Effects of Exertion and Distractions on Search Efficiency in Riverine Search and Rescue (SAR)

Hannah J. Moir, PhD[1], Alex Tasker, PhD[2,3], Christopher C.F. Howe, MSc[1] & Ian Greatbatch, PhD[4]

[1]School of Life Sciences, Pharmacy and Chemistry, Faculty of Health, Science, Social Care & Education, Kingston University, London, UK

[2]The Science Policy Research Unit (SPRU), University of Sussex, UK

[3]Department of Anthropology, Faculty of Social & Historical Sciences, University College London, UK

[4]School of the Environment, Geography and Geosciences, University of Portsmouth, UK

Email: Hannah.Moir@kingston.ac.uk

Abstract

This work sought to examine the impact of physical exercise, and mental exertion prior to launch on lifeboat search effectiveness.

Four three-person volunteer crews from the United Kingdom's Royal National Lifeboat Institution (RNLI), were exposed to combinations of physical and mental exertion tasks before launch and performance measured during riverine scenario-based search and rescue training. Two unchallenged groups (control) were deployed for comparison. Half the deployed crews were subjected to a distraction exercise completed during the search to simulate real-world conditions to place demands upon the attention of the crew (such as passing radio traffic, navigating or planning search tactics). Heart rate, GPS tracking and search success were monitored, with success defined as the location and transmission of an identifying code of each placed target.

Heart rate monitoring showed clear association between measured psychological stress and the physical challenges presented to the crews and demonstrated that the exertion and distracting elements of the experiment had a measurable effect on the participants, where lower heart rates corresponded to greater success in searching. Overall, results showed that exercise and mental activity generally improved perceptual performance of the crew in the pre-scenario-based training, whilst the distracting element (alone and in combination with exertion) diminished performance during the scenario-based training.

Increases in alertness and search performance have significant implications for those involved in search and rescue. This study contributes to an increasing body of cross-disciplinary work exploring team performance in high-pressure situations.

KEY WORDS: maritime search and rescue, Royal National Lifeboat Institution (RNLI), physiological stress, lifeboat, volunteer

Introduction

Riverine Search and Rescue responses for missing, and often vulnerable people, are complicated by both operational, environmental, and personnel-related factors. Operational problems include receiving limited or confused information about location (Johnson, 2008), the behaviour and appearance of the victim and witnesses (Fritz & Mathewson, 1957), and the use of generalised search techniques in non-standard environments (Correia, Moura, & Fonseca, 2020; Yan, Wu, Zhang, & Zhang, 2017). This study focuses on the activities of riverine Search and Rescue (SAR) crews, specifically the impacts of fatigue, stress and overloading of complex tasks places on those searchers.

Riverine search locations are complex, technical, and high energy environments (wide search area, fastest route, coordination of hazards). In many cases, operations will involve extensive periods of technical searching followed by shorter recovery actions. The swift, safe, and successful completion of a search requires clear communication, geographic understanding, and navigation, although other factors will be relevant (such as available light, weather or sea conditions, temperature, water speed, watercourse type and characteristics). Accurate assessment of factors influencing search and rescue success / effectiveness is of paramount importance for improving SAR outcomes through reduced operation times and improved target identification.

The Royal National Lifeboat Institution (RNLI) was founded in 1824 operating around the coasts of the United Kingdom (UK) and Republic of Ireland (ROI) and carries out the majority of the boat SAR operations on behalf of the two Nation's Coastguards. The RNLI has 238 stations in the UK and ROI; and in 2003, four new lifeboat stations were established on the River Thames, in response to the Clarke Report into the Marchioness disaster (Clarke, 2001).

The RNLI is a not-for-profit organisation consisting largely of volunteer crews that operate a lifeboat SAR service 24 hour per day, 365 days a year. The lifeboat crew are not station-based and are alerted by pager to respond (albeit there are four station-based, full-time stations). They are obliged to remain within a certain time-distance of the station when on duty. There are also between 80 and 100 'independent' lifeboat stations not affiliated with the RNLI. This mode of response has some potential risks associated with it. There is the potential for road traffic accidents, or other accidents associated with rushing to the station. There are also risks associated with lack of sleep, and the spike in stress associated with a sudden alert.

Limited research has been conducted on the influence of operational factors; those that do, primarily focus on environmental variables such as wave height, to calculate a statistical 'probability of containment' (Frost & Stone, 2001; Koester & Greatbatch, 2016; Koopman, 1979). Whilst a significant body of work exists addressing the role of human variability in task success such as human factors and situational awareness studies (see, for example, Endsley, 1995), many of these studies retain a tight disciplinary focus within transport, engineering, or medical contexts. Personnel-related factors in SAR have received less academic attention, however, literature does suggest that the appropriateness and levels of training of searchers, levels of fatigue, and degree of overworking of a search team may limit the chances of a successful search (Covassin, Weiss, Powell, & Womack, 2007; Hancock & McNaughton, 1986). Given the complex nature of SAR operations it is important to differentiate the goals of this paper in study success versus efficiency or effectiveness. These terms have been used in previous work (Greatbatch et al, 2014, Meredith & Greatbatch 2022) to understand SAR operations, whereby success is defined as the number if correct targets identified out of the total possible targets, and effectiveness is the total number of targets identified, out of a combined total of possible targets plus positives. To increase the clarity of the design and interpretation, success in this context is here defined as the location and transmission of a correct identifying code for placed targets.

A growing body of literature acknowledges the effects of physical and emotional stress on individual and team operations (Jeung, Kim & Chang, 2018; Murphy & Burke, 2005; Paton, 1994). From healthcare to aviation, significant research time has been dedicated to better understanding how these conditions may influence task performance (Barnettn & Kring, 2003; Alexander & Klein, 2009; Martin, Murray, Bates & Lee, 2015; Lawn et al., 2020), though less attention has been directed at SAR professionals or volunteers. The results of these academic investigations have driven changes across disciplines to adapt training practices to better reflect the stresses of ‘live’ situations (Kaddoura, 2010) and helping to improve skill and knowledge transfer (Maran & Glavin, 2003). For researchers interested in evaluating SAR responses, this move to closer emulate real-world incidents in training provides a welcome opportunity for researchers to sidestep the ethically complex task of exploring high-stress events, and instead experimentally evaluate the effect of these stressors on task performance. To date, literature on the relationship between stress and performance in SAR responders is scarce and often contradictory; for example literature linking individual-level stress and performance suggests anxiety can both improve (Fernández-Castillo & Gutiérrez Rojas, 2009) or inhibit (Robinson, Vytal, Cornwell, & Grillon, 2013) attention on the task in hand. Beyond the individual level the picture is further complicated by the influence of teamwork and communication on stress and performance (see, for example, Sonoda, Onozuka, & Hagihara, 2018), establishing a challenging foundation from which to build research.

The aim of the project was to map the impact of some of the human contributors and distractors to search effectiveness, specifically physical and mental exertion, and distractions. The study sought to examine the impact of physical exercise, and mental exertion prior to launch on lifeboat search effectiveness.

Methodology

Participants

A total of twelve crew members (consisting of eleven males and one female aged 48.9±6.6 years) from Teddington RNLI (covering the River Thames, United Kingdom) were recruited through their involvement in habitual search and rescue (SAR) training. The study was based on observing the current training practices of RNLI crew members. Participants were recruited/observed during typical training sessions and met inclusion based on their active crew membership of the RNLI and having been issued with a RNLI medical certificate where RNLI members are required to be over 18 years old and under 55 years old (inshore lifeboat). Crew members also have previously passed a medical and eyesight test and are classed as physically fit.

Responses/data were anonymously recorded and only personal data such as demographic variables including age and sex were recorded. All participants provided written informed consent and were screened for underlying health conditions with a physical activity readiness questionnaire (PARQ) (Warburton, Jamnik, Bredin, Shephard, & Gledhill, 2019).

