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Burden vs Agility and Vulnerability Trial Report

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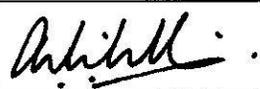
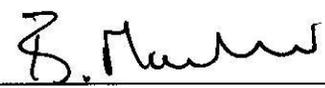
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Executive summary

Dstl were tasked by the Parsifal Board and Cap GM (Capability Ground Manoeuvre) with investigating the effects of burden on agility and vulnerability of the Dismounted Close Combat (DCC) soldier. The intention was to generate data with utility to inform the soldier system trade-off process.

The study was approved by the MOD Research Ethics Committee and carried out in two parts:

- Part 1: To assess the impact of increasing burden between 6-60kg, in a series of 5 different load configurations, on soldier agility in a number of military-type physical tasks (Load vs Agility);
- Part 2: To assess the impact of increasing burden between 6-60kg, in a series of 5 different load configurations, on soldier vulnerability to being hit by a shooter using a laser Tactical Engagement Simulation (TES) system (Agility vs Vulnerability).

The study was a repeated measures, randomised crossover design, with 17 subjects completing Parts 1 and 2 of the trials, during which they each wore five load configurations (6kg, 20kg, 30kg, 40kg and 60kg).

Physical performance during the tasks included: for Load vs Agility – live fire marksmanship; simulated fire and manoeuvre including a zig-zag run; a loaded 4.5 km march, repeated fire and manoeuvre, repeated marksmanship. For Agility vs Vulnerability the loaded subjects conducted short dashes between cover while a shooter attempted to shoot them with a blank firing laser system.

The relationship between increased load carried and physical performance over a short distance follows an obvious path: the more the load increases, the more difficult the manoeuvre becomes and the longer it takes to negotiate a simple course. In general, slower movement and performance times in the heaviest load condition could have serious implications for soldier lethality and vulnerability.

It was concluded that, for the militarily relevant tasks assessed in this study: a 60kg load will significantly degrade soldier performance; carrying loads of 6kg and 20kg will have little or no impact on performance; carrying loads of 30kg, 40kg (and higher) will result in progressive degradation of performance which may, in particular, affect vulnerability.

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1 Introduction

1.1 Dstl were tasked by the Parsifal Board and Cap GM (Capability Ground Manoeuvre) with investigating the effects of burden on agility and vulnerability of the Dismounted Close Combat (DCC) soldier. The data from this trial was required to inform decision making at ministerial level regarding questions on soldier protection and survivability and to inform the soldier system trade-off process (burden vs agility and vulnerability) by providing information for modelling and simulation programmes that can be used to predict soldier performance and protection.

1.2 Background

1.2.1 There is consensus that soldier load needs to be reduced and that excessive loads are having an adverse influence on DCC operations¹, particularly with regard to the lack of agility and mobility, and potentially contributing to increased casualties. However, whilst there is much anecdotal data and comment in reports such as the lessons learned series², there is a paucity of quantitative data on the specific impact of excessive loads on soldier agility, and the subsequent implications for soldier vulnerability and survivability. The purpose of this report is to provide data that will support the decision making process to find the correct balance between protection, load, agility, vulnerability and ultimately, survivability during DCC operations.

1.3 Aim

1.3.1 The specific aim of this study was to assess the impact of burden on soldier agility and vulnerability. This was assessed whilst performing activities that are representative of the physical demands of military tasks undertaken in the DCC environment whilst carrying a range of loads from 6 to 60 kg. This will generate data with utility to inform the soldier system trade-off process.

1.3.2 The study was carried out in two parts:

- Part 1: To assess the impact of increasing burden between 6-60kg, in a series of 5 different load configurations, on soldier agility in a number of military-type physical tasks;
- Part 2: To assess the impact of increasing burden between 6-60kg, in a series of 5 different load configurations, on soldier vulnerability to being hit by a shooter using a laser Tactical Engagement Simulation (TES) system.

¹ Loose Minute: 1 RIFLES, 3 Cdo Bde – Op HERRICK 9 (9/08-3/09) – OpIss4R POTD – Apr 09.

QINETIQ/IS/PS/LR0902682. 19 May 2009. J Kelly & R Antolik QinetiQ OpIss4R.

