	105.916	53.06412	0.884402
Waves	Bailer	16	62.26	179.12	116.86	85.7772	44.04102	0.734017
						121.6529		

Appendix G:

Bailing rate and volume maximum heart rates in beats·min^{-1}.

Alias	No Waves		Waves	
	Bailer	Bag	Bailer	Bag
1	169	126	153	136
2				
3	169	134	154	132
4	148	125	144	135
5	163	145	166	153
6	131	90	90	110
7		138	119	130
8	180	184	174	181
9	140	123	125	122
10	129	130	122	116
11	160	133	164	133
12	136	102	134	104
13	180	173	177	177
14	109	97	115	111
15	137	121	153	133
16	159	168		169