Generic task-related occupational requirements for Royal Naval personnel

J. L. J. Bilzon*, E. G. Scarpello*, E. Bilzon* and A. J. Allsopp*

*Environmental Medicine Unit, Institute of Naval Medicine, Alverstoke, Gosport, Hampshire PO12 2DL; and †Occupational Medicine Cell, Strategy Branch, Headquarters Army Training and Recruiting Agency, Trenchard Lines, Upavon, Pewsey, Wiltshire SN9 6BE, UK

Physical tests and selection criteria have historically been used by many military organizations. However, the standards associated with them have come under increasing scrutiny in recent years. This paper describes a series of experiments that were conducted to establish task-related occupational tests and standards (TBTs) for Royal Naval (RN) personnel. A total of 172 (106 male and 66 female) RN personnel volunteered for these experiments, which were designed to: identify the anthropometric requirements for operating various safety hatches and doors on board a RN Frigate (TBT1); quantify the metabolic demands of shipboard firefighting tasks and establish an aerobic fitness standard (TBT2); and identify a battery of tests to predict performance of shipboard casualty-carrying tasks (TBT3). Whilst all subjects completed the criterion tasks during TBT1, performance of the bulkhead door (BD) escape task was related to height (r = 0.50–0.62, P < 0.05) and vertical reach (r = 0.42–0.54, P < 0.05), with shorter subjects struggling to perform the task. During TBT2, the mean metabolic demand of representative firefighting tasks was 38 ml/min/kg, which must be sustained for 20–30 min. Finally, a battery of tests incorporating measures of lean body mass, fat mass, standing broad jump, 20 m sprint, press-ups, sit-ups and grip strength produced a high correlation (r = 0.89, P < 0.01) with casualty-carrying task performance. From the results of these experiments, it is recommended that RN personnel perform the BD simulation task at the recruitment stage (TBT1), to prove that they possess the anthropometric characteristics commensurate with survival at sea. Secondly, personnel should be frequently screened to ascertain whether they have the maximal aerobic power (41 ml/min/kg) commensurate with shipboard firefighting for 20–30 min (TBT2). Finally, they should perform the battery of proposed tests and score at least 34 points, in order to establish whether they have the anaerobic and strength capacity commensurate with shipboard casualty-carrying tasks (TBT3).

Key words: Fitness tests; occupational fitness; physical fitness; physical standards.

Received 17 June 2002; accepted 30 September 2002

Introduction

Physical tests and standards have historically been used by many organizations to assess the capability of personnel for demanding occupations. This is particularly true in military organizations, where it is widely acknowledged that individual physical capability may directly influence the combat effectiveness of the organization. Whilst the physical tests traditionally used by military organizations had some occupational relevance, the standards associated with them were in the main arbitrary, often differing for men and women of different ages. Such standards appear to have served the military well in times where employees were plentiful and the population more active. However, recent manpower shortfalls have highlighted

Correspondence to: Mr James L. J. Bilzon, Occupational Medicine Cell, Strategy Branch, Headquarters Army Training and Recruiting Agency, Trenchard Lines, Upavon, Pewsey, Wiltshire SN9 6BE, UK. Tel: +44 1980 618211; fax: +44 1980 615718; e-mail: strathqatra@gtnet.gov.uk

© British Crown Copyright 2002 MOD. Published with permission of Her Britannic Majesty’s Stationery Office.
the need to ensure that personnel possess the physical attributes to perform their operational roles. Arbitrary physical standards may unnecessarily discriminate against capable personnel and, more importantly, may lead the organization to predispose individuals to tasks that they are not physically capable of performing. As such practices may result in injury to individuals and litigation against the organization, the use of arbitrary standards has been the subject of increasing scrutiny.

In determining appropriate physical tests and standards, objective criteria must be used in order to ensure that the ‘occupational requirements’ are fair, valid and justifiable. Furthermore, the criteria should reflect the demands of the job, and refer only to its critical or essential components [1]. This approach has much wider implications, because military training regimens should be specifically tailored to allow individuals to progress towards achieving such occupational requirements, and thus proving their ability to perform the job. Without objective and clearly defined job requirements, this is virtually impossible to achieve.