² HQ Infantry Lessons Learned Identified Database Weights; ID 15 Need to reduce soldier load, March 2010

2 Method

2.1 Ethics

2.1.1 The study was approved by the Chairman and Deputy Chairman of the MOD Research Ethics Committee. All subjects read a trial brief and gave written informed consent before participating in the trial.

2.2 Subjects

2.2.1 Twenty male subjects were recruited from the 1 Regiment Royal Fusiliers attached to the Land Warfare Centre (LWC) Battlegroup. Subjects were aged between 18-35 years and classified as 'Fit Forward Everywhere'. Upon arrival at the ITDU all subjects undertook a personal fitness assessment under the supervision, and to the satisfaction, of a Physical Training Instructor (PTI).

2.3 Medical examination and cover

2.3.1 All subjects underwent a thorough medical examination immediately prior to participating in the trial. Three subjects were excluded from taking part, due to pre-existing medical conditions, leaving 17 participants. The Medical Officer supervised subjects throughout the tasks on each day of the trial.

2.4 Study design

2.4.1 The study was a repeated measures, randomised crossover design, with 17 subjects completing Parts 1 and 2 of the trials, during which they each wore five load configurations (a-e) over a baseline of Combat Soldier 95 (CS 95) trousers and field jacket, T shirt, underwear and socks with Combat Assault Boots (approx 2.5kg depending on size). The load configurations (a-e) were as follows:

- a. Weapon (4.5kg) and helmet (1.5kg).
Total load of 6kg;
- b. Weapon (4.5kg), helmet (1.5kg), webbing (2.5kg), 301 patrol pack (1.5kg) and lightweight body armour³ (10kg).
Total load of 20kg;
- c. Weapon (4.5kg), helmet (1.5kg), webbing (2.5kg), 301 patrol pack (1.5kg), OSPREY (13kg) and ballast (7kg).
Total load of 30kg;

³ Lightweight body armour comprised OSPREY with reduced weight plates of identical size and bulk to normal OSPREY plates. This was necessary to reach the target of 20kg.

- d. Weapon (4.5kg), helmet (1.5kg), webbing (2.5kg), 301 patrol pack (1.5kg), OSPREY (13kg) and ballast (17kg).
Total load of 40kg;
- e. Weapon (4.5kg), helmet (1.5kg), webbing (2.5kg), 301 patrol pack (1.5kg), OSPREY (13kg) and ballast (37kg).
Total load of 60kg.

2.4.2 Load configurations were checked each day and weights adjusted to within 1kg of the target load weight. Examples of load carried are shown in Figure 1.



Figure 1: Load configurations from 6kg, with no webbing, body armour or day sack (left) and 20-60kg, with body armour, webbing and day sack (right)

2.4.3 In Part 1 of the trial (Burden vs Agility), subjects conducted the following activity set on each test day:

- Live fire marksmanship shoot 1
- Simulated fire & manoeuvre task, and zig zag run 1
- Loaded 4.5km march
- Simulated fire & manoeuvre task, and zig zag run 2
- Live fire marksmanship shoot 2

2.4.3.1 These tasks are described in detail in Section 2. 5.

2.4.4 In Part 2 of the trial (Agility vs Vulnerability) subjects carried out short dashes between cover whilst a shooter attempted to shoot them with a blank firing laser system. They

were required to run from cover to cover in 10m bounds followed by a further tactical zig zag run to reach cover 15m away.

2.4.5 Photo and video footage was captured throughout the trial to support the analysis.

2.5 Burden vs Agility Tasks (Part 1)

2.5.1 The battery of tests assessed the impact of the load being carried on soldier agility in a series of tasks. These were as follows:

2.5.2 Live Fire Marksmanship shoot 1

2.5.2.1 Personal weapons (SA80 with SUSAT⁴ sight) were zeroed on the first day under the supervision of the range supervisor. Once weapons were zeroed, subjects, in groups of 4, adopted a prone firing position (Figure 2) and fired 10 live rounds from their personal weapons at a standard, military 'Figure 12' target at a distance of 100m in a maximum time of 30s⁵. The range supervisor gave a countdown of time remaining every 10s. The performance metrics were the total score and the group size (spread of shot between the two furthest hits on the target).



