Physiological demands of mountain rescue work

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ABSTRACT

Objective To characterise the physical fitness of mountain rescue (MR) volunteers and the physical demands of a typical MR callout.

Methods Eight MR volunteers (age ± SD: 45.5 ± 8.9 years) completed a laboratory-based treadmill exercise test to exhaustion. One week later subjects completed a field-based simulated callout to retrieve a casualty by stretcher. In both studies exercise intensity was evaluated by determination of oxygen uptake and other cardiovascular measures.

Results The maximal oxygen uptake of the participants was 53 ml/kg/min (95% CI 45 to 60). In an unassisted callout, a typical rucksack load was 17% of body mass. Ascent time was 56 min (95% CI 40 to 72), of which 82% (95% CI 66% to 98%) was completed at hard or very hard intensity (above the respiratory compensation point). Descent time with a stretcher was 58 min (95% CI 52 to 64), of which only 6% (95% CI −4% to 16%) was completed at hard or very hard intensity. Correlations between heart rate and oxygen uptake were similar (p=0.254 by analysis of variance) during laboratory (r=0.72) and field testing, especially for the ascent (r=0.75).

Conclusions Mountain rescuers generally have high levels of physical fitness and are required to perform at very hard intensity for the majority of the ascent to a casualty. Heart rate is a simple yet valid measure of exercise intensity in MR personnel. These findings highlight important information on the unique physical demands faced by MR volunteers and provide direction for future research, volunteer selection and training.

INTRODUCTION

Mountain rescue (MR) teams provide a 24 h emergency service to upland areas, and in the UK respond to approximately 950 incidents a year.1 2 Although description is sparse, MR volunteers are highly trained but may represent a wide variety of backgrounds, physical fitness levels and age groups.3

MR personnel attend incidents in remote locations, often in difficult terrain and weather conditions.4 Callouts commonly involve extended periods in mountainous or moorland terrain without vehicle or aircraft support. In addition, technical climbing, scrambling on rock and negotiating snow or ice may be required to access, secure and medically stabilise single or multiple casualties.5 Egress may then require the manual transfer of a casualty on a stretcher to a rendezvous with an ambulance or helicopter. Prolonged searches may be undertaken, potentially placing different sets of physiological demands on rescuers. Despite these difficulties, characterisation of the physiological demands of MR work is lacking.

Previous studies examining the physiological demands of hill walking have suggested mean exercise intensities in the region of 50% of VO2 peak (59±2 ml/kg/min) during ascent.6 In MR work, it is likely that exercise intensities are higher owing to the more urgent nature of the task, fewer rest stops and the added weight of emergency equipment. Indeed, studies have established that load carrying increases the metabolic cost of walking as a function of both speed and rucksack weight.7 8 However, these studies may have limited application to MR as they fail to take into account factors such as terrain and the specific MR tasks that further influence physiological demand.

Previous studies using military personnel have examined the cardiovascular responses to various stretcher carrying modalities during manual transfer of the casualty.8 9 However, these studies employed stretcher designs and carrying modalities not usually found within MR. Of greater relevance, Hignett, Willmott and Clemes studied the usability of four stretchers commonly used in MR, each requiring six individuals and a variety of carrying methods. Mean ratings of perceived exertion between 12 and 13 (on a 6–20 scale), or between ‘light’ and ‘somewhat hard,’ were found for a simulated 1 km carrying distance.5

Although physiological demands of other emergency service occupational activities, such as fire fighting, have been characterised, the authors are unaware of any published work measuring cardiovascular demand in MR. Thus this study aims to characterise MR personnel and the physical demands placed upon them during their work. It also aims to assess the validity of heart rate telemetry as an indicator of exercise intensity in an MR setting. Such data are essential to direct further research, to aid volunteer selection and training and to improve, eventually, the effectiveness of MR so that casualties are reached and evacuated more quickly.

METHODS

Participants

Eight experienced male members drawn from the Patterdale and Penrith MR teams volunteered for the study (age 45.5±8.9 years; height 177±6 cm; mass 80.6±6.9 kg; body fat 14.0±3.3%; all mean±SD). Participants were current team members who expected to perform a similar task at least once a year. The volunteers provided informed consent, and the study was approved by the ethics committee of the School of Sport, Health and Exercise Science, Bangor University.