There were no exclusion criteria as all were active members of the RNLI, with no known absolute contraindication (e.g., angina, ischemia, heart failure). Only participants with a recent joint or muscle injury (within the prior two weeks) which resulted in impairing their ability to complete the testing were excluded from the test. Ethical Approval (1617 026) was granted by Kingston University Faculty Ethics Committee. All testing was conducted in accordance with the Declaration of Helsinki.

Experimental design

The study followed a cross-disciplinary design, drawing on three streams: the use of search patterns and the efficiency of the SAR crew; the role and impact of exertion on SAR performance, and impact on operational effects, to explore this complex and under-researched topic. Participants were part of a crew of four completing a riverine SAR operation (Scenario Based Training). The use of search patterns and the efficiency of the SAR crew was assessed using a protocol adapted from (Robe & Frost, 2002).

The scenarios took place over a two-week duration consisting of four possible trial scenarios (Table 1). During session one, participants received an introduction to the study and crew members were randomly allocated to one of four crews consisting of three people with an allocated experienced helm (12 crew in total). Two crews were put under 'distracted' conditions, and two crews were under 'undistracted' conditions as well as being either under a 'physically and mentally exerted' [exerted] state or not [non-exerted]. These formed the four conditions of (A) non-distracted, non-exerted [control]; (B) distracted, non-exerted, (C) non- distracted, exerted state and (D) distracted and exerted state (Table 1). The crews were reversed between week one and two trials to provide comparative data for each crew.

Table 1. Crew and condition allocations (N=No, Y=Yes), where (A) non-distracted, non-exerted [control]; (B) distracted, non-exerted, (C) non-distracted, exerted and (D) distracted and exerted.

	Week 1				Week 2			
Crew	1	2	3	4	1	2	3	4
Condition	A	B	C	D	D	C	B	A
Distracted	N	Y	N	Y	Y	N	Y	N
Exerted	N	N	Y	Y	Y	Y	N	N

Search and Rescue Targets

Search target locations and appearances were specifically designed for this study, using a protocol adapted from existing lowland search data (Greatbatch et al, 2015). Twelve targets were randomly placed along a river section. The locations were generated using a combination of Microsoft Excel (version 2010, Microsoft Corporation, USA) and geographic information system (GIS) software (ESRI ArcMap 10.4). Ordnance Survey (GB) VectorMap® Local (scale 1:10,000) raster data and OS VectorMap™ Local vector data were obtained using the EDINA Digimap Ordnance Survey Service (http://digimap.edina.ac.uk) and added to the maps to provide context, and river boundaries. The type (size) and visibility status of each target was randomised using the 'RAND' function in Excel. Twelve targets were randomly placed in the search corridor using the 'Create Random Points' tool in ESRI ArcMap (Figure 1), creating a maximum of two targets within each sub area. The visibility and size codes were then joined to the spatially randomised points and plotted.

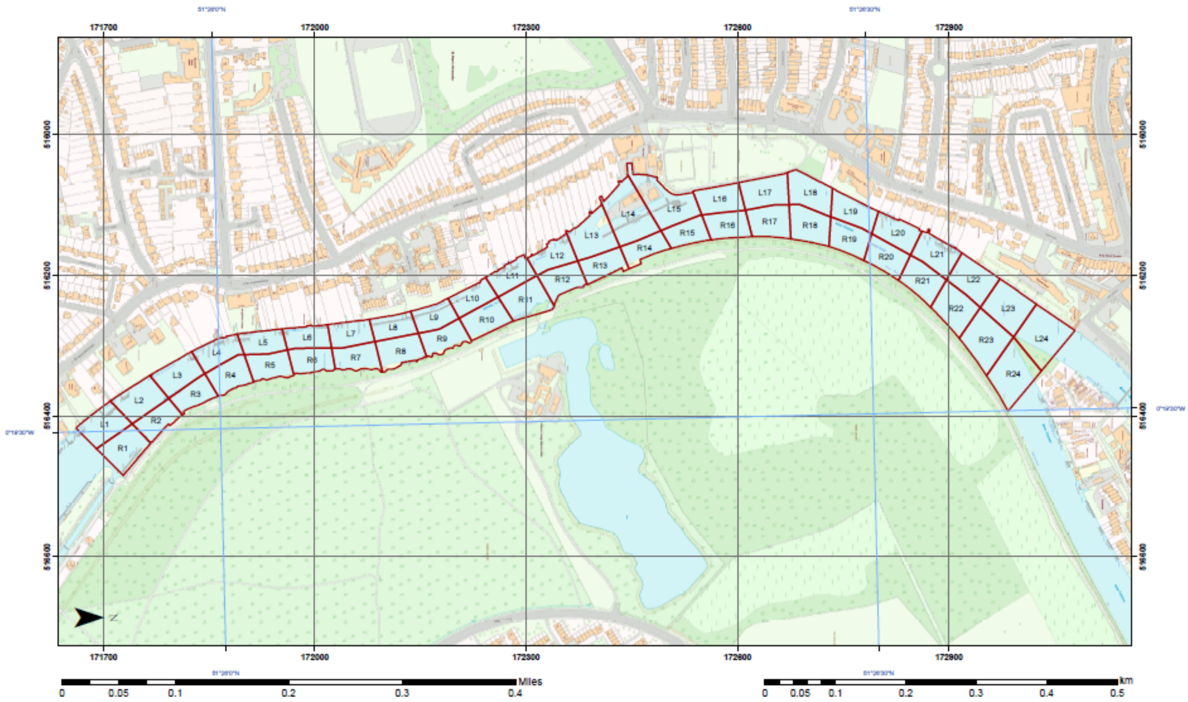

Figure 1: Gridded Exercise Area

These targets reflected four of the most commonly encountered body positions (Koester, Gordon, Wells, & Tucker, 2013), further divided by two levels of clothing visibility (high and low). 'Low' visibility consisted of drab and dark coloured clothing or colouring, with no white or reflective components and 'High' visibility incorporated reflective strips and bright colours.

The target body positions were: (1) swim failure - top of head visible, (2) floating - head above water (secured with weights / anchor), (3) prone on shore and (4) standing on shore/pathway. University members (students and staff) were voluntarily recruited as live human shore/pathway targets with co-supervisors (for safety) placed along the route. Targets were assigned using a random number generator for each test run with their number, distance along the route, and position to the left or the right of the route randomly determined (Figure 2). Each target was identified by a unique four-character alphanumeric code. Crews were required to identify all targets in the predetermined search area by transmitting and reporting the code from the target to the exercise control station via a marine VHF radio and the time of report logged.

Figure 2: random target placement

During the operation, the crew were distracted by interruptions in the search at predetermined intervals by asking crewmembers to perform a distracting task such as locating and reporting extraneous data. The speed and length of journey was recorded through a global positioning system (GPS) tracker (Garmin etrex, Garmin Ltd., Olathe KS), and, in combination with the number of targets correctly, to calculate a value for the 'success' of the crew. This value formed the basis of the comparative evaluation between distracted and 'exerted' crews.

Distracting Protocol

Search and rescue can often require complex organisation, communication and navigation with the RNLI increasingly working in multi-agency response that requires coordination with groups external to the immediate team such as Her Majesty's Coastguard, Port of London Authority, Metropolitan Police, London Ambulance Service, and members of the public. To recreate this sort of possible environment, a distracting protocol was used during the Scenario Based Training. During the SAR, distraction of the crews was achieved by interrupting the SAR routine at predetermined intervals and asking crewmembers to perform a distracting task such as locating and reporting extraneous data. This took the form of a three-way radio transmission exercise, in which a pair of words (Table 2) were transmitted to the crew via the VHF radio, where each word required looking up in a laminated booklet, which gave a corresponding output word or colour for each input word or colour. This required both non-helming crew members to be distracted for the period required to look up the corresponding translation, inform the helm, who then translated the responding coded message. The requirement to helm the boat safely, as well as receive and transmit information of this kind, also served to distract the helms. Examples of the structure of the outward / return messages can be seen in Table 2.