Figure 2: Subject on range in 20-60kg configuration.

⁴ Sight Unit Small Arms Trilux - the standard optic sight issued with the SA 80 system.

⁵ Simulating a rapid rate of fire (Inf Trg Vol 2, Pam 5, the SA 80 A2)

2.5.3 Simulated Fire & Manoeuvre 1

2.5.3.1 Subjects undertook a series of 10m simulated fire & manoeuvre⁶ activities in order to assess individual ability to move forward and adopt different firing postures. Subjects carried out the following task sequence:

- start at starting line, in the prone position, taking aim at a Figure11 target;
- stand and run 10m in a forward direction to a box marked out on the ground;
- adopt the prone position and aim at a Figure11 target;
- stand and run 10m in a forward direction to a box marked out on the ground;
- adopt the kneeling position and aim at a Figure11 target;
- stand and run 10m in a forward direction to a box marked out on the ground;
- adopt the prone position and aim at a Figure11 target;
- stand and run 10m in a forward direction toward the finish line.

2.5.3.2 This task, as illustrated in Figures 3 and 4, was self (best) paced and conducted on an even grassed terrain with a slight incline. The performance metrics were the total time taken to complete the course and split times for each fire position / manoeuvre. Subjects continued, without stopping, into the zig zag run.



Figure 3: Fire and Manoeuvre activities and Zig Zag run

2.5.4 Zig Zag run 1

2.5.4.1 Subjects continued from the Fire & Manoeuvre activity to run a further distance of 50m, at their best pace in a ‘zig zag’ manner. The test was conducted on flat, even, grassed terrain. Subjects ran five 10m legs, each changing direction at approx 135° until they reached the finish line. The distance from the end of the Fire & Manoeuvre to the end of

⁶ Although this activity may be termed ‘fire and movement’ by the military the term ‘fire and manoeuvre’ is used here for consistency with previous reports e.g. R J Edwards, H L Vicary, G Newell, T Powell, A Curtis, M Hayes and S Byfield. Personal Equipment Common Operational Clothing : Agility versus Protection Study. Summary Report DSTL/CR32151/1.0 10 November 2008

the zig zag course was 50m. The performance metric was the time taken to complete the task.

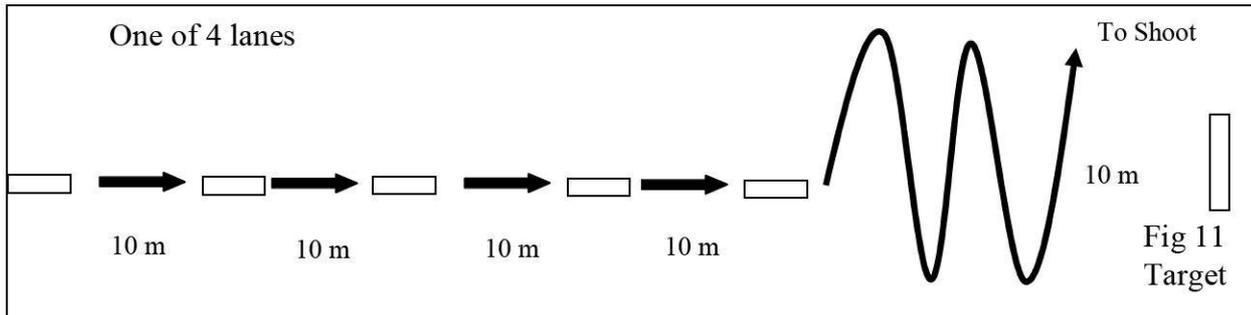


Figure 4: Fire and Manoeuvre and Zig Zag run course.

