**A Job Task Analysis to Describe the Physical Demands of Specialist Paramedic Roles in the National Ambulance Resilience Unit (NARU)**

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**Abstract**

**BACKGROUND:** The National Ambulance Resilience Unit (NARU) works on behalf of each National Health Service (NHS) Ambulance Trust in England to strengthen national resilience and improve patient outcome in challenging pre-hospital scenarios. **OBJECTIVE:** To conduct a Job Task Analysis and describe the physical demands of NARU roles. **METHODS:** A focus group was conducted to describe the physically demanding tasks performed by NARU personnel. Subsequently, the physical demands of the identified tasks were measured in 34 NARU personnel (29 male and 5 female). **RESULTS:** Eleven criterion tasks were identified; Swift Water Rescue (SWR), Re-board Inflatable Boat (RBIB), Set up Decontamination Tent (SDT), Clinical Decontamination (CD), Movement in Gas Tight Suits (MGTS), Marauding Terrorist Fire Arms (MTFA), Over Ground Rescue (OGR), Unload Incidence Response Unit Vehicle (UIRUV), Above Ground Rescue (AGR), Over Rubble Rescue (ORR) and Subterranean Rescue (SR). The greatest cardiovascular strain was measured during SWR, MGTS, and MTFA. The most thermally challenging tasks were the MTFA, CD, SR and OGR. The greatest muscular strength requirements were during MTFA and OGR. **CONCLUSIONS:** All five components of fitness (aerobic endurance, anaerobic endurance, muscular strength, muscular endurance and mobility) were required for successful completion of the physically demanding tasks performed by NARU personnel.

**Keywords:** Emergency Services, Paramedics, Physical Employment Standards

**1.0 Introduction**

Physical Employment Standards (PES) are critical for recruiting, training and maintaining operational effectiveness of personnel in physically demanding occupations (e.g. fire and rescue, police, military, paramedic services) [1]{Blacker, 2015 #9;Blacker, 2015 #9}. PES can be utilized at various stages of a career including recruitment, annual in-service assessments and selection or screening to undertake specialist roles. To be legally defensible and ensure the best job-person fit, PES should be based on empirical evidence and subject matter expert opinion of the physical demands of the tasks undertaken within an occupation. Various frameworks have been proposed to develop PES [2-5], these usually comprise of four phases;

1. Conducting a job task analysis (JTA) to identify and quantify the physical demands of criterion tasks.

2. Developing simulations of these criterion tasks that are representative of the actual job.

3. Establishing the efficacy of using predictor tests to assess personnel (which if implemented before a period of training should also take into account any gains in physical fitness).

4. Proposing evidence-based performance standards.

A paramedic’s role often involves attending emergency scenes arising from road traffic and rail incidents, criminal violence, terrorist threats, fires and sudden illness. Emergency situations which require greater specialist capabilities are often attended to by roles within the National Ambulance Resilience Unit (NARU). NARU works on behalf of each National Health Service (NHS) Ambulance Trust in the United Kingdom (UK) to strengthen national resilience and improve patient outcome in challenging pre-hospital scenarios. Such scenarios include tasks undertaken by the Hazardous Area Response Team (HART), Chemical Biological Radiological and Nuclear (CBRN) staff and Marauding Terrorist Fire Arms (MTFA) teams. HART staff comprise of Paramedics who are selected and trained to operate in environments where there is a threat from explosive devices, a requirement for Urban Search and Rescue (USAR) and situations that involve operating in Inland Water (IW). CBRN staff are Paramedics and emergency medical technicians or other levels of staff deemed suited by a Ambulance Trust to wear the NHS PPE of Powered Respirator Protective Suit (PRPS), to decontaminate patients. MTFA staff are Paramedics and emergency medical technicians who will work alongside HART staff to provide clinical care in the event of an MTFA incident.

All specialist roles undertaken by NARU personnel involve tasks such as casualty extraction, manual handling and carrying of equipment while wearing the Personal Protective Clothing (PPE). These types of activities result in substantial physiological strain which can be exacerbated through cumulative fatigue, dehydration and high and low ambient temperatures [6, 7]. Safe and effective completion of tasks undertaken by NARU personnel are likely to require a combination of five key components of fitness i.e. aerobic endurance, anaerobic endurance, muscular strength, muscular endurance and mobility. A JTA is a critical step to identify the extent to which each of these components of fitness are required in NARU job roles and underpin the development of PES.

Personnel applying to join NARU currently complete a Physical Competency Assessment (PCA), which was developed in 2010. However, since 2010 NARU personnel have been tasked to complete a broader range of special operations meaning that a new JTA is required to underpin the development of a new PCA. Therefore, the aims of the present study were to identify the criterion tasks undertaken by NARU personnel (Phase 1) and document the physiological responses and limitations to performance when undertaking these criterion tasks (Phase 2) to underpin the future development of a revised PCA.