Table 2. Examples of outward / inward code transmissions used in the distracting tool.

Outward transmission	Colour Look-up	Object Look-up	Return Transmission
RED FOX	(RED = BLUE)	(FOX=LEMUR)	BLUE LEMUR
YELLOW FISH	(YELLOW = RED)	(FISH = EMU)	RED EMU

Physical and Mental Exertion Protocol

In addition to the Scenario Based Training and the distracted condition, two of the four crews were also 'exerted' with both physical and cognitive (mental) stressors (i.e., change blindness, gradual change, and movie perception tests as developed by Simons and Levin (1998)). For physical exertion, an exercise protocol developed by the authors, specifically for this study based on existing research (Duncan, Smith, & Lyons, 2013; Welford, 1980) consisted of submaximal exercise of continuous Harvard stepping (stepping up and down a step-up box) for a maximum of 30 minutes between a target of 70-90% of age-predicted heart rate maximum (220-age; 171.1±6.6 bpm), in time to a metronomic beat. The exertion was conducted immediately prior to the initiation of the Scenario Based Training and all crew members performed the activity wearing inshore lifeboat dry suits. During the physical exercise, heart rate was continuously monitored using telemetric polar heart rate monitors with chest strap (Polar Electro Oy, Kempele, Finland). For mental exertion, cognitive measures of change blindness, visual perception, memory recall and reaction time were monitored every 5-10 minutes during the 30 minute exercise protocol. During the SAR Scenario Based Training, heart rate was also continuously monitored using a portable Global Positioning System (GPS) with integrated HR receiver (GPSport, SPI-Pro, Canberra, Australia) device.

Reaction time tests

Reaction time was measured before and on completion of the physical and cognitive exertion bout. Participants first performed a practice (five attempts) using the Deary-Liewald (Deary, Liewald, & Nissan, 2011) reaction time software (V3.10; CCACE software, The University of Edinburgh, Scotland), followed by five recorded reaction time responses. From the results, an average 'time taken' was generated.

Safety Precautions

To ensure that the public were not alarmed by field study design, precautions were taken which included the study being conducted as part of typical weekly RNLI training practice and conducted in accordance to their policies and procedures. This was therefore a registered event, where Her Majesty's Coast Guard (HMCG), who are the coordinating authority on tidal and coastal waters, was made aware of the training session, identifying exact location and exact timings taking place, so that any calls raised by the public were identified against the training event. In addition, the project was coordinated by 'supervisors' patrolling the area to ensure the safety of targets and the general public.

Performance success of SAR

Success in the SAR element of the experiment was defined as the location and transmission of the identifying code of each of the placed targets. Therefore, the quantification of success can be described as the percentage of targets correctly found calculated as [Hits / potential targets] (Greatbatch et al., 2015). In other works, (for example Koester, Cooper, Frost, and Robe (2004)) other elements, such as speed over ground or sweep width were calculated. In Greatbatch et al. (2015), an additional effectiveness statistic was calculated, by incorporating false positives, but in this experiment, a simple success statistic was deemed sufficient.

Statistical analysis

Data are presented as mean ± standard deviation (SD). Data was pooled before analysis, and from these data values for both success and effectiveness were calculated. Success is defined as the accomplishment of the purpose, this being to find the target. Therefore, success was classified as the number of targets correctly found, calculated as [Hits/Potential Targets]. Differences in reaction time (msec) between conditions (baseline and post-exertion stressors) were analysed by an independent sample t-test. Cross conditions [(A) control, (B) distracted only, (C) exerted only, (D) distracted and exerted] x time [mins] were analysed using a two-way repeated measures analysis of variance (ANOVA) with Bonferroni post-hoc analysis. Effect sizes were calculated using Cohen's d (d) or using eta2 (η^2). All statistical analyses were conducted as two-tailed with IBM SPSS Statistics 23 (IBM Corp., New York, USA) and significance set at $P<0.05$.

Results

The results are presented in two stages; firstly the pre-exercise stressors, and secondly the effects on search performance of the various crews.

Physical and mental exertion protocol

During the physical and mental 'exertion' protocol, crew members were analysed on their recall of a number of cognitive perceptual tests to induce cognitive (mental) stress. Exerted crew members (n = 12) were able to recall 52±35% of all correct information, 27.5% significantly less accurate recall ($P=0.007$) compared to 79±29% of the control crew (n= 10) performed at rest.

Heart rate at rest was 78.9±5.0 bpm. During the physical exertion protocol, participant's average heart rate reached 146.1±5.5 bpm, which was 86±1% of age-predicted heart rate max. Heart rate response varied between 120 (70%THR) and 160 bpm (90-100% THR) during the protocol (Figure 3), however there was no significance difference in heart rate response to the protocol between crews ($P=0.143$; $2.407(3,8)=F$; $\eta^2=0.464$).

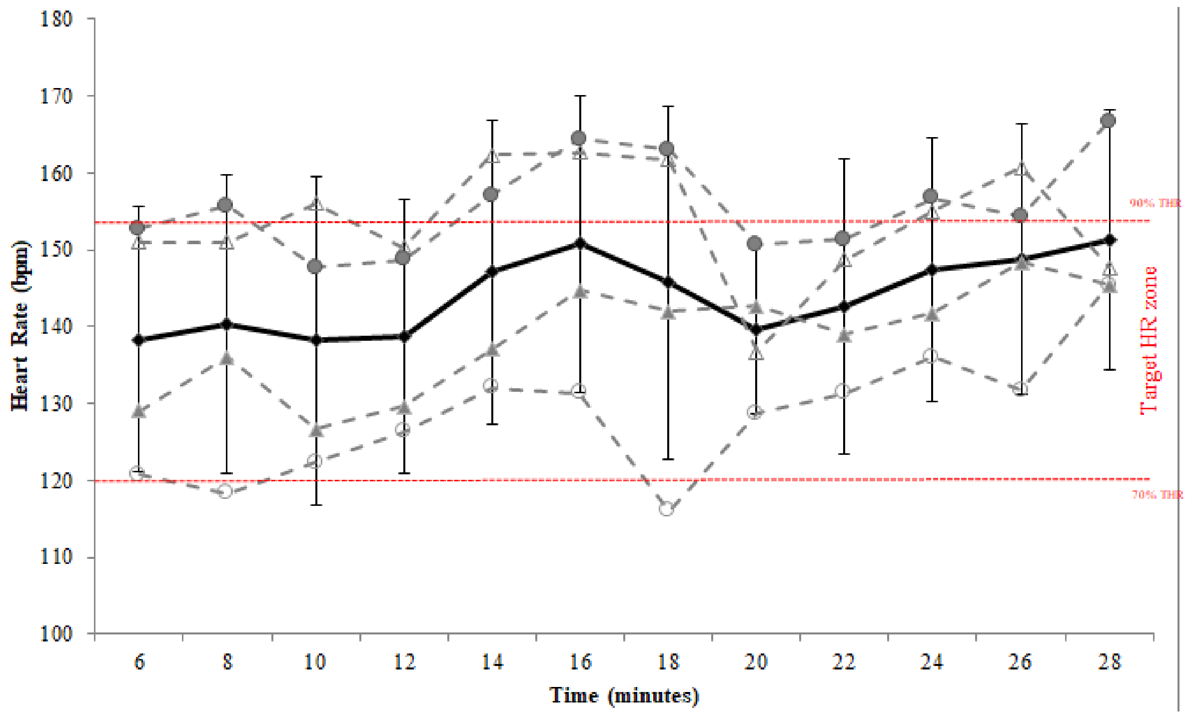

Figure 3: Heart rate response of crews during physical and mental exertion protocol (black solid line represents average±SD bpm; dashed lines represent the four crews average±SD bpm, where solid triangle are (A) control crew, open circle was the (B) distracted only crew, solid circle was (C) exerted only crew and open triangle were(D) distracted and exerted state crew.