2.5.5 Loaded 4.5km March

2.5.5.1 On each day, with each load condition placed in a randomised order, subjects completed a 4.5 km march (Figure 5) at a target pace of approximately 5km/hr⁷. The pace of the march was set to be achievable by participants with the heaviest load, and remained constant throughout the task, and across each subsequent day's 4.5km march. A suitably qualified military PTI accompanied the subjects and controlled the pace throughout the march. This march was on a pre-defined course, conducted over undulating terrain with a significant gradient between 2.6 and 3.0km. Subjects were given a brief 'water stop' at approx 2.5km. Performance metrics were heart rate (HR) recorded during the march, Rate Perceived Exertion (RPE – using the Borg Scale), Perceived Heat Strain; (ASHRAE), and a cognitive performance test (Stroop Test) administered immediately after the march. The target exercise intensity over level ground was no more than 60 % of mean maximum aerobic exercise capacity⁸. The aim was to ensure that all participants could complete the 4.5km march with the heaviest load of 60 kg.



Figure 5: Loaded 4.5 km march at the start and 2.8km points, supervised by PTI.

⁷ The original target pace was 3.2 km/h but the soldiers participating felt that this was too slow and they set the pace themselves at 5 km/h on the first day.

⁸ calculated using the 'Karvonen' formula: $([220 - \text{age}] - \text{resting heart rate} \times 60\%) + \text{Resting HR}$

2.5.6 Simulated Fire & Manoeuvre 2

2.5.6.1 This was the same as the Simulated Fire & Manoeuvre 1, but repeated to examine the effects of fatigue on performance.

2.5.7 Zig Zag run 2

2.5.7.1 As Zig Zag run 1, but repeated to examine the effects of fatigue on performance.

2.5.8 Live Fire Marksmanship Shoot 2

2.5.8.1 As Live Fire Marksmanship 1, but repeated to examine the effects of fatigue on performance.

2.6 Agility vs Vulnerability (Part 2)

2.6.1 Subjects were instrumented with the TES laser system vest in order to record hits from two 'shooters'⁹ with a blank firing TES¹⁰ laser system. The TES system was zeroed on each of the two weapons the day before the trial day. Subjects completed a predetermined route between areas of cover (4 runs – 3 x 10m and 1 x 15m as shown in Figures 6 and 7) in each of the load configurations (a-e, as defined in Section 2.4.1). Two shooters fired 20 rounds from 50m¹¹ and alternated for each target subject. The performance metric was the total number of hits recorded during each run of the course (from the start to the finish including the 4 run sections), in each load configuration. Recorded hits were downloaded immediately following each soldier's run of the course. If there were any anomalies with the equipment, then the run was halted and re-commenced. Load order was randomised and the whole activity of 5 load configurations, with 17 subjects, was completed in one full day. Weather was sunny and fine, with a temperature between 10-16°C.

⁹ Shooters were members of ITDU trials staff

¹⁰ TES – Tactical Engagement Simulation System

¹¹ Accuracy compares to approximately 200 m using live ammunition – the anomaly is due to sensor positioning and sensor masking on the TES system