As a first step in identifying relevant occupational requirements (i.e. tests and standards) for the Royal Navy (RN), traditional physical test criteria were reviewed and a number of task analyses of critical job components were conducted [2–4]. These critical and generic components of the job were identified as shipboard firefighting, casualty carrying, and escaping through various hatches and safety doors on board a typical RN vessel. Failure to perform such tasks to a minimum acceptable standard could put the individual, their colleagues, and ultimately the vessel and the whole ship’s complement at severe risk in an operational scenario.

The ability to escape through a bulkhead door on a RN vessel requires an individual to open and close the top clip, which is 204 cm from the ground, and clearly related to individual anthropometric criteria. However, performance of this task does not appear to be related to height per se, but to functional overhead reach [5]. It is also well established that prolonged firefighting exposures demand a relatively high level of aerobic fitness [6,7], and shipboard firefighting appears to be no exception [8]. Furthermore, casualty carrying requires a certain level of muscular strength and endurance for the safe evacuation of a casualty during an emergency [9]. This paper describes a series of experiments that were performed to develop generic task-related occupational requirements for RN personnel, otherwise known as task-based tests (TBTs). The task simulations for these experiments were endorsed by naval ‘subject matter experts’. The aim of the experiments was to develop a battery of tests and standards to be used to assess the ability of RN personnel to perform generic occupational tasks commensurate with survival at sea.

Methods

Three experiments were conducted between 1998 and 2001, which aimed to identify: an anthropometric test to simulate escaping through a bulkhead door on a RN vessel (TBT1); an aerobic fitness standard commensurate with shipboard firefighting tasks (TBT2); and a battery of strength and anaerobic fitness tests commensurate with shipboard casualty carrying (TBT3). All volunteers gave their informed written consent to act as subjects for these experiments, which were conducted following approval from the Ministry of Defence (Navy) Personnel Research Ethics Committee.

TBT1 (anthropometry)

Thirty healthy RN volunteers (20 male and 10 female) acted as subjects for this experiment. Each subject’s height and body mass were determined, and the percentage body fat was estimated from skinfold thickness at four sites [10]. Grip strength was measured in the dominant hand, and various other body circumferences were measured as described previously [11]. The mean (± SD) physical characteristics of the male and female subjects are given in Table 1.

All of the experiments were performed on board a RN Type 23 Frigate. Each subject was randomly assigned to complete three tasks as quickly as possible. The tasks were a vertical climb through an escape hatch (EH; Figure 1); open and secure a kidney hatch (KH) from above and below; and open and secure a bulkhead door (BD) from both sides. Each subject completed each task three times in different clothing ensembles: a firefighting suit and breathing apparatus (FF); a nuclear, biological and chemical defence ensemble (NBCD); and action working dress with anti-flash hood (AWD). Performance times were recorded (seconds) and the results of an observational analysis were used to determine which factors influenced performance times during each task. Individual performance times were subsequently correlated with anthropometric measurements.

TBT2 (aerobic fitness)

Forty-nine healthy RN volunteers (34 male and 15 female) acted as subjects for this experiment and each underwent a full medical examination (including a 12-lead ECG). Each subject’s height and body mass were determined and percentage body fat was estimated from skinfold thickness at four sites [10]. Lean body mass (LBM) and fat mass (FM) were estimated from these data. Grip strength was measured in the dominant hand and each subject completed a continuous incremental treadmill run to fatigue [12], for the direct assessment of maximal oxygen uptake \(V_O^{max}\). The mean (± SD)
The main experiments were performed on a ship simulation unit at the RN Fire Training School, HMS Phoenix. Each subject was randomly assigned to complete five 4 min simulated shipboard firefighting tasks, with at least 60 min recovery between each. Tasks were performed at a fixed rate commensurate with the minimum acceptable performance during operational firefighting. The ‘steady-state’ metabolic demand of each task was assessed via a portable indirect calorimetry system (Cortex Metamax, Leipzig, Germany), and defined as the mean $V_{O_2}$ during the final minute. The tasks were liquid foam drum carrying (DC), extinguisher carrying (EC), boundary cooling (BC), hose running (HR; Figure 2) and ladder climbing (LC). The aerobic and anaerobic demands of each task were also calculated. These methods are described in greater detail elsewhere [8].