Reaction time response

Comparing baseline, reaction time was 286±41 msec vs. 311±41 msec post stressor. Mean reaction time (ms) between baseline compared to post-exercise and cognitive stressors significantly differed by 24.6msecs (Figure 4; p=0.012, d=0.6).

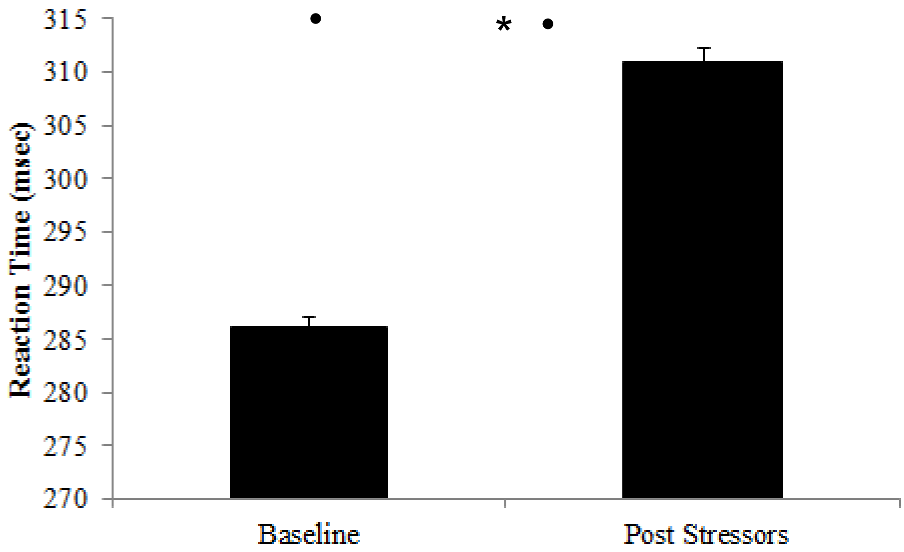

Figure 4: Mean ± SD reaction time (msecs) at baseline and post physical and mental stressors (denotes a significant difference (p<0.05) from baseline).*

Heart Rate response during SAR

During the Scenario Based Training, the average heart rate of all crews was 112.3±20.5bpm, which was 66±12% of predicted heart rate max, and average maximal heart rate reached 123.9±22.7bpm which was just 72±12% of predicted heart rate max. As can be seen in Figure 3, the average heart rate response was significantly higher in the (D) distracted and exerted crew (P=0.005, 3.267(11.4,31)=F; η2=0.551) with average heart rate being 131.5±7.8bpm compared to (A) control average heart rate of 108.3±11.1 bpm. Distracted only crew (B) versus the exerted only crew (C) were also higher than control (A) but not significantly different between crews (P>0.05) apart from distracted (B) being at times more significant than control (A) (P<0.05; Figure 5).

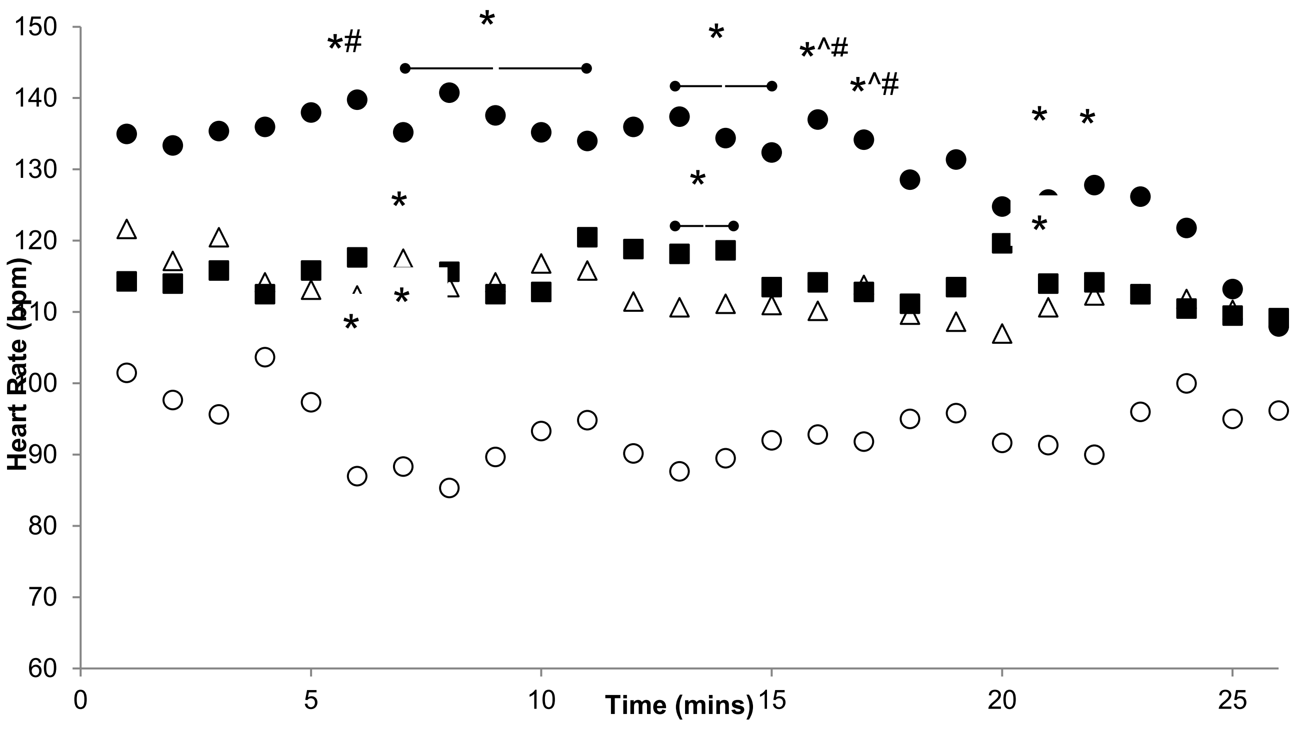

*Figure 5: Average heart rates (bpm) during Scenario Based Training (*denotes a significant difference from (A) control crew, ^denotes significant difference from (B) distracted crew, #denotes significant difference from (C) exerted crew), n=60, open circle represents (A) control, solid square represents (B) distracted, open triangle represents (C) exerted and solid circle represents (D) distracted and exerted)).*

As shown in Figure 6, maximal heart rate was significantly higher in the distracted and 'exerted' crew (D) (P=0.014, 4.529(3,20)=F; η2=0.405), with the average maximal heart rate reaching 140.3±8.7bpm compared to 108.3±11.1bpm for control (A). Distracted crew (B) versus the exerted only crew (C) were also higher than control but not significantly different between crews (P>0.05) apart from being at times more significant than control (P<0.05; Figure 6).

