

The physiological demand of pulling a rescue sled across the mud and the impact experience has on this task.

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Abstract

BACKGROUND: To establish a Physical Employment Standard for tasks with high physical demands, it is important to determine the physiological requirements. One such task for the UK Coastguard is mud rescue.

OBJECTIVE: To quantify the physiological demand of pulling a rescue sled across estuary mud, and determine whether rescuer experience has an impact on the physiological demand of this task.

METHODS: Forty participants walked 150 m in 3 minutes across estuary mud. Following 3 minute rest, they walked 150 m pulling a rescue sled (61 kg) in pairs (based on experience).

RESULTS: Experienced rescuers had a total oxygen consumption approximately 24% lower than those inexperienced in the task. Relative oxygen consumption ($\dot{V}O_2$) was significantly ($p < 0.05$) greater in the non-experienced (mean [SD]; 42.90 [6.55] mL.kg⁻¹.min⁻¹) compared to the experienced group (32.85 [5.79] mL.kg⁻¹.min⁻¹) when controlled for pace. Required $\dot{V}O_2$ for various speeds were predicted based on non-experienced participants and assessed for agreement. LoA (95%) mean \pm difference was 0.0003 \pm 3.48 mL.kg⁻¹.min⁻¹, with a CV of 2.30 %.

CONCLUSIONS: For tasks that require a high relative $\dot{V}O_2$, such as mud rescue, the minimum level of fitness at entry should be based upon the metabolic demands measured on those who are inexperienced.

Key Words: Physical employment standards; Occupational tasks; Physiological demands of rescue.

1.0 Introduction

Determining the physiological cost of an occupational task is becoming more common in industries and the emergency services, where the physical demands of such tasks are high [1-5] It is important to determine the physiological demands of such tasks to ensure the safe and successful completion of the job, through the development of defensible physical employment standards (PES) [5]. The rationale for a task based fitness standard ensures that job selection is based on the ability to perform the job rather than age or sex [5]. This is increasingly important within an ageing work-force particularly to ensure that work related injuries, due to a lack of physical capability, are minimised. One such arduous task for UK Coastguard Rescue Officers (CROs) is mud rescue, which consists of travelling across estuary mud and then extracting and recovering trapped casualties. The Coastguard categorize the rescuers as *mud technicians*, their job is to work in pairs to traverse the mud pulling a rescue sled that is loaded with equipment (combined load of 61 kg) and then extract the casualty from the mud for subsequent recovery.

The measurement of oxygen consumption ($\dot{V}O_2$) is an accepted method for determining the aerobic metabolic demand of an activity. This method has been used to assess an individual's capability to perform a job or a simulation of a job [6-11]. Early

studies investigating workloads tended to report the demand of essential tasks in terms of energy expended ($\text{kcal}\cdot\text{min}^{-1}$) using indirect calorimetry [12]. This method fails to take into account the relative cost of work normalised for variations in body weight. The appropriate method of scaling of oxygen consumption data has received much attention, however these data are usually in resting or maximally exercising animals (including humans) [5]. It has been well established to normalise maximum oxygen uptake ($\dot{V}O_{2\text{max}}$) between different sized animals, $\dot{V}O_{2\text{max}}$ is scaled by mass in $\text{kg}^{0.67}$ [13]. Further research is needed to determine whether such an approach is relevant for the oxygen consumptions measured during occupational tasks performed at minimum acceptable rates whilst sometimes carrying a load [5]. It has been recommended that to establish the physiological demand of a task, it should be undertaken with representative clothing or equipment; thus normalisation might then be best achieved by expressing the oxygen demand in “unit per total mass” (body + clothing + equipment) [5].

The mean (SD) $\dot{V}O_2$ of military skiers pulling loaded sleds over snow at a fixed speed of $3.6 \text{ km}\cdot\text{h}^{-1}$ has been shown to be $19.5 (1.1) \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $24.8 (2.3) \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $27.0 (3.3) \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, when hauling loads of 24 kg, 56 kg and 80 kg, representing 30%, 70% and 100% of the participant’s body

mass respectively [14]. The $\dot{V}O_2$ of pulling a load of 10 kg at speeds of 3.7 km.h⁻¹ and 4.7 km.h⁻¹ on a treadmill was reported to be 23.7 (3.6) mL.kg⁻¹.min⁻¹ and 29.5 (3.8) mL.kg⁻¹.min⁻¹ respectively [15]. These differences highlight the impact that load, speed and terrain can have on the physiological demand of an essential task and the importance of ensuring that simulations of tasks are as representative as possible.