Statistical comparison of the metabolic demand of the tasks was made using analysis of variance techniques with significant differences identified using Tukey’s $T$-method of multiple comparisons.

**TBT3 (strength and anaerobic fitness)**

Ninety-three healthy RN volunteers (52 male and 41 female) acted as subjects for this experiment and each underwent a full medical examination (including a 12-lead ECG) by an independent medical officer. The height and body mass of each subject were determined and the percentage body fat estimated using four-point bioelectrical impedance (Bodystat 1500, Douglas, Isle of Man). LBM and FM were estimated from these data. The mean (± SD) physical characteristics of the male and female subjects are given in Table 1.

Ninety-three healthy RN volunteers (52 male and 41 female) acted as subjects for this experiment and each underwent a full medical examination (including a 12-lead ECG) by an independent medical officer. The height and body mass of each subject were determined and the percentage body fat estimated using four-point bioelectrical impedance (Bodystat 1500, Douglas, Isle of Man). LBM and FM were estimated from these data. The mean (± SD) physical characteristics of the male and female subjects are given in Table 1.

Figure 1. Subject performing the escape hatch (EH) task in the full firefighting (FF) clothing ensemble during the TBT1 experiments.

<table>
<thead>
<tr>
<th></th>
<th>TBT1</th>
<th></th>
<th>TBT2</th>
<th></th>
<th>TBT3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n = 20)</td>
<td></td>
<td>Female (n = 10)</td>
<td></td>
<td>Female (n = 15)</td>
<td></td>
<td>Female (n = 41)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>29 ± 7</td>
<td>27 ± 7</td>
<td>26 ± 7</td>
<td>26 ± 6</td>
<td>28 ± 5</td>
<td>29 ± 6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177 ± 79</td>
<td>163 ± 53</td>
<td>178 ± 7</td>
<td>166 ± 5</td>
<td>178 ± 6</td>
<td>165 ± 6</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>86 ± 13</td>
<td>69 ± 11</td>
<td>77 ± 11</td>
<td>65 ± 12</td>
<td>81 ± 9</td>
<td>67 ± 12</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>22 ± 5</td>
<td>30 ± 5</td>
<td>17 ± 4</td>
<td>26 ± 5</td>
<td>15 ± 5</td>
<td>27 ± 7</td>
</tr>
<tr>
<td>$V_{O_2,max}$ (ml/min/kg)</td>
<td>53 ± 5</td>
<td>43 ± 8</td>
<td>53 ± 8</td>
<td>41 ± 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Group mean ± SD physical characteristics of the male and female subjects from experiments TBT1, TBT2 and TBT3.
were used to simulate carrying a casualty freely or in a stretcher. To simulate the free carry (FC), a half manikin was used to simulate the head-end of a 50th percentile RN casualty (37 kg). To simulate the stretcher carry (SC), a set of dumb-bells at fixed width were used to simulate the head-end of a 50th percentile RN casualty plus the mass of the stretcher (41 kg).

In addition to the carry simulation tasks, each subject was required to perform a series of field tests of physical fitness. The two field tests of maximal aerobic power were: a timed 2.4 km run, with maximal aerobic power ($V_{O2,max}$) being estimated from the performance time recorded, using previously described methods [13]; and the Multi-Stage Fitness Test (MSFT) [14]. The three field tests of muscular strength and power were: grip strength; upright pull; and standing broad jump. Finally, the four field tests of muscular endurance were: maximum number of pull-ups in 1 min; maximum number of press-ups in 1 min; maximum number of sit-ups in 1 min; and maximum number of 20 m shuttle sprints in 2 min.