**2.0 Methods**

*Phase 1*: Ten NARU personnel, who had experience in the planning, preparation and / or execution of NARU operations, were invited to attend a focus group in line with the recommendations of Blacklock et al. [8]. The focus group was facilitated using the Technique for Research of Information by Animation of a Group of Experts (TRIAGE) process which involves three stages. Stage 1 – Prior to the workshop, the research team reviewed policy and previous publications describing the physical demands of NARU roles. Participants were asked to complete and return a questionnaire and list the 10 most physically demanding tasks in their roles. Stage 2 – At the start of the focus group, the participants were briefed on the TRIAGE process and the physically demanding tasks listed in their pre-focus group questionnaires were collated and grouped for similarity, discussed in detail and the task descriptions generated. The participants were asked to vote anonymously to rate the tasks and provide a rating using a 1-6 scale with word anchors describing the “Importance” (“Not Applicable” to “Critical”), “Physical Demands” (“Very Light” to “Maximum”) and “Frequency” (“Never to Very Frequent”). Stage 3 - After the focus group, the researchers collated the outcomes of Stages 1 and 2 and produced a full written summary of the 11 physically demanding criterion tasks that were identified and outlined the scenarios for Phase 2.

*Phase 2:* Thirty-four Paramedics (29 male and 5 female) from five of the ten UK Ambulance Service Trusts volunteered to participate. The participants completed 11 criterion tasks, during each criterion task scenario the total number of participants differed due to the personnel being drawn from different NARU roles (HART, CBRN, MTFA). The number and characteristics of the participants that undertook each task are described in Table 1. Ethical approval was provided by the University of Chichester Ethics Committee. All participants were medically screened, received a full procedural brief and provided written informed consent. Participant’s involvement in a criterion task ended if they met one of the three following criteria:

1. Core temperature reached 39.5°C

2. Paramedics or investigator judged the participants conduct unsafe to continue

3. Successful completion of the task

**[INSERT TABLE 1 HERE]**

*2.1 Preliminary Measures*

Stature (Stadiometer, SECA Ltd, Birmingham, UK) and body mass (Kern Balances, Balingen, Germany) were measured. Participants competed a Multistage Fitness Test (MSFT) to estimate maximal aerobic capacity (O2max) and maximum heart rate (HRmax), and a 40 m sprint to quantify anaerobic power. Muscular strength and power were quantified from three methods:

1. Handgrip strength using a handgrip dynamometer with the peak force recorded during a 3 s maximal contraction reported as the performance score [TKK 5401 GRIPD, Cranlea & Co. Birmingham, UK].

2. An upright, maximal isometric pull of a bar, which was connected to a strain gauge via a chain positioned 38 cm from the floor [University of Chichester, West Sussex, UK] where peak force during a 3 s maximal contraction was recorded as the performance score

3. Vertical countermovement jump performed on a jump timer mat [University of Chichester, West Sussex, UK] where participants were instructed to place their hands on the hips and perform a maximal jump and flight time was recorded as the performance score.

*2.2 Physiological Measures during Criterion Tasks*

Participants arrived at least 1 hour before performing each criterion task. On arrival, each participant provided a urine sample to determine hydration status [9] . Urine samples were assessed using both a urine colour chart and urine osmolality (Osmocheck, Vitech Scientific Ltd, Horsham, UK).

To estimate sweat loss during each task, participants’ nude body mass was measured to the nearest 0.1 kg (Kern Balances, Balingen, Germany) and then again immediately after towelling down following each task once PPE and measurement instruments had been removed. Participants were free to drink ad libitum from labelled 250 ml bottles, throughout the tasks. The volume of water consumed by each participant was recorded by totalling the number of bottles finished during the task, and where a bottle was unfinished the remaining water was recorded and added to the value. The difference in body mass between the start and end of each scenario minus the total mass of water consumed was used to estimate sweat loss [10] .

Prior to each criterion task, participants self-inserted a rectal thermistor (Grant Instruments Ltd, Cambridge, UK) to a depth of 10 cm past the sphincter for the measurement of core temperature (Tc). Readings were logged telemetrically on a wireless data logger (Eltek Ltd, Cambridge, UK), which each volunteer wore around their waist. Recordings were transmitted to PC software for real-time monitoring (Darca Version 3.0.12.35, Eltek Ltd, UK).

To measure skin temperature (T̅sk), iButtons® (iButton®, HomeChip Ltd, Milton Keynes, UK) were secured to four sites (neck, shoulder, hand and shin) of the participants’ skin and data were recorded every 20 seconds. Data were logged internally and downloaded using PC software (Thermodata 3.1, Thermodata Pty Ltd, Queensland, Australia) following the task. Mean skin temperature was calculated using the following equation: T̅sk = (0.28\*neck) + (0.28\*shoulder) + (0.16\*hand) + (0.28\*shin) (11). Total body temperature (T̅b) was calculated using the following equation: T̅b = (0.79\*Tc) + (0.21\*T̅sk) [12].

All participants wore a heart rate monitor (Polar Team 2 System, Polar Electro Oy, Finland) around their chest which recorded heart rate every 5 seconds. Heart rates during the tasks are expressed as a percentage of maximal heart rate and the proportion of total time (%) spent in each of five zones from <50 % to 100 % were calculated [13].

Ratings of Perceived Exertion (RPE) (14) and Thermal Comfort scale ratings (TC) [15] were recorded at the start and at the end of each criterion task.