In addition, the cohort from whom the physiological data are collected should be genuinely representative of those with task experience [5]. Two approaches have been taken to define representative; the first is that the cross-sectional sample should be comprised of existing employees [16], whilst the second should be representative of the wider population of those that could apply for a job [5,17]. These two approaches will be different if job experience has an influence on the physiological demand of a task. A study examining the influence of experience on swim performance in the sea found experienced surf swimmers were significantly ($p < 0.05$) faster swimming 200 m in a surf sea than those with no experience. Thus concluding there was a significant and quantifiable experience factor in surf swimming [18]. Improvements in running economy have also been shown in those that spend more time performing the task [19], thus suggesting that experience would reduce the physiological demand required to

undertake a task. The measurement of the physiological demand of a task has a significant impact in on the development of a valid and legally defensible PES [5], thus the experience factor in tasks such as pulling a rescue sled across estuary mud, and the impact this has on physiological load, should be further investigated.

There are no studies to date that have directly compared the metabolic differences that may result from comparing experienced and non-experienced populations during physical demanding tasks, such as pulling a rescue sled across estuary mud. The purpose of this study was to directly measure the physiological cost of pulling a rescue sled across estuary mud, and secondly to assess if there were any differences based on the experience of the rescuers. It was hypothesised that those with experience in mud rescue would be more economical at performing the task than those with little-to-no experience, and would thus complete the task with less physiological cost.

2.0 Method

To standardise conditions and ensure specificity, a thorough task analysis of mud rescue was performed. The task analyses were conducted through: interviews with current members of the Coastguard Rescue Service; observations of CROs performing tasks; participation in tasks; reviewing operational

manuals; and discussions with subject matter experts (SMEs). The SME group comprised of the Technical Rescue Consultant, the Assistant Coastal Resource Manager, four experienced Sector Managers and six experienced CROs from across the country. The mean time served with the UK Coastguard was 11 years (minimum 2 years, maximum 22 years); they were considered to have the best knowledge of the methods, techniques and equipment used during rescues [17, 20].

The task analysis showed that there are three aspects to a mud rescue: Mud walk to a casualty pulling the rescue equipment on a rescue sled; Extracting the casualty from the mud; Recovery of casualty across the mud to dry land using a powered winch (or occasionally other assisted rescue e.g. boat, hovercraft, or helicopter). Of these three tasks it was shown that the mud walk to casualty pulling the rescue equipment on a rescue sled was the most aerobically demanding.¹⁷ The methods of best practice and minimum performance standards were determined and required two mud technicians to pull a rescue sled of 61 kg across estuary mud at a speed of 3 km.h⁻¹; whilst wearing dry suits and “Mudders” footwear (Ambarr Product Inc. USA; Figure 1).

INSERT FIGURE 1 HERE

The tests were conducted on mud flats in Portsmouth, Weston-Super-Mare and Clevedon (UK). Following ethical approval 40 male (n = 37) and female (n = 3) volunteer participants aged 18 to 60 years took part in the study. Fourteen participants were UK CROs; of these eight were the primary mud technicians for their area with an excess of 10 years' experience each in mud rescue, and were the primary responders for rescues in their sector during incidences. The remaining six CROs did not undertake mud rescues operationally, but undertaken a training day in the past year and were classified as non-experienced. Staff and students (n=26) of the University of Portsmouth with no experience of mud rescue were also classified as non-experienced.