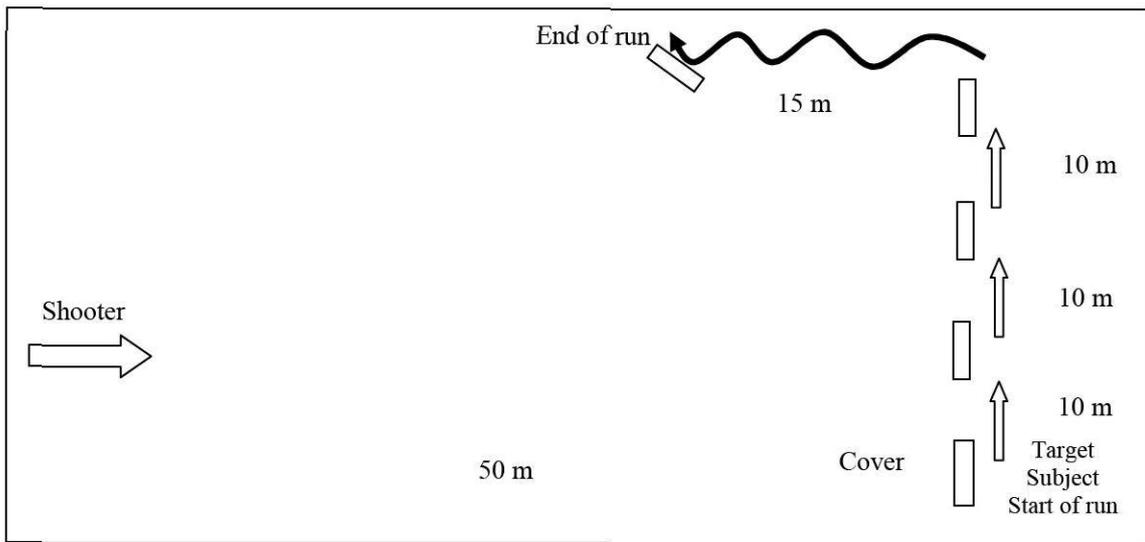


Figure 6: Agility vs Vulnerability course



Figure 7: Subject running between cover points wearing body armour, webbing, day sack and TES vest, with shooter firing blank and laser shots.

3 Results

3.1 Data are presented as mean values. Statistical analyses (one or two way repeated measures analysis of variance with pair-wise comparisons) were carried out to compare differences between mean values for each load condition.

3.2 Part 1 Load vs Agility – 4.5 km March

3.2.1 Temperature and weather conditions were similar throughout each day of the trial. Temperature ranged from 5°C in the morning to 12°C in the afternoon on the coolest day to 12°C in the morning to 16°C in the afternoon on the warmest day with sunshine and fair weather cumulus clouds or clear skies. There was no rain.

3.3 Heart Rate (HR)

3.3.1 Figure 8 shows the mean HR of 17 subjects at 0.5km points during the 4.5 km paced march (error bars removed for clarity of presentation). The march took approximately one hour to complete each day.

3.3.2 HR increases during the first 500m and then remains stable for 2.5km reducing slightly as the march course descends by approx 70m over 2.5 km. Mean HR ranged between values of 109 to 120 beats per minute (bpm) for 6kg to 20kg loads, and 151 bpm for the 60kg load. At 2.5km there was a 5 min 'water stop' – this is not shown on the graph. Between 2.6 and 3.0km, the course included a significant incline and the subsequent rise in HR during this ascent is evident in all load conditions. Mean HR reached its peak at the top of the incline ranging from 128 bpm for the 6kg load, to 177 bpm for the 60kg load. Mean HR remained elevated as the course levelled out at the top of the hill. It remained elevated by a further 9 bpm and 20 bpm respectively for the 6kg and 60kg load conditions.

3.3.3 One subject could not maintain the set pace with a 60kg load and completed the course 2 min after the main group. The data from this subject is included. On a separate day, a second subject with the 60kg load lagged behind the main group too far and was withdrawn from the march at the 3 km point, rejoining the group for the following Fire & Manoeuvre tasks. The HR data from this subject is not included after the 3km point.

3.3.4 Mean HRs appear different for load conditions at rest (0km), but this may reflect the walk to the march start point and is, therefore, not a true resting condition. Comparing the 6kg vs 20kg loads, at all subsequent 0.5km points, mean HR is not significantly different between the two conditions ($P>0.05$). Similarly, for the 30kg vs 40kg loads, at all 0.5 km marching points, mean HR is not significantly different for these two conditions ($P>0.05$).

3.3.5 Comparing HR for the 6kg vs 60kg, 20kg vs 60kg, 30kg vs 60kg and 40kg vs 60kg load conditions (Figure 8), HR is significantly higher at all 0.5km points in the 60 kg

condition ($P < 0.0001$). Mean HRs for the whole march in each condition were 114, 115, 123, 129 and 154bpm for the 6, 20, 30, 40 and 60kg conditions respectively.