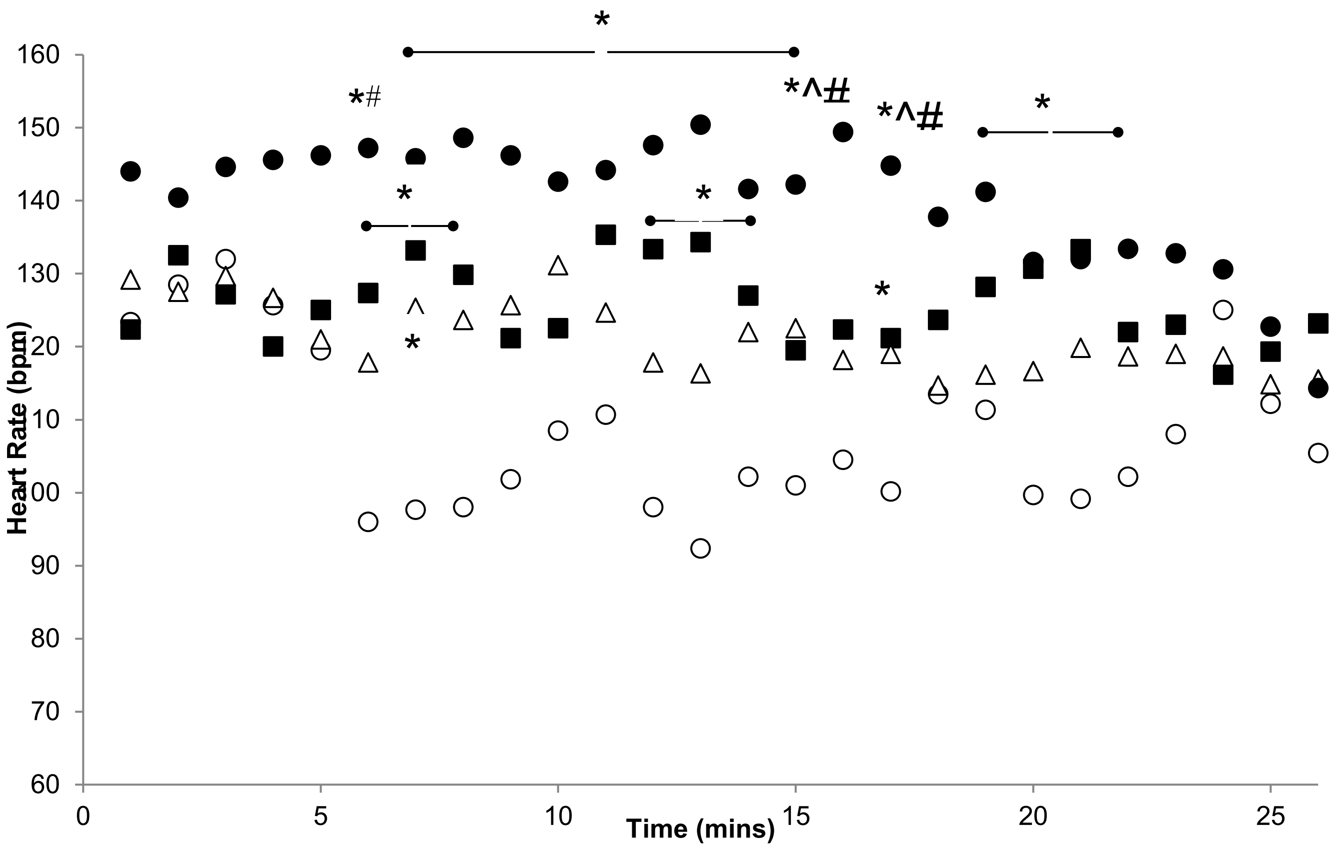

Figure 6: Maximal heart rates (bpm) during Scenario Based Training (denotes a significant difference from control crew (A), ^denotes significant difference from distracted crew (B), #denotes significant difference from exerted only crew (C), n=60, open circle represents control (A), solid square represents distracted (B), open triangle represents exerted (C) and solid circle represents distracted and exerted (D)).*

Impacts of stressors and distraction on searches.

The following data presents the disaggregated data by target type, stressor/distraction, and boat crew to enable cross-comparisons.

Performance success of SAR

Success in the SAR element of the experiment was defined as the location and transmission of the identifying code of each of the placed targets. Table 3 gives comparative success statistics across target types, and fatigue / distracted group types. The 'control' group (A) i.e. non- distracted and non-exerted crew were the most successful at locating the targets (78%), whereas the 'distracted and exerted' crew (D) were least successful only locating 57% of targets, as well as the 'distracted only' crew (B). The 'exerted only' (C) crew were able to locate 70% or targets.

Table 3: Comparative success values (located/total) for each set of stressors and distractions, with targets grouped and disaggregated by visibility and size (where HH= high head, LH= low head, HB= high body, LB= low body). Despite extensive pre-test preparation, one high-visibility whole-body target was recovered and returned to the RNLI station by a member of the public. This target was therefore excluded from the calculations of success values.

	Total (n=23)	**Heads** (n=12)	**Bodies** (n=11)	**High-Vis** (n=11)[1]	**Low-vis** (n=12)	**HH** (n=6)	**LH** (n=6)	**HB** (n=5)	**LB** (n=6)
(A) Control [Non-distracted, non-exerted]	0.78	0.75	0.82	0.73	0.83	0.67	0.83	0.80	0.83
B) Distracted only	0.57	0.50	0.64	0.55	0.58	0.50	0.50	0.60	0.67
(C) Exerted only	0.70	0.58	0.82	0.82	0.58	0.83	0.33	0.80	0.83
(D) Distracted & exerted	0.57	0.67	0.45	0.64	0.50	0.67	0.67	0.60	0.33

To establish comparison between conditions and their corresponding levels of success, a ranking system was implemented to compare conditions (Table 4). In this system, the conditions were compared based on the crews' average percentage of maximum heart rate, with the lowest average value indicating less physical exertion during the SAR operation, and higher values indicating greater success in locating targets. The control crew (A), which underwent typical Scenario Based Training, demonstrated the most effective SAR response. On the other hand, the distracted and exerted crew (D), had the least successful SAR outcome, and they also exhibited the highest percentage of maximum heart rate during the trial.

Those crews (i.e. control [A]) with the lowest heart rate (indicated as % of heart rate max), had the higher SAR success (indicated as % effectiveness of SAR), compared to those crews (i.e. exerted and distracted [D]) with the highest heart rate had the lowest success rate (Figure 7). 'Exerted' or 'distracted' only conditions had some impact on SAR success with 'distracted' being slightly more impactful over 'exerted'. This is supported by ranking the crews (Table 4) based on lower heart rate being better than higher (scored one for lowest and four for highest) and SAR effectiveness (scored one for best success, scored four for worst success).

1

Table 4. Ranking of SAR performance according to comparative success versus stressors and distractions

Condition (ranked best to worst)	**Heart rate response** (%HRmax)	**Search and Rescue effectiveness** (%Success)	**Outcome** (Scoring out of 8; Ranked 1- best, 4- worst)
(A) Control	55	78	1+1=2
(C) Exerted only	66	70	2+2=4
(B) Distracted	67	57	3+3.5=6.5
(D) Distracted & Exerted	77	57	4+3.5=7.5

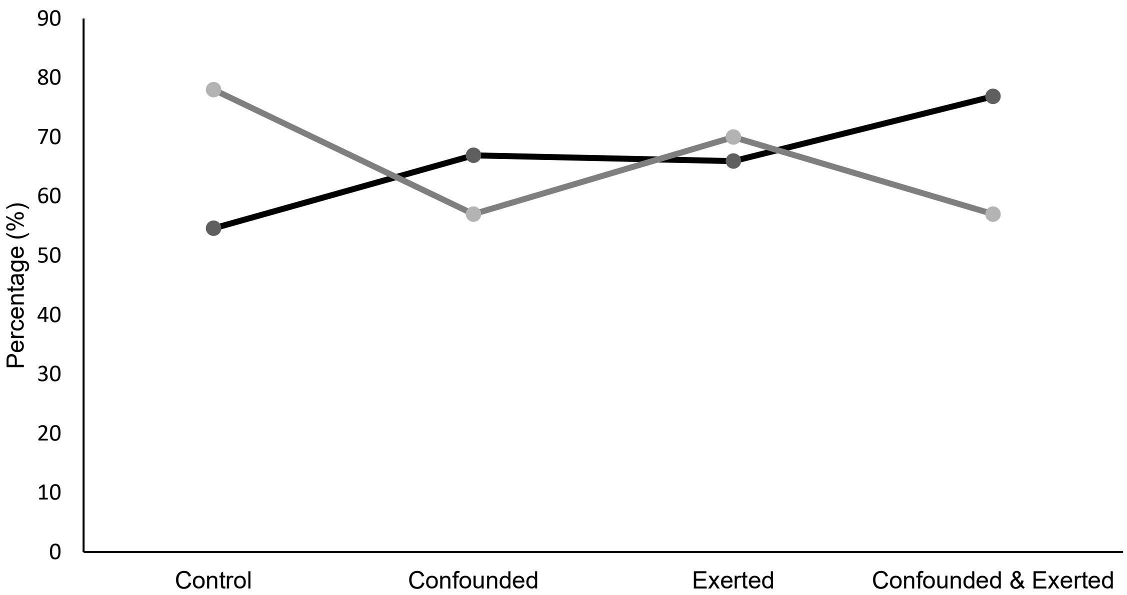

Figure 7: A graphical representation of heart rate response (%HRmax; black line) against search and rescue effectiveness (% success; grey line).