All participants were asked to walk 150 m over mud in three minutes, requiring a speed of $3 \text{ km}\cdot\text{h}^{-1}$; this involved a 75 m walk with a turn, whilst wearing dry suits and "Mudders" footwear (Ambarr Product Inc. USA). The 3 minute walk served to accustom participants with little or no experience on the mud. Following the walk, and after a 3 minute rest, participants were asked to walk a further 150 m, whilst pulling a loaded rescue sled (61 kg) in pairs [17]. A whistle was sounded at the start of both walks. During the walks the whistle was blown once if participants were travelling too slowly, to encourage

them to go faster and twice if participants were travelling too fast, to indicate that they should slow down. If they could not maintain this pace they did the task at their fastest comfortable pace. Participants were paired with individuals of similar ability *i.e.* the experienced mud technicians were paired together. The metabolic demands of mud rescue were measured using a Metamax ambulatory gas analysis system (Cortex Biophysic GmbH, Germany).

2.1 Data Analyses

Metabolic data were reported relative to body mass ($\text{mL.kg}^{-1}.\text{min}^{-1}$) and as total oxygen consumed (L), in order to assess the data without the influence of speed and body mass.

Statistical analyses were performed using IBM SPSS 21 (IBM SPSS Statistics, USA). Data were checked for normality using Skewness and Kurtosis in the range of -2 to 2, if data were found to be normally distributed differences were assessed using independent *t*-test and Cohens *d* (*d*). Non-parametric data were assessed using a Mann-Whitney U and effect size calculated using non-parametric independent samples ($r = z/[\sqrt{n}]$) [21]. It was not possible for all participants to keep to the required pace of 3 km.h^{-1} , thus R^2 was used to determine how much of the variance in relative $\dot{V}O_2$ was explained by the time (converted to speed) taken to complete the task, as this was

the only independent variable measured. Simple regression was used to produce a prediction equation that could determine the physiological demand of mud rescue at various speeds. Standardised residuals were calculated and considered acceptable in the range of -2 to 2. Residuals were plotted against speed to ensure an even distribution. Agreement was assessed by comparing the measured $\dot{V}O_2$ during the rescue sled scenario and the predicted $\dot{V}O_2$ of the regression equation. Coefficient of variation (CV), confidence intervals (CI) and limits of agreement (LoA) were used in the assessment of agreement [22, 23].

3.0 Results

Participant demographics are presented in Table 1, no significant differences were found between the mass ($t_{(38)} = -0.784$; $p = 0.438$; $d = 0.32$) and height ($t_{(38)} = 1.785$; $p = 0.082$; $d = 0.63$) of the two groups. The experienced group were found to be significantly older ($Z_{(38)} = 10.045$; $p = 0.002$; $r = 1.6$) than the non-experienced group (Table 1).

INSERT TABLE 1 HERE

Of the 20 teams (40 individuals) tested on the mud, four of the non-experienced teams were unable to complete the stretcher-pull at the required pace (3 km.h^{-1}). Two teams failed to

complete the course due to exhaustion of a team member (one team were CRO's). There were no significant differences ($Z_{(34)} = -1.543$; $p = 0.129$; $r = -0.26$) in the average speed for the sled pull between the experienced technicians (median [range]; $2.61 [0.56]$ km.h⁻¹) and the non-experienced participants ($2.77 [1.62]$ km.h⁻¹).

The non-experienced group required a significantly ($t_{(34)} = -2.586$; $p = 0.014$; $d = 2.34$) greater total oxygen consumption of $11.7 (2.86)$ L compared to experienced group who required $8.99 (1.31)$ L to complete the task. During the sled pull mean relative $\dot{V}O_2$ was significantly ($t_{(34)} = 3.916$; $p < 0.001$; $d = 1.57$) lower for the experienced technicians (mean [SD]; $32.85 [5.79]$ mL.kg⁻¹.min⁻¹) compared to the non-experienced participants ($42.90 [6.55]$ mL.kg⁻¹.min⁻¹). Figure 2 shows the relationship between the relative $\dot{V}O_2$ required to travel at various speeds across the mud.

INSERT FIGURE 2 HERE

The regression equation ($\dot{V}O_2 = 8.4667 \times \text{speed} + 20.673$; based on non-experienced participants) to predict the physical requirement ($\dot{V}O_2$) of pulling a sled across the mud, based on speed (km.h⁻¹), was assessed for validity. All standardised residuals fell within the range of -1.64 to -1.86 and demonstrated and even spread when plotted against speed.