In order to normalize the data distribution, carry simulation times were converted into a work rate (m/s) and multiplied by 100. The relationship between the criterion casualty carrying rate and physical performance measures was assessed using the Pearson product-moment correlation and multiple linear regression analysis. All data are presented as mean ± SD and were accepted as being statistically significant if $P < 0.05$.

Results

TBT1

All 30 subjects completed all of the tasks satisfactorily and within the times given for minimum acceptable performance. The group mean (± SD) performance times for each task in the different clothing ensembles are given in Table 2. Whilst all of the tasks were performed satisfactorily, it is evident from these data that the FF ensemble limited performance on the EH and KH tasks, but not the BD task. The BD task appeared to be limited by functional reach. Not surprisingly, therefore, performance time during the BD task was strongly associated with the anthropometric measurements of stature ($r = −0.50$ to $−0.62$, $P < 0.05$) and reach ($r = −0.42$ to $−0.54$, $P < 0.05$). The top latch of the bulkhead door was 204 cm from the ground and the shortest overhead reach of a female subject was 199.5 cm (barefoot). Whilst this subject was able to complete the task in shoes, it was completed with greater difficulty than the others, and the subject had to go on to tiptoes to push the latch open and into the retaining clip above.

TBT2

Almost all of the subjects (99.6%) reported that they had received adequate instruction, allowing them to complete the firefighting tasks systematically and without hesitation. Furthermore, a high percentage of respondents stated that the firefighting task simulations were an adequate reflection of the tasks (96.8%) and work rates (78.2%) that they would perform in a training or operational scenario.

With the exception of the DC task, where only 4 of the 15 female subjects were able to perform the task at the prescribed work rate, all subjects were able to complete the five firefighting tasks successfully. The task eliciting the highest steady-state metabolic demand was the DC.
task \((P < 0.01)\), which was equivalent to 82\% \(V_O^{\text{max}}\) (Table 3). The BC task elicited the lowest \((P < 0.01)\) steady-state metabolic demand in all subjects, and was equivalent to 47\% \(V_O^{\text{max}}\). There were no differences in metabolic demand between the EC, HR and LC tasks \((< 78\% V_O^{\text{max}})\). Further analysis revealed that the four female subjects who were able to complete the DC task successfully had a group mean \(V_O^{\text{max}}\) of 54 ml/min/kg, which was greater than \((P < 0.01)\) the remaining females (39 ml/min/kg) and similar to the males (53 ml/min/kg). Furthermore, subjects with a \(V_O^{\text{max}}\) of >43 ml/min/kg were able to perform each task at a lower percentage of heart rate maximum \((P < 0.01)\) and with a greater proportion of energy being derived from aerobic metabolism \((P < 0.05)\).

TBT3

Of the 93 volunteers, 52 male and 37 female volunteers \((n = 89)\) completed all 11 components of the study. Of the 89 who completed the casualty-carrying tasks, five females failed to complete one or both of the tasks within the requisite time of 3 min. Of the four who failed to complete the tasks, one female subject sustained an acute muscular/ligamentous back strain during the simulated SC task and was unable to complete the study. Almost all of the subjects (98.8\%) reported having been given adequate instruction and practice to perform the task systematically and without hesitation. The majority also reported that they were an accurate or very accurate reflection of the FC (81\%) and SC (74\%) carry tasks performed onboard ship and/or in training.

The relationships between FC and SC carry task performance and the physical performance and anthropometric measures are given in Table 4. Many of the physical performance and anthropometric measures provided high correlation coefficients with FC and SC task performance. Of all the physical performance measures, the standing broad jump (SBJ) produced the strongest independent correlation with FC \((r = 0.84, P < 0.01)\) and SC \((r = 0.81, P < 0.01)\) task performance. Furthermore, the derived anthropometric variable of LBM to dead mass (fat mass + casualty mass; DM) ratio produced strong independent relationships with FC \((r = 0.87, P < 0.01)\) and SC \((r = 0.85, P < 0.01)\) task performance.