Discussion

This study sought to examine the impact of physical exercise and mental exertion, prior to the launch of a lifeboat, on the crew's performance. The experiment was undertaken during Scenario Based Training and the impact of 'during SAR distractions' was measured to determine the search effectiveness of the crew. The study established the impact of human contributors and distractors to search effectiveness, specifically physical and mental exertion and distractions. This is one of the few published studies to consider distracting and exertional approaches in a 'live' SAR riverine rescue of the RNLI.

As discussed earlier, the work of water SAR crews can often be complicated by both operational and personnel-related factors, such as limited information about location, behaviour and appearance of the victim, and the use of maritime search techniques that were developed for open water in the 1940s (Koopman, 1979). Limited research has been conducted on the influence of these factors. The appropriateness, or levels, of training of searchers and the status (physical fitness and mental alertness) of a search team may limit the chances of a successful search. This study identified that such variables may significantly impact the effectiveness of the SAR.

Impact of Physical and Mental Exertion Protocol

The study aimed to recreate the stressors of everyday life, overworking and levels of fatigue to establish the impact on SAR performance. To do this the authors established a physical and mental exertion protocol to complete during the Scenario Based Training. Thirty minutes prior to the Scenario Based Training, crews completed an exercise protocol at 86±1% of age-predicted heart rate max. Such an exercise intensity resulted in a 27.5% decline in perceptual recall and significantly slowed reaction time by 24.6msecs (Figure 4; $p=0.012$) compared to control crews. This indicated that the protocol induced both physical and mental exertion, aiming to recreate the stress experienced by the volunteer crew members upon receiving an emergency SAR call and arriving at the RNLI station.

Although both distracted (B) and exerted (C) crews experienced declines in search success compared to the control, the subsequent performance in the Scenario Based Training was only slightly impacted in the exerted crews (C). This was less so than hypothesised, where it had been presumed that the physical and mental exertion would degrade the performance when compared to control (A) and distracted alone (B). What the current study indicates is that, despite experiencing physical and mental exertion through the pre-SAR exercise, the crews still performed well cognitively prior to initiating the boat launch (as indicated by reaction time, Figure 4), but physiologically they were more stressed (as indicated by heart rate, Figure 3). This could indicate that the condition of the exertion protocol heightened their alertness (such as due to hypothalamic–anterior pituitary–adrenocortical axis (HPA) activation and the subsequent release of epinephrine) and therefore cognitively performed better as a result (Sünram-Lea, Owen-Lynch, Robinson, Jones, & Hu, 2012).

Performance success of SAR

During the Scenario Based Training, the average heart rate of all crews were between 66-72% of maximal heart rate which corresponded with the pre-SAR exertion protocol that required participants to exercise between a target heart rate of 70-90% maximal heart rate. This indicates that crews experience a moderate to high-intensity of physiological stress during the Scenario Based Training, but that all crew members were fairly well adapted to these conditions and that additional physical or mental exertion prior to the SAR did not significantly impact on their performance (Table 4). However, the highest physiological stress, as indicated by heart rate (Figure 3 and Figure 6), was seen in the 'distracted and exerted' crew (D) which was significantly different to all other conditions ($P<0.05$). This demonstrates that SAR success can be significantly impacted by the amalgamation of operational and personnel-related factors such as distraction, fatigue and over-working. This is especially important for those in voluntary SAR roles who may be on shifts following long working days, who are impacted by lack of sleep, personal life stress and stress linked to sudden alerts to an emergency call. This may also apply to those in retained (on-call) firefighter roles, or even wholetime firefighters responding towards the end of a busy set of shifts.

This finding was reiterated by the ranking (Table 4); when crews experienced both physical and mental exertion as well as distraction during the Scenario Based Training, there was a significant decline in search success. The 'distracted and exerted' crews (D) were least successful and only located 57% of targets (with 77% maximal heart rate) compared to 78% of the control crews (A, Table 4). The second least successful condition was the 'distracted' only crew (B) which also only located 57% of targets but were physiologically less stressed (as indicated by heart rate of 67% maximal heart rate). This was comparable to the 'exerted' only crew (C) but they were more successful in locating 70% of targets. This indicates that distraction is more impactful on search success over physiological exertion, but that both have implications, and that individuals experiencing a combination of both have a significant impact on success rates (Figure 7).

As may be expected, crews that were 'distracted', either by distraction alone (B), or exacerbated by physical and mental exertion (C) prior to the SAR (Tables 3 & 4), were less successful in the SAR response in comparison to the 'control' crew. However, the physical and mentally 'exerted' crew (C), were the *least* adversely impacted in their SAR success (7%).

This contradicts the initial hypothesis and may reflect a heightened alertness (e.g. released epinephrine) rather than inducing sufficient levels of fatigue. However, this is consistent with Fernández-Castillo and Gutiérrez Rojas (2009) who demonstrated individual-level stress and performance can improve attention. The findings of the main Scenario Based Training demonstrate a combination or increase in number of demands, such as the influence of teamwork and communication (Sonoda et al., 2018) can inhibit task attention (Robinson et al., 2013). Findings by McMorris et al.,(2011) have demonstrated that moderate-intensity activity (as seen in the current study) impacts the speed of response in working memory tasks and reduces accuracy in performance due to the increase in arousal levels. The increased release of glucocorticoids (specifically cortisol) in response to stressors, such as the physical and psychological demands experienced during 'live' SAR situations (Kaddoura, 2010), along with the aims of the current study design, may have resulted in increased circulating catecholamines (epinephrine and norepinephrine). These catecholamines can enhance the speed of neural transmission but may also have led to errors in judgement, either through omission or commission (Sandi, 2013).

Typically, physical and cognitive stress, and thus psychological stress, tends to also cause changes in heart rate and heart rate variability, where acute stress results in elevated heart rate response. Of additional interest was the decline in control group maximal heart rate (Figure 6) during the initial five minutes of the Scenario Based Training. This decrease, we hypothesise, may reflect the physical exertion of the SAR crew while manoeuvring their D-class lifeboat and subsequently entering the water. However, it is noteworthy that the crew managed to maintain a relatively calm state throughout the Scenario Based Training, as indicated by an average heart rate of 93.4±4.5 bpm (55% maximal heart rate).

Heart rate monitoring demonstrated that psychological stress and the physical challenges presented to the crews heightened physiological parameters. The heart rate of the crews showed that the exercise and distracted elements of the experiment had a measurable effect on the participants, and higher heart rates corresponded to poorer success in searching (Figure 7). Overall, the results showed that exercise and mental activity generally improved the perceptual performance of the crew, whilst the distracting element diminished performance.