Limits of agreement (95 %) produced a mean \pm difference to be $0.0003 \pm 3.48 \text{ mL.kg}^{-1}.\text{min}^{-1}$, with a CV of 2.30 %. The predicted $\dot{V}O_2$ were not significantly different from the measured $\dot{V}O_2$, ($t_{(13)} = 0.001$; $p = 0.999$). The validity of the equation to predict the $\dot{V}O_2$ required to walk across the mud is reported in Table 2.

INSERT TABLE 2 HERE

Based on these data (Figure 2), it was clear that teams struggled to complete the task in the required 3 minutes. Thus, the regression equation presented in Figure 2 was used to determine the $\dot{V}O_2$ requirement at different speeds and the distance that would be covered in this time (Table 3).

INSERT TABLE 3 HERE

4.0 Conclusions

The only other study to examine pulling loads in excess of 60 kg by sled, reported an aerobic demand of $27 \text{ mL.kg}^{-1}.\text{min}^{-1}$ to pull a stretcher weighing approximately 80 kg across snow at a speed of 3.6 km.h^{-1} [14], this represents both a load (19 kg) and speed (approximately 1 km.h^{-1}) greater than used in this study. The increased physiological strain (approximate increase of 18% and 37% in experienced and non-experienced participants respectively) associated with pulling loads across mud

compared to snow confirms the importance of simulating the performance of essential tasks on the terrain on which they are normally undertaken.

Analysis of the physiological requirement of pulling a stretcher across the mud revealed that those experienced in mud rescue were considerably more economical on the mud (*i.e.* lower oxygen consumption for a given speed, Figure 2). To ensure that this was not a factor of body mass or speed total oxygen consumption was calculated. Those mud teams with more than 10 years' experience in mud rescue has a total oxygen consumption approximately 24% lower for a given speed on the mud compared to the non-experienced group. It should be noted that one pair demonstrated a lower total oxygen consumption than the experienced group whilst two further pairs were found to elicit total oxygen consumptions in the range of the experienced group. Due to this study only measuring time taken (speed) to complete the task, further work is needed to fully assess what constitutes a biomechanically efficient sled pull over estuary mud and the reasons for some non-experienced pairs ability to achieve results similar the experienced cohort.

It has been reported that economy can be effected by a number of factors including: physiological e.g. maximal oxygen

uptake ($\dot{V}O_{2max}$); biomechanical e.g. kinematics and kinetics; anthropometry e.g. bodyweight and composition and physical fitness training undertaken e.g. resistance [19]. A limit of this study was that parameters such as $\dot{V}O_{2max}$ and lean body mass were not measured. The significantly lower $\dot{V}O_2$ reported by the experienced group suggests that they have a greater biomechanical efficiency due to time spent on the mud, and have obtained a certain degree of training specificity due to the nature of the task. The differences between experienced and inexperienced mud technicians or those with no experience highlights the need for workers in physically demanding roles that have a particular technique to practise regularly and realistically.

A recent study [24] reported a 20.2% decrease in the time taken to complete the Canadian Forces Firefighter Physical Fitness Maintenance Evaluation by non-experienced applicants from trial one to six. This is comparable to the difference observed in this study. It was suggested that improvements may have been due to significant increases in skeletal muscle oxidative capacity after the exposure to six sessions of low-volume, high-intensity resulting in enhanced physical capacity, however, no data were presented to support this notion [25]. This study supports that the metabolic demand of a task can be reduced with experience, but larger participant numbers are

required to quantify the effect of repeated exposures. It is difficult to find a large number of experienced mud technicians due to the specialist nature of the task, thus further research is needed to determine the time taken to become biomechanically efficient in a non-experienced cohort and the relative effect this has on the physiological demand.

A greater variance was observed in all measures in the non-experienced group, this is likely due to the greater participant numbers in the non-experienced group. The unequal group sizes and limited participant numbers in the experienced groups are a weakness of this study. Another limit of this study was that trials were not repeated meaning reliability could not be assessed within groups.