***Environmental Conditions***

Dry bulb temperature and relative humidity were recorded during each task. Measurements of the temperature inside PPE was recorded using iButtons® (iButton®, HomeChip Ltd, Milton Keynes, UK), these were placed between the participants’ base layers and PPE.

**3.0 Results**

*3.1 Criterion Tasks and Scenario Descriptions*

In Phase 1, 11 physically demanding criterion tasks were described by the participants. Scenarios were constructed by the researchers and NARU subject matter experts (SMEs) to simulate the physical demands of the 11 criterion tasks based on the task descriptions in the Phase 1 workshop. The scenarios were undertaken in accordance with NARU Standard Operating Procedures (SOP’s) and the PPE worn differed between criterion tasks as shown in Figure 1.

**[INSERT FIGURE 1 HERE]**

*Swift Water Rescue (SWR):* Eleven participants wearing SWR PPE (~9 kg), were deployed to a fast-flowing river to rescue a conscious casualty on the far bank. The rescue of the casualty was affected by means of an individual ~ 25 m tethered swim and recovery across the moving water. The participants entered the water, swam to the casualty from the opposite bank, secured the casualty and then recovered the casualty to entry point, which was assisted by use of their tether pulled by one person.

*Re-board Inflatable Boat (RBIB):* Eleven participants wearing SWR PPE (~9 kg) were deployed as a SWR team to right an overturned First Response Service Rigid Inflatable Boat (FRS RIB). Participants were then required to re-enter the boat from the water unaided other than the use of a foot strop where required.

*Set up Decontamination Tent (SDT):* Eight participants wearing Incident Ground Kit (IGK) weighing ~4 kg, were directed to set up a decontamination tent facility in a designated area. The task required the participants to lift and carry equipment weighing between 21 kg to 167 kg, 20 m to 25 m either as an individual or as a team to the designated area before erecting the decontamination tent.

*Clinical Decontamination (CD):* Eight participants wearing Gas Tight Suits (GTS; ~ 12 kg) completed a criterion task scenario directing them to carry out CD of casualties. The task comprised of three roles: 1. Recovery Team (n=4); 2. Decontamination Team (n=2) and 3. Rescue Team (n=2). The teams changed role every ~24 minutes (dependent on when a casualty had been passed from the Recovery Team to the Decontamination Team) until the completion of the whole scenario (total time of 2 hours). The Recovery Team entered the “warm zone” (the area between the contaminated area and decontaminating facility) and walked 200 m to collect a casualty (88 kg) and returned them (200 m) to the decontamination facility on a wheeled litter carrier at the participants self-selected pace. The casualties were handed over to the Decontamination Team before the Recovery Team repeated the process. The Recovery Team completed their activity at a self-selected pace and recovered between 2 to 4 casualties every ~24 min. The Decontamination Team worked inside the decontamination facility carrying out wet decontamination of casualties using following NARU SOPs (decontamination of each casualty taking a total of 12 min). The Rescue Team were based at the entrance to the decontamination facility in half-suited Protective Powered Respiratory Suit (PPRS), to simulate being on standby to don full PPRS and enter the warm zone to rescue a member of staff if required.

*Movement in Gas Tight Suits (MGTS):* Six participants worked in pairs to a complete a simulated Individual Chemical Exposure (ICE) scenario wearing Extended Duration Breathing Apparatus (EDBA) and GTS (~ 37 kg). The scenario began by the pairs picking up their equipment consisting of a Cube, Forward Oxygen and Rescue Bag. The Cube (31 kg) contains equipment that did not need to be taken all the way to the casualties so was carried 20 m and left. The participants then walked a further 180 m to the casualties. As a team, the rescuers dragged two casualties (88 kg each) 20 m into fresh air and worked in a pair to provide CPR for 15 minutes. The team then withdrew back to the start point (200 m) without the casualties as other rescuers would collect them.

*Marauding Terrorist Firearms (MTFA):* Six participants completed simulated activities associated with an MTFA incident over a 2-hour period wearing full ballistic PPE (~19 kg). The activities were conducted in pairs. The task comprised the following activities repeated in the same order as a circuit until 2 hours had elapsed:

1. 400 m walk at a brisk pace remaining tactically aware.

2. 3 x 20 m ‘dashes’ with simulated triage/treatment of wounds in between, treating and dragging 3 individual casualties ~10 m to cover.

3. At a holding point, treatment of wounds of 4 (of 8) casualties (~83 kg manikins) followed by movement of each one 5-10 m to cover.

4. 60 m sprint to an area of cover due to an unexpected threat.

5. In a pair, using a strop drag a stretcher with one pre-loaded casualty (combined mass of casualty and stretcher 89 kg) 200 m.

6. Recovery walk back to the start point.

All of the activities were conducted according to NARU SOPs and self-paced by the participants in their pairs.

*Overground Rescue (OGR):* Four participants wearing IGK, performed an OGR task. The task required the team to walk 3 km, at a pace of approximately 4 km.h-1 (directed by SMEs as a reasonable safe pace to complete this task). During the 3 km walk, the participants rotated carrying equipment (Total load ~30 kg), at the end of the route, a casualty (88 kg dummy) was attached to a stretcher and lifted to a height of ~1 m onto a vehicle for extraction.