This is the first study that indicates such implications on rescue crew team performance in high-pressure situations of a riverine SAR and provides knowledge and awareness of the importance of training to target managing both physical and cognitive stressors to improve skill and knowledge, although other studies have explored the role of simulation (Maran & Glavin, 2003). The implication is that emergency response organisations may consider the crewing levels, and role distribution within craft. It may be that the traditional role of "helm", where one individual is responsible for manoeuvring the vessel, all communications, as well as having overall command of the incident may need to be reconsidered. The National Operational Guidance for Incident Command (NOG, 2020) recognises that exceeding spans of control can lead to poor situational awareness and decision-making, and can contribute to a loss of control of an incident. This work provides additional evidence that excessive tasking ('distracting') on rescue craft may contribute to reduced incident command, and as such consideration should be given to roles and tasks within crews. Consideration may also be given to establishing additional levels of incident command away from the vessel itself, in order to provide a more holistic view of the incident, and reduce the task loading on the vessel commander.

Limitations

One factor that was not screened for, or taken into account, was the experience or skill level of the crews. Therefore, it is possible that crews that performed better on the runs may have been doing so as a result of factors other than exertion or distraction. There may also have been external environmental factors, such as light conditions, tidal conditions or river traffic – that may have had an impact on the search success. These factors would be difficult to eradicate but must be acknowledged between crews. Scenario Based Training was conducted in a randomised order for both conditions and crew order in order to mitigate the variables.

Additionally, the fitness level of participants was not assessed. Chang et. al, 2012 argue that cognitive function can be affected by physical fitness level, with higher fitness associated with improved cognitive function such as information processing and reaction time. However, all RNLI crew are routinely tested and classed as physically fit to be an active member.

Furthermore, cognitive disorders such as depression, and chronic personal levels of stress and mood were not established in the crews which may have impacted individual performance (Yaribeygi, Panahi, Sahraei, Johnston, & Sahebkar, 2017). Physiological measures of stress and arousal level were also not monitored during the study, therefore future studies should look to monitor both cognitive levels of stress and hormonal responses such as catecholamine response during Scenario Based Training, where glucocorticoid levels can impair attentional processes (Bohnen et al.,1990).

For this study, only a predetermined Scenario Based Training of 30 minutes in duration was utilised. However, it is important for further studies to investigate the long-term implications of SAR performance with longer searches. Typical callouts can include events that last beyond 4.5hours where additional fatigue, loss of concentration and focus may occur. Regarding the Teddington Lifeboat specifically, RNLI records show that the average response duration between 2007 and 2012 was 57.4 minutes with the maximum duration of 9.5 hours for one incident, with 282 incidents in total.

For the ‘distracted’ condition, a model that stressed external-intra-team forms of communication was utilised. However, with large multi-agency responses, individuals may require more mental bandwidth, and the need to retain information for longer and integrate it over a broader remit. The timely and accurate communication of individual, group, and environmental inputs are vital for collective success, with authors noting of aircraft crews “communication processes are of central importance to the group activities that rely on verbal exchanges and information transfer” (Kanki, 2019, p.120). As group complexity increases, so does the need to process and act on diverse sources of information and resources within, and outside, of the immediate team. The authors of the current study suggest the distraction model is appropriate for small-team use, but a more appropriate model should be developed to reflect the complexities of larger SAR operations.

Finally, it is also worth noting, that the participants of the RNLI crews are voluntary and aspects such as diet and pre-SAR conditions were not monitored or controlled, and findings may have been affected by underlying aspects beyond the scope of the study design. For example, caffeine and carbohydrates have been known to enhance cognitive performance (Lieberman, 2003). However, it was deemed appropriate to maintain the ecological validity of the study to replicate real-world conditions the RNLI crew members face at the time of a SAR call to simulate the typical demands put upon the attention of the crew.

These findings provide support for the efforts of the emergency services and emphasise the importance of considering confounding factors, such as physical and mental exertion, as well as distractions, when assessing search effectiveness. This is particularly relevant for responders who have to rapidly respond from their home or work environments. Furthermore, the findings underscore the significance of the appropriateness and levels of training of searchers, taking into consideration factors such as fatigue, and potential for overworking a search team, in order to improve the likelihood of a successful search (Covassin et al., 2007; Hancock & McNaughton, 1986). This may however, be difficult in a voluntary setting such as for the RNLI crew who are also managing personal and work commitments, and as such, approaches to mitigate such consequences should be investigated further.

Conclusion

The findings from this study indicate that increases in alertness and search performance have significant implications for those involved in SAR. The data overview suggests that distractions may have a greater influence on operational search success than exertion but that both conditions have significant implications for those involved in Search and Rescue. This study recommends the need to review emergency response organisation at crewing levels, and role distribution within craft. Consideration should include additional levels of incident command away from the vessel itself, in order to provide a more holistic view of the incident, and reduce the task loading on the vessel commander. This should be set against observations that individual crew performance may also be a significant contributing factor to the success of a mission that warrants further evaluation.

Future studies in the domain of riverine search and rescue performance could look at the effects of additional factors, such as dietary supplements, and mental training techniques such as mindfulness. Examining the effects of dietary supplements could demonstrate how specific nutrients or supplements may enhance cognitive abilities, endurance, or overall physical wellbeing, thus potentially influencing search and rescue operations. Furthermore, exploring the application of mental training techniques like mindfulness, could reveal their potential in improving focus, decision-making abilities, stress management, and overall mental resilience, all of which are crucial in the demanding and high-pressure situations encountered during riverine search and rescue operations.

Acknowledgements

The authors would like to thank the RNLI and all targets and co-supervisors who contributed their time and goodwill to this project. Thank you to Teddington RNLI Crew, the students and staff of Kingston University London, who gave their time as runners and targets and Dr Rebecca Gosling, for assistance in running the experiments.

Author Biographies

Dr Hannah Jayne Moir is an Honorary Senior Fellow (Associate Professor in Health and Prescription) in the Department of Applied and Human Sciences, Faculty of Health, Science, Social Care & Education, at Kingston University London. Her expertise is in exercise physiology with an interest in occupational physiology. Her research examines the physiological, pathophysiological and psychological responses and recovery patterns to extreme physical challenges. She is also a Senior Medical Writer and Moderator for EMJ, London, a European medical journal.

Dr Alex Tasker is a Lecturer (Teaching) in Human Ecology in the Department of Anthropology at University College London. His expertise is in the combined influence of social, cultural, ecological, and biological drivers of health and performance, with a specific interest in marginalised and extreme populations. His biosocial research currently examines multi-dimensional drivers of health and disease linked to human-animal contact in forced migration settlements.

Christopher C.F. Howe is Research and Innovation Lead for ai.io, a technology company providing solutions to generate and analyse amateur and professional sport data, and also Researcher in Sport and Exercise Physiology in the Faculty of Health, Science, Social Care and Education, at Kingston University London. His expertise is in psycho-physiology of extreme environments and endurance performance.

Dr Ian Greatbatch is a fire officer, Visiting Researcher at the University of Portsmouth and formerly Associate Professor at Kingston University London. His research concerns the operational effectiveness of Search and Rescue and Fire and Rescue Operations.

References

Alexander, D., & Klein, S. (2009). First Responders after Disasters: A Review of Stress Reactions, At-Risk, Vulnerability, and Resilience Factors. *Prehospital and Disaster Medicine*, *24*(2), 87-94.

Barnett, J. S., & Kring, J. P. (2003). Human Performance in Extreme Environments: A Preliminary Taxonomy of Shared Factors. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *47*(8), 961–964.

Bohnen, N., Houx, P., Nicolson, N., & Jolles, J. (1990). Cortisol Reactivity and Cognitive Performance in a Continuous Mental Task Paradigm. *Biological Psychology, 31*(2), 107-116.

Chang, Y.-K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The Effects of Acute Exercise on Cognitive Performance: A Meta-Analysis. *Brain Research, 1453*, 87-101.