Using multiple linear regression techniques, the variables producing the strongest relationship with FC carry rate were: SBJ, LBM, DM, 20 m sprints, press-ups, sit-ups and grip strength \((r = 0.89, P < 0.01, \text{SEE} = 9)\). The following equation was used to predict FC casualty carrying rate, and the relationship between predicted and actual FC carry rates is given in Figure 4:

![Figure 3. Subject performing the stretcher carry (SC) simulation task during the TBT3 experiments.](image-url)
\[ TBT3 = -4.9 + (0.174 \times SBJ) + (0.864 \times LBM) - (0.611 \times DM) + (0.972 \times sprints) + (0.006 \times pressups) + (0.036 \times situps) - (0.02 \times gripstrength) \]

where \( SBJ \) is standing broad jump (cm), \( LBM \) is lean body mass (kg), \( DM \) is fat mass plus 37 kg average RN casualty mass (kg), \( sprints \) is the number of 20 m shuttle sprints in 2 min, \( pressups \) is the number of press-ups completed in 1 min, \( situps \) is the number of sit-ups completed in 1 min and \( gripstrength \) is grip strength (N).

**Table 4.** Correlation coefficients based on the linear relationship between free carry (FC) and stretcher carry (SC) task performance (m/s), and various physical performance measures and derived indices \((n = 89)\)

<table>
<thead>
<tr>
<th></th>
<th>FC</th>
<th>SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>0.40</td>
<td>0.42</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>-0.75</td>
<td>-0.73</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>0.76</td>
<td>0.76</td>
</tr>
<tr>
<td>LBM/DM ratio</td>
<td>0.87</td>
<td>0.85</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.64</td>
<td>0.65</td>
</tr>
<tr>
<td>SBJ (cm)</td>
<td>0.84</td>
<td>0.81</td>
</tr>
<tr>
<td>Grip strength (N)</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>Upright pull (N)</td>
<td>0.77</td>
<td>0.79</td>
</tr>
<tr>
<td>MSFT (( V_O{\text{2max}} ))</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>2.4 km run (( V_O{\text{2max}} ))</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>20 m shuttle sprints (n)</td>
<td>0.60</td>
<td>0.56</td>
</tr>
<tr>
<td>Sit-ups (n)</td>
<td>0.56</td>
<td>0.58</td>
</tr>
<tr>
<td>Press-ups (n)</td>
<td>0.69</td>
<td>0.70</td>
</tr>
<tr>
<td>Pull-ups (n)</td>
<td>0.72</td>
<td>0.72</td>
</tr>
</tbody>
</table>

All correlation coefficients showed a significant relationship with carry task performance \((P < 0.01)\).

**Discussion**

The results of these experiments demonstrate that, where it would be dangerous, expensive or impractical to directly assess the occupational fitness of RN personnel, their effectiveness may be determined by the use of surrogate tests and task simulations. Taken together as true occupational requirements, the battery of physical tests and standards proposed would ensure that, in the main, successful employees would be capable of critical, generic sea survival duties. Whilst the use of such tests and standards would indirectly discriminate against a greater percentage of the female population, it should be remembered that the same people would not be capable of performing the ‘true’ occupational tasks, placing them at graver risk of injury. As such, this approach may be more desirable than to put them at risk by exposing them to highly dangerous operational tasks that they are not physically capable of performing. Moreover, with the exception of a proposed reach test, there are very few males or females who could not achieve the required standards for TBT2 [15] and TBT3 [16] with appropriate physical training.