Procedures

Participants attended two test days. On day 1, participants attended a local leisure centre for anthropometric testing, including height (cm), body mass (kg) and body composition (% body fat,
by bioelectrical impedance analyser, InBody 230; Biospace, Seoul, Korea). After a 5 min warm-up participants then underwent an incremental treadmill exercise to exhaustion test, including a separate confirmation stage. This enabled determination of each individual’s maximal oxygen uptake (VO2 max, or the upper limit of oxygen use), anaerobic threshold (AT, or the point at which aerobic energy production is supplemented by anaerobic mechanisms) and respiratory compensation point (RCP, or the increase in respiratory drive as the carotid bodies respond to decreasing pH). A higher VO2 max suggests a higher aerobic power, is related to endurance performance and is useful for setting training intensities. The AT and RCP provide further information on aerobic fitness, are more sensitive to training and detraining and are useful for objectively defining moderate and hard exercise intensities above which the body is no longer exercising at steady state.

During the test, inspired and expired gases were analysed and recorded with a calibrated, portable metabolic analyser (Metamax 3B, Cortex, Leipzig, Germany). Heart rate was recorded by telemetry (Polar S625X; Polar Electro, Finland) and perceived exertion was reported by the Borg 6–20 scale.9 Capillary blood samples were taken from the earlobe at 1 min after exercise to assess blood lactate concentration (Lactate Pro LT-1710, Arkray, Kyoto, Japan).

Field testing was carried out on day 2, at least 7 days after the treadmill test. The weather on the test day was light wind, sunny spells and one short period of light rain, with a peak temperature at 81 m above sea level of 15°C. The field test consisted of a simulated callout modelled on a situation of no helicopter support: a casualty was situated in the square kilometre within the MR team’s catchment area that had had the highest number of rescues in the preceding 3 years. Such a situation would be expected to occur 0.7 times a year (see ‘Results’ for further details of typical callouts). Participants were required to walk to, and evacuate, a simulated ‘casualty’ (70 kg of water bottles) on a stretcher to the closest access point for a vehicle. The casualty site was located 2.96 km from the road head with a vertical height gain of 472 m. Figure 1 shows the ascent and descent profile. The terrain was largely mountain path, consisting of variable terrain angles with loose stones and short rocky sections but did not require any technical climbing. Participants wore their standard team clothing and each carried personal equipment plus one half of the stretcher (14 kg each; Bell Mk. 3 Stretcher; Ambleside) using its attached rucksack straps.

Participants were encouraged to move at a speed consistent with a real callout and allowed rest stops if required. A predetermined 20 min stop at the casualty site (to simulate casualty assessment and packaging) was included before starting the evacuation. The evacuation party consisted of at least eight people; the two participants being tested who controlled walking speed and carried the stretcher for the entirety of the test, plus at least six helpers. The helpers consisted of male and female active hill walkers from a variety of backgrounds (age 34.9±11.4 years; height: 176±7 cm; mass: 71.5±8.7 kg; body fat 13.7±10.9 kg). All were familiar with walking in a mountainous environment and a different team of volunteers assisted each test pair to prevent any influence of helper fatigue. Two researchers were present during each task to collect data and ensure the protocol was adhered to correctly. The total stretcher load carried during the descent was 124.9 kg including the stretcher (28 kg), ‘casualty’ (70 kg), vacuum mattress (8.1 kg), casualty bag (9.2 kg) and Entonox (9.6 kg). A mixture of carrying and sledging techniques was used as the terrain dictated in line with current team practice.

During the simulated callout participants wore the portable metabolic analyser and heart rate telemetry unit. Analysis began upon leaving the road head and terminated upon return. Rating of perceived exertion was recorded at 11 points located by global positioning system and indicated by clearly visible markers. These points were located at the end of extended sections of constant gradient in attempt to obtain steady-state readings.