Clarke, A. (2001). *Public Inquiry into the Identification of Victims Following Major Transport Accidents*: Department of the Environment, Transport and the Regions.

Correia, A., Moura, R., & Fonseca, M. (2020). Assessing the Location of Search and Rescue Stations on the Portuguese Coast. In *Developments and Advances in Defense and Security* (pp. 321-331): Springer.

Covassin, T., Weiss, L., Powell, J., & Womack, C. (2007). Effects of a Maximal Exercise Test on Neurocognitive Function. *British Journal of Sports Medicine, 41*(6), 370-374.

Deary, I. J., Liewald, D., & Nissan, J. (2011). A Free, Easy-to-Use, Computer-Based Simple and Four-Choice Reaction Time Programme: The Deary-Liewald Reaction Time Task. *Behavior Research Methods, 43*(1), 258-268.

Duncan, M., Smith, M., & Lyons, M. (2013). The Effect of Exercise Intensity on Coincidence Anticipation Performance at Different Stimulus Speeds. *European Journal of Sport Science, 13*(5), 559-566.

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors, 37*(1), 32-64.

Fernández-Castillo, A., & Gutiérrez Rojas, M. E. (2009). Selective Attention, Anxiety, Depressive Symptomatology and Academic Performance in Adolescents. *Rev Electron Investig Psicoeduc Psigopedag., 7*(10), 49-76.

Fritz, C. E., & Mathewson, J. H. (1957). *Convergence Behavior in Disasters: A Problem in Social Control*: National Academy of Sciences-National Research Council.

Frost, J. R., & Stone, L. D. (2001). *Review of Search Theory: Advances and Applications to Search and Rescue Decision Support*. SOZA and company LTD: Fairfax, VA.

Greatbatch, I., Gosling, R. J., & Allen, S. (2015). Quantifying Search Dog Effectiveness in a Terrestrial Search and Rescue Environment. *Wilderness and Environmental Medicine, 26*(3), 327-334.

Hancock, S., & McNaughton, L. (1986). Effects of Fatigue on Ability to Process Visual Information by Experienced Orienteers. *Perceptual and Motor Skills, 62*(2), 491-498.

Jeung D.Y., Kim, C., & Chang, S.J. (2018). Emotional Labour and Burnout: A Review of the Literature. *Yonsei Medical Journal*, *59*(2),187-193.

Johnson, C. W. (2008). *Complexity, Structured Chaos and the Importance of Information Management for Mobile Computing in the UK Floods of 2007.* Paper presented at the International Workshop on Mobile Information Technology for Emergency Response, Berlin.

Kaddoura, M. A. (2010). New Graduate Nurses' Perceptions of the Effects of Clinical Simulation on Their Critical Thinking, Learning, and Confidence. *The Journal of Continuing Education in Nursing, 41*(11), 506-516.

Kanki, B. G. (2019). Communication and Crew Resource Management. In B. G. Kanki (Ed.), *Crew Resource Management* (pp. 103-137): Elsevier.

Koester, R. J., Cooper, D. C., Frost, J., & Robe, R. (2004). *Sweep Width Estimation for Ground Search and Rescue*. Retrieved from Alexandria, VA: https://www.dco.uscg.mil/Portals/9/CG-5R/nsarc/DetExpReport_2004_final_s.pdf

Koester, R. J., Gordon, R., Wells, T., & Tucker, R. (2013). Auditory and Light Based Two-Way Effective Sweep Width for Responsive Search Subjects in New Zealand Mountainous Terrain. *Journal of Search and Rescue, 1*(1), 1-18.

Koester, R. J., & Greatbatch, I. (2016). Missing Aircraft Crash Sites and Spatial Relationships to the Last Radar Fix. *Aerospace Medicine and Human Performance, 87*(2), 114-121.

Koopman, B. O. (1979). Search and Its Optimization. *The American Mathematical Monthly, 86*(7), 527-540.

Lawn, S., Roberts, L., Willis, E., Couzner, L., Mohammadi, L. and Goble, E. (2020). The effects of emergency medical service work on the psychological, physical, and social well-being of ambulance personnel: a systematic review of qualitative research. *BMC Psychiatry*, 20, 1-16.

Lieberman, H. R. (2003). Nutrition, Brain Function and Cognitive Performance. *Appetite, 40*(3), 245-254.

Maran, N. J., & Glavin, R. J. (2003). Low-to High-Fidelity Simulation–a Continuum of Medical Education? *Medical Education, 37*, 22-28.

Martin, W.L., Murray, P.S., Bates, P.R. and Lee, P.S. (2015). Fear-potentiated startle: A review from an aviation perspective. *The International Journal of Aviation Psychology*, *25*(2), 97-107.

McMorris, T., Sproule, J., Turner, A., & Hale, B. J. (2011). Acute, Intermediate Intensity Exercise, and Speed and Accuracy in Working Memory Tasks: A Meta-Analytical Comparison of Effects. *Physiology and Behavior, 102*(3-4), 421-428.

Meredith, T & Greatbatch I. (2022). Experiments to determine optimal effectiveness of drones for post-disaster search and rescue. UK National Earth Observation Conference 2022.

Murphy, R. R., & Burke, J. L. (2005). Up from the Rubble: Lessons Learned about HRI from Search and Rescue. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 49(3), 437–441.

NOG. (2020). *National Operational Guidance: Incident Command 2020*. Retrieved from https://www.ukfrs.com/guidance/incident-command

Paton, D. (1994). Disaster relief work: An assessment of training effectiveness. *Journal of Traumatic Stress*, *7*(2), 275-288.

Robe, R. Q., & Frost, J. (2002). *A Method for Determining Effective Sweep Widths for Land Searches. Procedures for Conducting Detection Experiments*. Retrieved from https://www.dco.uscg.mil/Portals/9/CG-5R/nsarc/LandSweepWidthDemoReportFinal.pdf

Robinson, O. J., Vytal, K., Cornwell, B. R., & Grillon, C. (2013). The Impact of Anxiety Upon Cognition: Perspectives from Human Threat of Shock Studies. *Frontiers in Human Neuroscience, 7*, 203.

Sandi, C. (2013). Stress and Cognition. *Wiley Interdisciplinary Reviews: Cognitive Science, 4*(3), 245-261.

Simons, D. J., & Levin, D. T. (1998). Failure to Detect Changes to People During a Real-World Interaction. *Psychonomic Bulletin & Review, 5*(4), 644-649.

Sonoda, Y., Onozuka, D., & Hagihara, A. (2018). Factors Related to Teamwork Performance and Stress of Operating Room Nurses. *Journal of Nursing Management, 26*(1), 66-73.

Sünram-Lea, S. I., Owen-Lynch, J., Robinson, S. J., Jones, E., & Hu, H. (2012). The Effect of Energy Drinks on Cortisol Levels, Cognition and Mood During a Fire-Fighting Exercise. *Psychopharmacology, 219*(1), 83-97.

Warburton, D. E., Jamnik, V., Bredin, S. S., Shephard, R. J., & Gledhill, N. (2019). The 2020 Physical Activity Readiness Questionnaire for Everyone (Par-Q+) and Electronic Physical Activity Readiness Medical Examination (Eparmed-X+). *The Health & Fitness Journal of Canada, 12*(4), 58-61.

Welford, A. (1980). Relationships between Reaction Time and Fatigue, Stress, Age and Sex. *Reaction Times*, 321-354.

Yan, X., Wu, B., Zhang, D., & Zhang, J. (2017). Emergency Management of Maritime Accidents in the Yangtze River: Problems, Practice and Prospects. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 11*(1).

Yaribeygi, H., Panahi, Y., Sahraei, H., Johnston, T. P., & Sahebkar, A. (2017). The Impact of Stress on Body Function: A Review. *EXCLI journal, 16*, 1057.