*Unload IRU Vehicle (UIRUV):* Four participants wearing IGK, simulated unloading equipment of various size and weight (8 kg to 33 kg) from the back of a vehicle (lifting from between waist to head height depending on the item) and carrying it 200 m at a self-selected pace to set up a casualty clearing station.

*Above Ground Rescue (AGR):* Four participants wearing Safe Working at Height (SWaH) PPE (~14 kg) completed a simulated ascent of a 70 m scaffolding tower. Working in pairs, each team climbed the scaffolding rig using a 7 m ladder (maintaining three points of contact). Once at the top, they were required to climb down three shorter ladders to ground level. This sequence was repeated 10 times to simulate a 70 m climb and descent. It should be noted that repeatedly acceding and descending a shorter ladder (i.e. 7 x 10 m), is likely to underestimate the energy cost of ascending and descending a single longer (70 m) ladder [16, 17]. During the tenth descent, staff had to individually treat and secure a casualty to a stretcher (combined casualty and stretcher mass 89 kg) on the first floor and drag them 5 m to a designated point. Once completed, the team of four left the scaffolding structure and carried a casualty 10 m on the ground using a stretcher (combined casualty and stretcher mass 75 kg).

*Over Rubble Rescue (ORR):* Four Paramedics, working as a team, performed an ORR task wearing full USAR PPE weighing (~7 kg) and carrying a 10 kg response bag and a Multi-integrated Bodysplint Stretcher (MIBS, 6 kg) by passing it between them as required to move over the rubble pile. The task required moving 50 m as a team following a designated route on an uneven surface, replicating a building collapse. Three points of contact (i.e. hands or feet) were maintained with the rubble pile throughout. At the 50 m point, the team treated and packaged a casualty (88 kg) into a MIBS stretcher before progressing 50 m to safe ground.

*Subterranean Rescue (SR):* Four participants wearing USAR PPE (~7 kg) performed a SR of a casualty simulating an unconscious casualty (89 kg). The participants had to locate and extricate a number of casualties from two different locations: 1. A building and 2. Underneath a train carriage. The team deployed forward following a guideline in the building to locate any casualties; on completion of this task the team was re-tasked to the area of the train to locate further casualties. The participants worked in pairs and between them; a USAR Tombstone (12 kg), full MIBS (6 kg) and Forward Oxygen (14 kg) when under the train.

*3.2 Physical demand of the criterion tasks*

Summary data for each scenario are presented in Table 2. The shortest scenario durations were 1 minute (SWR and RBIB) and the longest were 120 minutes (CD, MTFA and SR). Environmental conditions were temperate during all criterion tasks with dry bulb temperature ranging from a dry bulb temperature of 13.2 °C and 16.8 °C and relative humidity between 42.9 % and 93.7 %, the environmental conditions for each scenario can be seen in Table 2.

**[INSERT TABLE 2 HERE]**

Manual handling differed for each criterion task, in some instances load was carried, pulled or dragged by a single individual. For other criterion tasks, the load was often shared between teams of 2 to 6 individuals (Table 3). The heaviest load carried or lifted by an individual was 23 kg, whereas the heaviest load carried or lifted was 167 kg in a team of 6 individuals and therefore a relative individual load of 28 kg was lifted and carried. The maximum load dragged on a stretcher by an individual was 88 kg (SR).

**[INSERT TABLE 3 HERE]**

*Cardiovascular Strain* - Heart rate responses to each of the criterion tasks are displayed in Table 4. Criterion tasks with greater cardiovascular strain were SWR, MGTS and MTFA. Using the zones proposed by Howley [13] , during these three tasks, the participants spent over 40 % of the task in the ‘Hard’ zone (77 to 93 % HRmax) with the remainder of the time predominantly spent in the ‘Moderate’ zone (64 to 76 %HRmax). The criterion tasks presenting the least cardiovascular strain were RBIB, CD, OGR, AGR, ORR and SR, during all these tasks, less than 25% of the total task time was spent in the ‘Hard’, ‘Very Hard’ and ‘Maximal’ zone (77 – 100 %HRmax).

**[INSERT TABLE 4 HERE]**

*Core, Skin and Body Temperature -* Table 5 shows that the highest mean and peak T̅c occurred during the MTFA, CD, SR and OGR tasks. The T̅c increased during all criterion tasks; with the MTFA producing the highest mean T̅c of 38.1 °C, highest peak T̅c of 39.2 °C compared to the other tasks. However, the rate of Tc rise was moderate at 1.3 °C·h-1.

Table 5 shows that the highest peak and mean T̅sk occurred during the CD, MTFA and SR. The T̅sk increased during all criterion tasks; with the SR producing the highest mean T̅sk of 33.7 °C compared to the other tasks. In addition, the MTFA produced the highest peak T̅sk of 37.2 °C compared to the other tasks. The most thermally challenging tasks when combining both T̅c and T̅sk to generate T̅b were MTFA and SR, these tasks produced a mean T̅b of 37.1 ± 0.9 °C and 37.1 ± 0.3 °C, respectively.