**Data analysis**

In the main manuscript data are presented as means±SD. To determine fitness levels of the participants, breath-by-breath data from laboratory testing were used to determine VO2 max, AT (V slope method) and RCP (ventilatory equivalent method).10

To determine exercise intensity during the simulated callout, data were presented as mean absolute values for the entire task and also as a percentage of the laboratory-determined maximal values. This enabled description of the simulated callout exercise intensity relative to laboratory-determined fitness parameters. This was achieved by assigning breath-by-breath data points collected during the simulated callout to one of four intensity zones as previously defined during the laboratory test: below AT, above AT but below RCP, above RCP but below laboratory-determined VO2 max and above VO2 max. Thus the proportion of the task spent in easy, moderate, hard and very hard exercise intensity zones was determined.

To determine whether heart rate could be used as a surrogate marker for exercise intensity, correlations between heart rate and...
oxygen uptake were determined. Then the average correlation obtained in the laboratory was compared with the field test as ascent correlation and the descent correlation, by repeated-measures analysis of variance on Fisher Z transformed values. Statistical significance was assumed at p<0.05.

RESULTS

Data on callouts attended by the Patterdale MR team over a 3-year period showed 101 callouts requiring stretcher evacuation, of which 44 were undertaken without motorised support. For these unsupported callouts, the mean horizontal distance travelled by foot on ascent to a casualty was 1043±914 m, and on descent 1056±864 m, while mean vertical distances ascended and descended were 160±150 m and 146±169 m, respectively. Furthermore, 55% of these callouts (8.2 callouts a year) required stretcher carrying distances in excess of 750 m. The most remote casualty site was 3600 m horizontal distance and 1500 m and 146 ±914 m, respectively.

Data attained during the two tests are presented in table 1. VO2 max, respiratory compensation point, and anaerobic threshold were determined during laboratory testing. Heart rate was determined during both laboratory and simulated callouts. Table 1 shows all data are means ±SD. Anaerobic threshold and respiratory compensation point, calculated using the V-slope method and ventilatory equivalent methods, respectively. N/A, data not determined during the field test because work intensity could not be incremented in a controlled way, preventing calculation of these parameters.

Table 1 Physiological parameters of mountain rescue personnel during a laboratory exercise test and a simulated callout

<table>
<thead>
<tr>
<th>Variables</th>
<th>Laboratory exercise test</th>
<th>Simulated callout</th>
</tr>
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<tbody>
<tr>
<td>VO2 (ml/kg/min)</td>
<td>52.6±3.9</td>
<td>51.1±3.3</td>
</tr>
<tr>
<td>Minute ventilation (l/min)</td>
<td>152.4±16.7</td>
<td>128.5±25.4</td>
</tr>
<tr>
<td>Breathing frequency (breaths/min)</td>
<td>56.4±8.8</td>
<td>52.3±8.1</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>189±12.2</td>
<td>178±13.5</td>
</tr>
<tr>
<td>Anaerobic threshold (ml/kg/min)</td>
<td>24.7±4.2</td>
<td>N/A</td>
</tr>
<tr>
<td>Anaerobic threshold (% VO2 max)</td>
<td>46.9±7.4</td>
<td>N/A</td>
</tr>
<tr>
<td>HR at anaerobic threshold (beats/min)</td>
<td>118±16</td>
<td>N/A</td>
</tr>
<tr>
<td>Respiratory compensation point (ml/kg/min)</td>
<td>36.8±3.6</td>
<td>N/A</td>
</tr>
<tr>
<td>Respiratory compensation point (% VO2 max)</td>
<td>81.8±7.2</td>
<td>N/A</td>
</tr>
<tr>
<td>HR at respiratory compensation point (beats/min)</td>
<td>154±16</td>
<td>N/A</td>
</tr>
</tbody>
</table>

All data are means ±SD. Anaerobic threshold and respiratory compensation point, calculated using the V-slope method and ventilatory equivalent methods, respectively. N/A, data not determined during the field test because work intensity could not be incremented in a controlled way, preventing calculation of these parameters.

HR, heart rate; VO2, maximal (for laboratory test) or peak (for simulated callout) oxygen consumption.

Figure 2 Percentage of ascent and descent duration spent at relative percentage of laboratory determined maximal oxygen uptake. % VO2 max, oxygen uptake during the field test expressed as a percentage of maximal oxygen uptake as determined during laboratory testing. Black bar, ascent; grey bar, descent. Data are means ±SD.