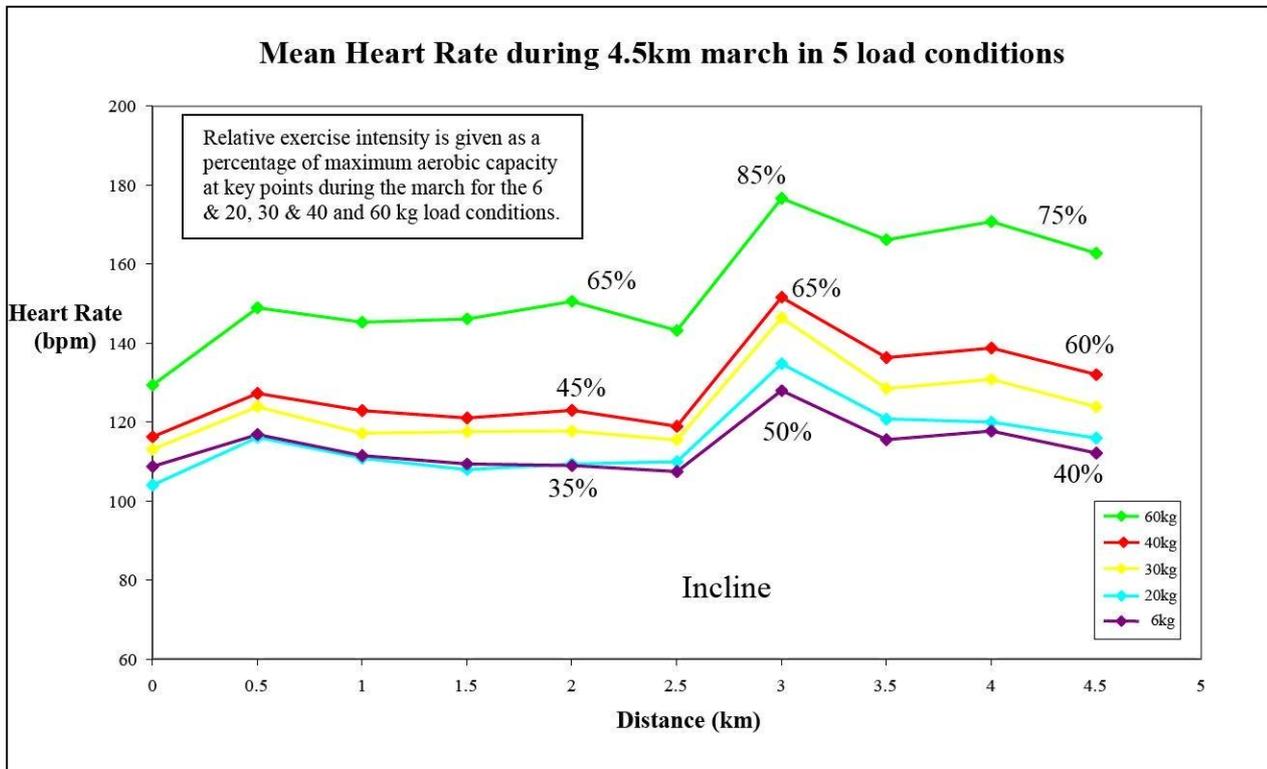


Figure 8: Mean heart rate (bpm), at 0.5km intervals during a 4.5km loaded march, with relative exercise intensity given as a percentage of maximum aerobic capacity at key points during the march for the 6 & 20, 30 & 40 and 60 kg load conditions.

3.4 Perceived Exertion (RPE) and Thermal Comfort (ASHRAE)

3.4.1 Perceived exertion and thermal comfort scales were administered immediately following the 4.5km march, on each of the 5 days, in each load condition. Data for perceived exertion and thermal comfort is displayed in Figure 9. Mean scores for RPE and thermal comfort increase with each load condition. Mean RPE scores were 7.4, 9.7, 11.6, 13.8 and 16.8 for the 6, 20, 30, 40 and 60kg load conditions respectively. Differences between loads were all significant ($P < 0.01$). Mean thermal comfort scores were 4.9, 6.4, 6.6, 7.2, and 8.8 for the 6, 20, 30, 40 and 60 kg loads respectively, with differences between loads all being significant ($P < 0.01$). The mean RPE score of 16.8 in the 60kg load condition represents a description between ‘Very Hard’ and ‘Very Very Hard’ on the Borg RPE scale. In contrast, the 6, 20 and 30kg loads produced mean RPE ratings from ‘Very Very light’ to ‘Fairly Light’ on the scale with 40kg rated between ‘Somewhat hard’ and ‘Hard’.

3.4.2 With respect to the ASHRAE thermal comfort scale, a score between 4 and 6 for an individual generally equates with thermal comfort. Higher scores, such as those recorded here for the 40 and 60 kg loads, would be commensurate with discomfort due to feeling very hot.