**[INSERT TABLE 5 HERE]**

*Hydration Status and Fluid Consumption -* Figure 2 shows each participants’ urine osmolality before each scenario, which across the eleven tasks, indicated that 77 % of participants were classified as ‘hydrated’, 20 % ‘borderline dehydrated’ and 3 % ‘dehydrated’ based on the American College of Sports Medicine Guidelines for Exercise and Fluid Replacement [9]. Fluid intake was greater than estimated fluid loss during all tasks except for the AGR and ORR, where estimated sweat loss slightly exceeded fluid intake (Figure 3).

**[INSERT FIGURE 2 HERE]**

**[INSERT FIGURE 3 HERE]**

*Ratings of Perceived Exertion (RPE) and Thermal Comfort (TC)* - Table 6 displays the RPE pre and post each criterion task, where RPEs were similar at the start (rest) of all 11 criterion tasks. The highest RPEs were reported at the end of MTFA task (17 ± 1) which corresponded to the word anchor ‘Very Hard’. The mean rating of thermal comfort was similar for all tasks, however thermal comfort was highest during the CD and MTFA (Table 6) which aligns with the highest mean T̅c measurements.

**[INSERT TABLE 6 HERE]**

**4.0** **Discussion**

The present study is the first to describe the physical performance and physiological responses of NARU personnel undertaking specialist role tasks. The scenario durations lasted between 1 minute (SWR) and two hours (CD, MTFA), where the heaviest load moved by a single person was 88 kg (a casualty during the SR scenario). Heavier loads were carried during the scenarios but, the load was shared between a team (e.g. 167 kg between 6 individuals, equating to an individual load carriage of 28 kg). The SWR, MGTS, MTFA, OGR and UIRUV elicited the highest cardiovascular strain of all the criterion tasks. After accounting for the scenario duration it appears that the MGTS was the most physically demanding task in relation to cardiovascular strain with 52 % of the total time spent in the ‘Hard’ zone and a further 5 % spent in the ‘Very Hard’ zone [13] . Core body temperature increased during all criterion tasks but was not a limiting factor for performance as all participants maintained a T̅c below 39.5°C. Despite various levels of PPE, some fully encapsulating, T̅sk was moderate throughout the tasks, with higher levels seen mainly in tasks that were prolonged (MTFA, SDT, SR).

The results of the present study can be used to develop a new PCA for NARU personnel which reflect the current job tasks that they are required to perform, and inform evidenced-based interventions to improve physical performance of their roles. This can be achieved by using the information in the present study to produce either single person simulations of the job tasks or informing the use of gym-based predictor tests to measure the components of fitness required to safely and effectively perform the job tasks. Single person simulations could include lifting and carrying items of equipment which replicate the mass of objects, distance, speed and type of movement and postures adopted when completing the job tasks. These simulations, typically closely replicate the job tasks, measure multiple components of fitness in a single test and are resource intensive. Gym-based predictor tests are less resource intensive and often easier to conduct than simulations but, do not directly replicate the job and typically only measure a single component of fitness in each test [4]. The decision of whether to adopt simulations, gym-based predictor tests or a hybrid approach should be guided by the organisational requirement and resources and information obtained during the research process to develop these tests. Other emergency service organisations such as the fire and rescue service and police forces use different combinations of task simulations and gym-based predictor tests to evaluate their personnel’s role-related fitness [1, 18-21].

The measurements of the mass of equipment, cardiovascular strain, distance, duration and speed of movement and postures observed during the 11 criterion tasks through the actions of walking, running, lifting, carrying and dragging demonstrated that safe and effective completion of each task required five components of fitness; muscular strength, muscular endurance, aerobic endurance, anaerobic endurance and mobility . Although the proportions of each component of fitness could not be quantified, aerobic and anaerobic endurance were particularly important for the MTFA, MGTS and SWR tasks due to the combination of sustained and short bursts of intermittent high-intensity activity. The criterion tasks requiring greatest muscular strength were the AGR (HART), CD (CBRN) and MTFA (MTFA) due to the relatively high mass of the items lifted and dragged (predominantly the casualties). The tasks requiring greater mobility were MTFA and the SR (HART) due to the range of postures that participants adopted, e.g. crawling and kneeling.

Cardiovascular strain was predominantly categorised as ‘moderate’ using Howley’s classifications of exercise intensity [10] across all 11 criterion tasks, with the exception of RBIB, AGR and SR which were all classified as ‘light’. The tasks which presented greater cardiovascular strain were the SWR, MGTS, and MTFA, where participants spent over 40 % of the scenario in the ‘Hard’ zone (77 to 93 %HRmax) with the remainder of the time predominantly spent in the ‘moderate’ zone (64 to 76 %HRmax). These data were somewhat supported by the RPE which corresponded to ‘Somewhat Hard’ for the SWR, and to ‘Very Hard’ for the MTFA Scenario. Although, from a cardiovascular perspective SWR, MGTS and MTFA appear challenging, it is unlikely that the high heart rates needed to be sustained for prolonged periods, for example, the SWR task was only ~70 s in duration. Where tasks were more prolonged, it is plausible that the higher heart rates were interspersed throughout the task, for example, during the MTFA task, there were periods of walking, running and sprinting.