Figure 2 shows that the percentage of ascent and descent duration spent at relative percentage of laboratory determined maximal oxygen uptake, % VO2 max, oxygen uptake during the field test expressed as a percentage of maximal oxygen uptake as determined during laboratory testing. Black bar, ascent; grey bar, descent. Data are means ±SD.
descent. Visual inspection of ascent data in figures 2 and 3 further suggests that when ascending, similar exercise intensities would be identified using either the oxygen uptake or the heart rate data. However, inspection of descent data in the same figures suggests that when descending with a stretcher, a narrower and slightly higher exercise intensity range would be defined when evaluating heart rate as opposed to oxygen uptake. This was also the case when data were expressed as % VO₂ Reserve max or % heart rate Reserve max (data not shown).

DISCUSSION

In this study we describe the physiological attributes of MR volunteers and the demands placed upon them. Although small, our sample is probably representative of this population, showing comparable demographics (mean age 46 years, range 25–55) with previous studies (age 44 years, range 53–62)\(^3\) and unpublished data from the entire Patterdale team (age 45 years, range 25–65, Patterdale MR team, personal communication, 2010).

The volunteers described in this study had a higher laboratory-measured VO₂ max than male members of one city-based ambulance service (53±4 vs 57±1 ml/kg/min, respectively), despite being older (46±9 vs 37±1 years).\(^11\) The high aerobic capacity seen among MR volunteers is very similar to that reported in naval fire fighters (53±4 vs 53±5 ml/kg/min), again despite MR volunteers being considerably older (46±9 vs 26±7 years).\(^12\) They also had similar relative body fat composition (17±4 vs 17±4%).\(^11\)

Our simulation was based on a number of recent true callouts with our casualty site being located in the vicinity of a common accident ‘black spot’. Experienced MR volunteers deemed that both the scenario and pace were realistic and similar to a real incident. Comparison of the simulated incident with the work of other emergency services shows that MR work is unique in its physical demands. For example, MR volunteers encountered considerably higher demands than city-based ambulance personnel (97% vs 60% of VO₂ max).\(^11\) Notwithstanding any differences in assessment method, naval fire-fighters encountered maximal VO₂ demands of 43±6 ml/kg/min while performing seaboard fire suppression tasks, somewhat lower than the 52±3 ml/kg/min peak observed herein.\(^12\) A surprisingly large percentage of the MR team’s ascent time (82%) was spent exercising at hard exercise intensities, working above the objectively measured RCP. The MR team personnel also perceived the simulated callout to be very demanding, reporting the exercise to feel ‘hard (heavy)’ on average and ‘very hard’ at peak. Furthermore, the mean exercise duration of the simulated MR callout was 114 min and thus considerably longer than that seen in studies of other emergency personnel, where the mean exercise duration was, for example, <25 min.\(^13\)

Part of the reason for this heavy physiological demand of MR work is the need to carry large rucksack loads. The standard load used herein, representing ~17% of the mean group body mass, was typical for unassisted callouts (Patterdale MR team, personal communication, 2010). While evacuating a casualty, stretcher loads well exceeding 100 kg are encountered. Only the previous study of Hignett, Willmott and Clemes used current MR equipment and a team of six to eight people to carry at any one time.\(^3\) Their mean rating of perceived exertion for the descent stage (12–13) was comparable to that reported here (12±1) despite a lower total carried load. However, the mean rating of perceived exertion for ascent (16, between ‘hard (heavy)’ and ‘very hard’) in our study suggests that there is a greater perceived intensity during ascent. This finding was consistent with the observed greater metabolic demand during ascent, with 82% of the time being spent above RCP versus only 6% during descent. Therefore a lighter stretcher design could reduce the metabolic demand of ascent and other loads could.