With regard to setting the selection standard for new recruits PES, the “experience” factor should not be used as a rationale for reducing the required aerobic capacity; if the need for fitness to do the task precedes the opportunity to develop the skill on the task. It has been suggested that the level of skill required to perform a task should be taken into consideration [26], but it would be unjustifiable to base selection on an attribute that will be obtained whilst employed [26], this highlights the importance of measuring the physiological demand of a task across the range of experience levels to

determine a minimum acceptable level of performance [5]. Whilst the use of the experienced mud technician's results would have led to a lower aerobic standard, it would be misleading; potentially putting new mud technicians who achieved this standard on a validated predictive test (e.g. step test or shuttle run) at risk of exhaustion or injury during a rescue on the mud, thereby also risking the casualties requiring rescue, and possibly causing further casualties (the intended rescuers). This problem would be prolonged in cases where a formal training programme for the task, in this case mud rescue, was not in place. This rationale is not so clear for setting an incumbent PES where experience of the task has been attained. Thus more work is needed to not only distinguish between PES for recruits (*i.e.* non-experienced) vs. incumbents (*i.e.* experienced), but how many exposures to the task are required or what level of skill should be demonstrated before someone can be classed as experienced.

From the data collected during this study the requirement to maintain a speed of 3 km.h^{-1} was considered too arduous for the likely population that would apply to be a coastguard rescue officer. Thus the speed to perform the task of pulling a rescue sled across estuary mud were reduced to 0.8 km.h^{-1} , which equates to a distance of 200 m being covered in 15 minutes. These values were sanctioned by the UK Coastguard Service

as the minimum acceptable standard for mud rescue in the development of a PES [17]. This speed is considerably slower than the 3 km.h^{-1} originally suggested by the SMEs. This unrealistic expectation could have been due to all of the SMEs being competent and experienced mud technicians, and therefore considerably more economical on the mud, perhaps not appreciating the additional demands that would be placed on new recruits. This highlights the importance of objectively measuring task performance to quantify the recommendation of the SMEs.

It is concluded that for tasks such as mud rescue where the task has a high physical component the minimum level of fitness used to establish a PES for recruits should be based on the metabolic demands measured on an in-experienced group. Unless specific studies are carried out to determine the magnitude and time taken to reach an experienced level, incumbent PES should also be based on the metabolic demands measured on an in-experienced group

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6.0 References

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Table 1. Mean participant demographics (n = 40; Male = 37; Female = 3).

Demographic	Mean (SD)	Minimum	Maximum
Combined (n=40)			
Mass (kg)	81.5 (14.4)	61.6	112.4
Height (cm)	177.0 (7.4)	160.2	194.3
Age (yrs)*	28 (42)	18	60
Experienced (n=14)			
Mass (kg)	85.1 (18.3)	62.1	110.85
Height (cm)	173.0 (7.5)	161.0	184.9
Age (yrs)*	44 (38)	22	60
Non-Experienced (n=26)			
Mass (kg)	80.6 (13.4)	61.6	112.4
Height (cm)	178.0(7.1)	160.2	194.3
Age (yrs)*	25 (32)	18	54
*Data reported as Median (Range)			

Table 2. Ninety-five percent limits of agreement between the predicted and the measured aerobic requirement to walk on the mud (n = 28).

	$\dot{V}O_2$ (mL.kg ⁻¹ .min ⁻¹)
Mean difference (SD)	-0.00 (1.77)
LoA + mL.kg ⁻¹ .min ⁻¹	+3.49
LoA - mL.kg ⁻¹ .min ⁻¹	-3.49
Percentage (%) of participants falling outside the LoA	0

Table 3. Predicted oxygen requirement required to walk 200 m on the mud at different speeds (data from in-experienced teams' n = 28).

Time to walk 200 m (minutes)	Speed (km.h ⁻¹)	Predicted Oxygen requirement (mL.kg ⁻¹ .min ⁻¹)
7.5	1.5	33.4
10	1.2	30.8
15	0.8	27.4
20	0.6	25.8

Figure 1. Mud technicians pulling a rescue sled (61 kg) across estuary mud.



Figure 2. Oxygen consumption ($\dot{V}O_2$) required to pull a rescue stretcher 150 m over mud at different speeds (each point represents the mean of two people pulling the stretcher, [n=36], two teams [n=4] failed to complete the task).