A rise in T̅c and T̅sk was observed in response to all of the tasks completed where these measurements were recorded. The most thermally challenging criterion tasks were MTFA, CD, SR and OGR, respectively. It is recognized that the thermal strain experienced by personnel was a function of the task requirements (frequency, intensity, and duration), environmental conditions (12 to 17 °C, 43 to 93 %RH), micro-environment of PPE (24 to 28 °C) and physical fitness (e.g. aerobic fitness, body size and composition). The MTFA task produced the equal highest mean T̅c of 38.1 °C, the highest mean maximum T̅c of 38.7 °C, and the highest individual peak T̅c of 39.2 °C. In combination with the highest sweat loss rate (2.2 L), it would suggest that this task was the most thermally challenging. However, the rate of rise in Tc was moderate (1.3 °C·h-1) when compared with OR (2.0° C·h-1). Given the strong association between heat tolerance and aerobic fitness demonstrated in previous research [22, 23], it is important to consider the level of aerobic fitness required to both complete the job tasks and potentially protect individuals from heat stress.

Across the 11 tasks, prior to commencement, 77 % of participants were classified as ‘hydrated’ and 20 % ‘borderline dehydrated’ and 3 % ‘dehydrated’ based on the American College of Sports Medicine Guidelines for Exercise and Fluid Replacement [9]. Fluid intake was greater than estimated fluid loss during all criterion tasks except for the AGR and ORR, where estimated sweat loss slightly exceeded fluid intake. None of the participants in any of the tasks exceeded 2 % body mass loss when fluid intake was accounted for, indicating that participants generally started the tasks in a hydrated state, which was maintained throughout, limiting any negative effects on performance, decreased work or cognitive impairment which is consistently associated with increased thermal strain [6]. However, levels of dehydration <1 % of body mass have been reported to reduce tolerable limits in individuals wearing PPE [24], therefore it is paramount that adequate hydration is ensured where possible to reduce the risk of heat illness during tasks that require additional PPE to be worn such as CD and MGTS.

In conclusion, each scenario identified in the Phase 1 workshop proved to be viable as a physically demanding criterion task for NARU roles, where five components of fitness were required for successful task performance including elements of aerobic endurance, anaerobic endurance, muscular strength, muscular endurance and mobility. However, several tasks were underpinned by skill as opposed to fitness e.g. swimming and operating in water, operating at height and operating in enclosed spaces. Where there is a significant skill element to successful task completion, individual task simulations are often required in a PES to best measure performance rather than predictor tests. Given the variance in each of the tasks performed by NARU personnel, it would be reasonable to suggest that there is a requirement for bespoke Physical Competency Standards (PCS) for each of the three NARU roles (HART, CBRN and MTFA). Therefore, future work will build upon the data presented here to further develop PCS for NARU personnel.

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Table 1 - Descriptive characteristics of Participants participating in NARU related criterion tasks Data are presented as mean ± SD. Where MSFT is Multi-stage Fitness Test. \* Only 28 participants competed the 10 m Sprint, 40 m Sprint and MSFT.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Criterion Task | SWR and RBIB | SDT and CD | MGTS | MTFA | OGR, UIRUV, AGR, ORR and SR | All |
| Number (male/female) | 11 (9/2) | 8 (8/0) | 6 (6/0)\* | 6 (5/1) | 4 (2/2) | 34 (29/5) |
| Body Mass (kg) | 86.1 ± 16.6 | 89.7 ± 15.8 | 79.6 ± 9.0 | 79.5 ± 12.2 | 80.6 ± 15.8 | 84.2 ± 14.4 |
| Stature (m) | 1.73 ± 0.09 | 1.79 ± 0.06 | 1.80 ± 0.05 | 1.81 ± 0.09 | 1.72 ± 0.08 | 1.77 ± 0.08 |
| Body Mass Index (kg·m-2) | 28.5 ± 4.4 | 27.8 ± 3.6 | 24.6 ± 2.9 | 24.2 ± 2.9 | 27.2 ± 3.1 | 26.9 ± 3.9 |
| Grip Strength (kg) | 45.5 ± 9.0 | 48.4 ± 6.5 | 47.2 ± 9.4 | 54.7 ± 10.2 | 51.1 ± 11.4 | 49.1 ± 10.2 |
| Upright Pull (Kgf) | 159.6 ± 34.5 | 159.6 ± 23.2 | 164.2 ± 29.5 | 199.7 ± 52.1 | 168.8 ± 36.7 | 168.5 ± 36.5 |
| Vertical Jump (m) | 0.27 ± 0.04 | 0.25 ± 0.03 | 0.28 ± 0.04 | 0.37 ± 0.04 | 0.28 ± 0.05 | 0.29 ± 0.06 |
| 10m Sprint (s)\* | 2.11 ± 0.16 | 2.30 ± 0.29 | 2.04 ± 0.08 | 1.90 ± 0.16 | 1.85 ± 0.35 | 2.07 ± 0.26 |
| 40m Sprint (s)\* | 6.80 ± 0.69 | 6.52 ± 0.32 | 6.23 ± 0.32 | 5.55 ± 0.11 | 6.16 ± 0.83 | 6.35 ± 0.67 |
| MSFT Level\* | 7:1 ± 2:6 | 6.4 ± 1.6 | 7.5 ± 1.3 | 9.8 ± 0.6 | 8.7 ± 2.3 | 7:8 ± 2:2 |
| Estimated VO2 max (L·min-1) | 3.00 ± 0.90 | 3.14 ± 0.51 | 2.92 ± 0.13 | 3.70 ± 0.62 | 3.40 ± 0.79 | 3.23 ± 0.68 |

\*One of the participants completing Set Up Decontamination Tent and Clinical Decontamination also completed the Movement in GTS criterion task, therefore the data for this individual is included in both columns. A total of 34 participants is correct.