Table 2  Regression equations between heart rate and oxygen uptake in laboratory and field settings

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Intercept</th>
<th>Slope</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory exercise test</td>
<td>0.72±0.11</td>
<td>−1.18±0.59</td>
<td>0.025±0.004</td>
</tr>
<tr>
<td>Simulated callout: ascent</td>
<td>0.75±0.12</td>
<td>−1.85±0.79</td>
<td>0.031±0.004</td>
</tr>
<tr>
<td>Simulated callout: descent</td>
<td>0.60±0.18</td>
<td>−1.58±1.26</td>
<td>0.030±0.013</td>
</tr>
<tr>
<td>Significance (p)</td>
<td>0.254</td>
<td>0.390</td>
<td>0.322</td>
</tr>
</tbody>
</table>

Data are means±SD.

Correlation, Pearson’s product moment correlation coefficient (average correlation determined by Fisher Z transformation); SEE, SE of the estimate; significance (p), determined from repeated measures analysis of variance (for correlation coefficients this test was completed on weighted Z values).

*Significant difference between laboratory test and both ascent and descent.

Figure 3  Percentage of ascent and descent duration spent at relative percentage of laboratory determined maximal heart rate. % HR max, heart rate during the field test expressed as a percentage of maximal heart rate as determined during laboratory testing. Black bar, Grey bar, Solid bar, ascent; hashed bar, descent. Data are means±SD.
where possible, be divided between more team members. However, operationally this might have a negative consequence if a crucial piece of equipment did not arrive in a timely fashion at the casualty site.

The consequences of the high physical demands over a relatively long duration when compared with other emergency services should be considered. Characteristically, all team members work at about the same rate; a few will then perform advanced first aid including cannulation, or safety manoeuvres at the casualty site. Whether degradation in occupational performance occurs as a result is unknown. Considering the high physical demands it is surprising that there are only two ‘on-duty’ sudden deaths of rescuers during the 75 years of MR activity in the UK known to the medical officer of Mountain Rescue England and Wales. In contrast, strenuous physical exertion has been associated with sudden death in a number of populations, including in firefighters when suppressing fires. Although an apparently reduced risk in MR personnel may be in part due to the higher fitness level and better body composition as observed in this study, it should be noted that fitness level did vary within our sample. Furthermore, performance measured as time to complete the specified task has been found to be inversely related to V02 max for fire service work. Our study was not a true time trial so a similar relationship cannot be confirmed for MR work. However, further research should investigate this topic as there are obvious implications for medical emergencies involving life-threatening conditions (4% of callouts in the Patterdale area) where speed of response may have a significant impact on patient outcome.

The study has a number of limitations. First, the findings relate to one busy MR team and may not represent every rescue team and situation possible, including differing weather conditions from those encountered here. Second, the volunteers were self-selected and may not represent the range of fitness within the team. However, there is no reason to suppose that those described here are much better than other teams with similar workloads and geographical terrain. As with any observational study, a Hawthorne effect might have led to increased effort from our participants. Alternatively, a real rescue might increase motivation compared with a simulated callout. It may also be the case that despite careful selection the non-team members used for stretcher carrying might have affected the data obtained during the descent period as they were less familiar with the activity. This study also failed to examine callouts involving technical terrain and prolonged searches. We have, however, ascertainment of the validity of heart rate as a simple measure to overcome these limitations in future studies. The finding that heart rate has a high correlation with metabolic demand during ascent (r=0.75±0.12) and a moderate correlation during descent (r=0.60±0.18, possibly lower owing to the influence of stretcher carrying) provides the option that during other studies and even real situations heart rate telemetry could be used.

In conclusion, MR volunteers have high levels of physical fitness and perform above the RCP (hard or very hard intensity) for more than 80% of the time during ascent to the casualty. The highest physiological demands are encountered during ascent, making ascent the most appropriate target for interventions to reduce overall time to reach and evacuate casualties. Heart rate is a valid technique for assessing exercise intensity in an MR setting, especially during ascent. Future studies may use this technique to extend these findings, which have importance for MR research, volunteer selection and training.

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Competing interests None.

Patient consent Obtained.

Ethics approval Ethics approval was provided by the School of Sport, Health and Exercise Sciences, Bangor University Ethics Committee.

Contributors NC, JE, and JHM conceived and designed the study. JHM and JE obtained ethical and regulatory approval. NC and JHM collected the data, under medical supervision of JE. Data analysis was by NC and JHM. Drafts were written by NC and JE, which were revised and edited by all authors. JHM takes responsibility for the paper as a whole.

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