Whilst all of the subjects recruited for the experiment into the anthropometric requirements for operating safety hatches (TBT1) were able to perform all of the tasks within the required time, it was apparent that shorter subjects with less reach struggled to perform the escape through a bulkhead door task. However, the ability to perform this task is likely to depend on several variables (e.g. height, arm length, flexibility, grip strength), and it is therefore impossible to suggest a height requirement at which employees will fail the task. It is therefore proposed
that a direct simulation of the ability to reach and operate the top clip of the bulkhead door be used at the recruitment stage, to directly assess the ability to operate safely on board an RN vessel (TBT1). TBT1 could be performed at the recruitment stage, in order that personnel with inadequate reach are not employed. From the results of the experiment into the metabolic demand of simulated shipboard firefighting tasks, it has also been possible to propose an aerobic fitness standard that is not substantially different from those proposed for civilian firefighting [17,18]. RN personnel are required to sustain a combination of the hose-running, ladder-climbing and boundary-cooling tasks whilst wearing full firefighting clothing and breathing apparatus. The mean metabolic demand of these three tasks was 32.8 ml/min/kg \( V_{O_2} \). Personnel must be able to sustain such levels of activity for 20–30 min, which is the estimated capacity of the current breathing apparatus. It is apparent from the literature that a firefighter wearing self-contained breathing apparatus is able to sustain a maximum work intensity equivalent to 80% \( V_{O_2,max} \) for a 20–30 min duration [19]. Therefore, it is recommended that all seagoing RN personnel attain a \( V_{O_2,max} \) of 41 ml/min/kg (TBT2).

This could be assessed by either the 2.4 km run [13] or MSFT [14], which are already in use within the RN. However, this aerobic fitness standard would ensure that seagoing personnel had a level of aerobic fitness commensurate with shipboard firefighting duties. This is important because failure within a firefighting scenario could endanger the individual, the firefighting team and ultimately the ship. Failure among less fit personnel is possible, given that we have demonstrated they would have to work more anaerobically during such tasks and fatigue would ensue more rapidly. As such, the aerobic fitness of personnel should be assessed regularly (e.g. annually) in order to ensure that such tasks can be performed satisfactorily.

The aim of the third experiment was to identify a battery of physical tests that would accurately predict performance of casualty-carrying tasks performed by seagoing RN personnel (TBT3). This general approach is supported by the fact that one of the subjects sustained an injury during the task simulations. The use of surrogate tests to predict performance is therefore more desirable than a true task simulation. Physiologically, the tests that produced the strong multivariate relationship with FC carry task performance (Figure 4) seem the most logical to use. Indeed, a high LBM relative to the DM being carried has previously been observed to influence load-carrying performance [20,21]. Together with measures of leg power for stair climbing, grip strength and whole-body muscular endurance, this battery of tests would appear highly relevant for such a high-intensity and short-duration carrying task. Indeed, the majority of these tests are already in use during RN training courses and performance scores could now be used to predict casualty-carrying performance. The minimum acceptable performance time for this casualty-carrying task was given as 3 min, which is equivalent to an actual FC carry rate of 26 in Figure 4. By inserting the results of the various tests into the regression equation from Figure 4, an individual score could be derived, and it is recommended that all RN personnel score >34 on the battery of surrogate tests (TBT3). Again, as body mass, composition, muscular strength and endurance may vary with age, this battery of tests would ideally be performed annually.

In conclusion, the battery of task simulations (TBT1) and surrogate tests (TBT2 and TBT3) proposed would ensure that seagoing RN personnel had the physical capacity commensurate with the performance of critical and generic sea survival duties. However, it should be noted that the standards proposed for TBT2 and TBT3 require validation on an independent sample, which should be the focus of further experimentation. With the exception of TBT1, which should be performed at the recruitment stage, personnel could be trained to achieve the standards given for TBT2 and TBT3. This would be a major step forward in terms of the operational capability of RN personnel, and RN training could also be specifically tailored toward achieving these occupational requirements and improving safety at sea. This may be particularly important, as the younger generation (available for recruitment) appear to be becoming increasingly inactive [22].

Acknowledgements

The authors are grateful to the RN personnel who volunteered as subjects for these experiments. Also, thanks are due to the RN Physical Training Branch for supporting these experiments and colleagues at the Institute of Naval Medicine for constructive comments on this manuscript. This work was sponsored by the Ministry of Defence (Navy).

References

6. O’Connell ER, Thomas PC, Cady LD. Energy costs of