Table 2 - Summary of each scenario. Data are presented as mean ± standard deviation.

|  | SWR | RBIB | SDT | CD | MGTS | MTFA | OGR | UIRUV | AGR | ORR | SR |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| NARU Capability | HART | HART | CBRN | CBRN | CBRN | HART / MTFA | HART | HART | HART | HART | HART |
| Task Duration (mins) | 1 | 1 | 32 | 120 | 109 | 120 | 40 | 17 | 104 | 31 | 120 |
| Mean PPE Mass (kg) | 8.6  ± 1.0 | 8.6  ± 1.0 | 4.2  ± 0.5 | 12.0  ± 0.3 | 36.7  ± 1.3 | 19.1  ± 1.0 | 8.0  ± 0.3 | 8.0  ± 0.3 | 13.9  ± 1.4 | 6.8  ± 0.3 | 7.6  ± 0.3 |
| Environmental Temperature (°C) | 14.3  ± 0.6 | 14.5  ± 0.7 | 16.8  ± 0.5 | 16.8  ± 0.4 | 14.7  ± 1.1 | 16.5  ± 0.8 | 13.7  ± 1.2 | 14.0  ± 1.4 | 15.8  ± 0.4 | 12.0  ± 0.1 | 13.2  ± 0.8 |
| Relative Humidity (%) | 93.7  ± 0.6 | 90.5  ± 3.5 | 44.3  ± 4.5 | 45.6  ± 7.1 | 81.3  ± 8.4 | 55.5  ± 5.9 | 67.3  ± 11.2 | 62.5  ± 10.6 | 42.9  ± 7.3 | 58  ± 5.7 | 46.7  ± 7.0 |
| PPE Temperature (°C) | \* | \* | 24  ± 5 | 28  ± 4 | 24  ± 1 | \* | \* | \* | \* | 24  ± 2 | 24  ± 1 |

\*Data not available for this scenario.

Table 3 – Summary of loads carried during criterion tasks which required manual handling including equipment, stretchers and casualties.

|  | SDT | CD | MGTS | MTFA | OGR | UIRUV | AGR | ORR | SR |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Max. Lift – 1 Person (kg) | 21 |  | 7 |  |  | 23 |  |  |  |
| Max. Lift – Team Persons (kg/#) | 45/2  110/4  167/6 | 88/3 | 88/2 |  | 88/4 | 33/2 | 88/4 | 88/4  88/6 | 89/2 |
| Max. Carry – 1 Person (kg) | 21 |  |  |  | 13 | 23 |  | 12 |  |
| Max. Carry – Team (kg/#) | 45/2  95/4  110/4  167/6 |  |  |  | 16/2  88/4 | 33/2 | 88/4 | 88/4 | 89/2 |
| Max. Drag – 1 Person (kg) |  |  |  | 83 |  |  | 75 |  | 88 |
| Max. Drag – Team (kg/#) |  |  | 88/2 | 89/2 |  |  |  |  |  |

Table 4 – Heart rate responses during each of the criterion tasks. Data are presented as mean ± standard deviation.

|  | SWR | RBIB | SDT | CD | MGTS | MTFA | OGR | UIRUV | AGR | ORR | SR |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mean Heart Rate (b·min-1) | 135  ± 19 | 107  ± 21 | 127  ± 20 | 118  ± 21 | 138  ± 24 | 143  ± 22 | 133  ± 24 | 141  ± 20 | 122  ± 26 | 144  ± 22 | 125  ± 20 |
| Mean %HRmax | 76  ± 10 | 61  ± 14 | 70  ± 11 | 65  ± 11 | 75  ± 14 | 73  ± 11 | 67  ± 11 | 71  ± 9 | 62  ± 12 | 57  ± 10 | 65  ± 9 |
| Peak %HRmax | 80  ± 11 | 66  ± 15 | 85  ± 8 | 90  ± 9 | 92  ± 7 | 92  ± 2 | 88  ± 7 | 77  ± 10 | 83  ± 7 | 69  ± 9 | 82  ± 5 |
| Very Light <50 %HRmax (%time) | 0.0 | 27.9 | 3.1 | 8.6 | 7.2 | 1.9 | 3.3 | 0.6 | 16.5 | 25.3 | 5.3 |
| Light 50-63 %HRmax (%time) | 11.1 | 18.1 | 21.4 | 35.9 | 12.9 | 15.2 | 35.0 | 17.9 | 40.1 | 45.3 | 36.0 |
| Moderate 64-76 %HRmax (%time) | 38.2 | 38.8 | 44.6 | 38.1 | 22.9 | 40.5 | 40.8 | 43.7 | 28.3 | 26.8 | 43.3 |
| Hard 77-93 %HRmax (%time) | 45.4 | 13.9 | 30.8 | 16.2 | 52.4 | 41.0 | 19.6 | 37.8 | 15.2 | 2.6 | 15.4 |
| Very Hard >94-99 %HRmax (%time) | 5.2 | 1.2 | 0.0 | 1.0 | 4.6 | 0.3 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Maximal 100 %HRmax (%time) | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table 5 – Core, skin and body temperature responses during each scenario. Data are presented as mean ± standard deviation.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | SWR | RBIB | SDT | CD | MGTS | MTFA | OGR | UIRUV | AGR | ORR | SR |
| Mean c (°C) | 37.9 ± 0.3 | 38.0 ± 0.3 | 37.9 ± 0.3 | 38.0 ± 0.2 | 37.7 ± 0.4 | 38.1 ± 0.5 | 38.0 ± 0.3 | 38.1 ± 0.3 | 37.9 ± 0.2 | 37.7 ± 0.2 | 38.0 ± 0.1 |
| Peak c (°C) | 37.9 ± 0.3 | 38.1 ± 0.3 | 38.0 ± 0.2 | 38.2 ± 0.2 | 38.2 ± 0.2 | 38.6 ± 0.5 | 38.3 ± 0.2 | 38.1 ± 0.3 | 38.0 ± 0.1 | 37.8 ± 0.1 | 38.4 ± 0.1 |
| Rate of Rise Tc (°C·h-1) | \* | \* | 1.1 ± 0.3 | 0.6 ± 0.5 | 0.7 ± 0.4 | 1.3 ± 0.3 | 2.0 ± 0.4 | 1.3 ± 0.4 | 0.5 ± 0.1 | 0.7 ± 0.4 | 0.6 ± 0.3 |
| Mean sk (°C) | 32.0 ± 1.2 | 30.1 ± 1.5 | 32.1 ± 1.7 | 33.0 ± 1.5 | 32.2 ± 1.4 | 33.1 ± 2.0 | 31.8 ± 0.7 | 31.3 ± 1.0 | 31.7 ± 0.6 | 32.5 ± 1.0 | 33.7 ± 0.8 |
| Peak sk (°C) | 33.2 ± 1.2 | 30.7 ± 1.4 | 35.6 ± 2.8 | 34.7 ± 1.1 | 34.6 ± 2.1 | 37.2 ± 4.0 | 32.9 ± 1.1 | 32.2 ± 1.2 | 33.1 ± 0.6 | 33.5 ± 0.8 | 35.4 ± 0.5 |
| Mean b (°C) | 36.7 ± 0.3 | 36.6 ± 0.5 | 36.6 ± 0.3 | 36.8 ± 0.3 | 36.3 ± 1.0 | 37.1 ± 0.9 | 36.8 ± 3.9 | 36.8 ± 0.2 | 36.6 ± 0.2 | 36.7 ± 0.3 | 37.1 ± 0.3 |

\*Data not available, scenario duration too short.

Table 6 – Rating of Perceived Exertion and Thermal Comfort ratings for each scenario. Data are presented as mean ± standard deviation.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | SWR | RBIB | SDT | CD | MGTS | MTFA | OGR | UIRUV | AGR | ORR | SR |
| RPE Pre (rest) | 6 ± 0 | 6 ± 1 | 7 ± 1 | 6 ± 0 | 6 ± 0 | 8 ± 1 | 6 ± 1 | 6 ± 0 | 6 ± 0 | 6 ± 0 | 6 ± 0 |
| RPE Post | 13 ± 2 | 11 ± 2 | 13 ± 3 | 13 ± 4 | 15 ± 3 | 17 ± 1 | 9 ± 2 | 8 ± 2 | 8 ± 3 | 11 ± 2 | 12 ± 4 |
| Thermal Comfort Pre (rest) | 6 ± 1 | 5 ± 0 | 5 ± 0 | 5 ± 0 | 5 ± 0 | 6 ± 0 | 5 ± 1 | 5 ± 0 | 5 ± 0 | 5 ± 0 | 5 ± 1 |
| Thermal Comfort Post | 6 ± 0 | 5 ± 1 | 7 ± 1 | 7 ± 1 | 7 ± 1 | 7 ± 1 | 6 ± 1 | 6 ± 1 | 6 ± 1 | 7 ± 1 | 7 ± 1 |

**Figures**

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**Figure 1.** Different configurations of PPE. From left to right; Incident Ground Kit (IGK), Safe Working at Height (SWaH), Extended Duration Breathing Apparatus (EDBA), Gas Tight Suits (GTS), Protective Powered Respiratory Suit (PPRS) , Civil Responder (CR1; not used during any trials), Swift Water Rescue (SWR), and Marauding Terrorist Fire Arms (MTFA).



Figure 2 - Hydration status of the participants before each task, where open circles represent individual participants and the closed triangles represent the group mean value for the given task.

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Figure 3 – The estimated sweat loss and measured fluid intake during each task. Note; it was not possible to measure estimated sweat loss and fluid intake during the SWR and RBIB tasks.