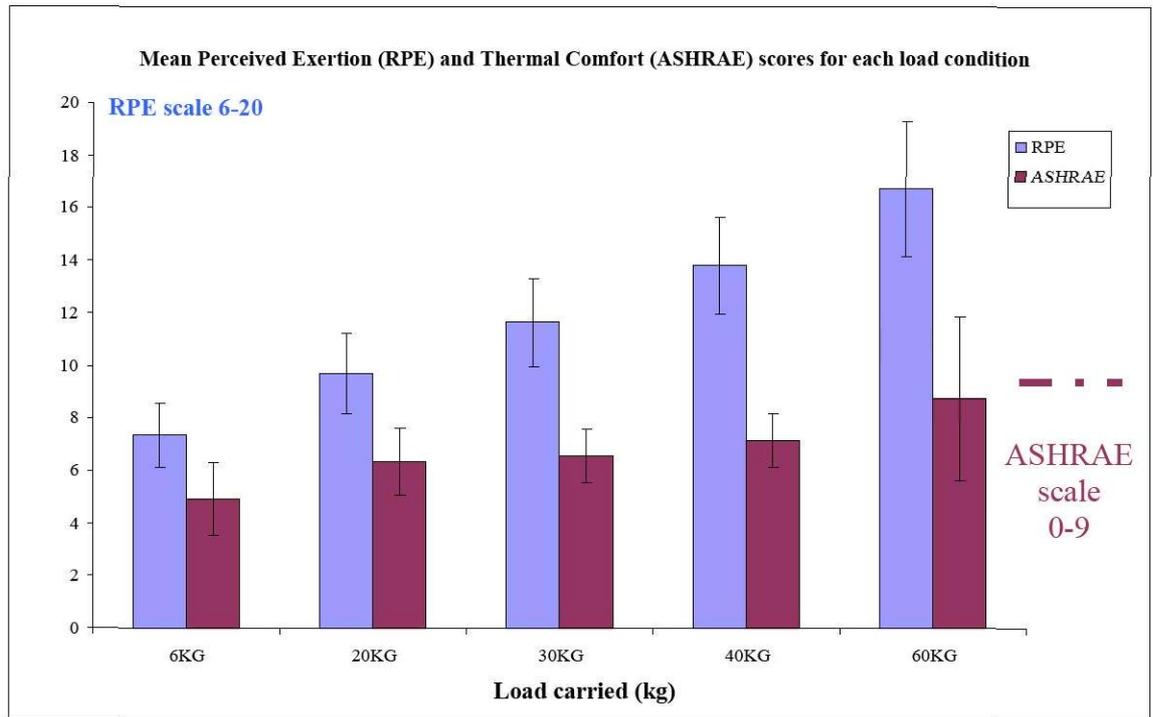


Figure 9: Mean ratings of perceived exertion and thermal comfort¹² following a 4.5 km march in each load condition

3.5 Stroop Colour Word Test

- 3.5.1 The Stroop colour word test¹³ was administered each day immediately following the 4.5km march. The baseline measure was recorded on a separate day, prior to any exertion. The mean time taken to complete the test is displayed in Figure 10 and the number of errors recorded are shown in Figure 11.
- 3.5.2 Mean time to complete the Stroop test at baseline was 21.3 secs and 27.8, 28.2, 24.6, 25.9 and 25.6 for 6, 20, 30, 40 and 60kg load conditions respectively immediately after the march. Although there were significant differences in the time taken to complete the Stroop test between load conditions ($P < 0.01$), there was no obvious pattern to the differences other than the baseline test being completed more quickly than in all other conditions ($P < 0.01$).
- 3.5.3 The mean number of errors made while completing the Stroop test following the march in each load condition is displayed in Figure 6. The mean number of errors made at baseline was 0.4, and 0.8, 0.5, 0.4, 0.9 and 0.6 in 6, 20, 30, 40 and 60kg load conditions. The difference between conditions was not significant ($P > 0.05$).

12 Thermal comfort (ASHRAE) scale reads from 1 – minimum (Cool) to 9 – maximum (Very Hot)

13 Stroop colour word test assesses cognitive function and requires conscious attention – full reference: Stroop, J.R. (1935) Studies Of Interference In Serial Verbal Reactions. Journal of Experimental Psychology, 18, 643-662.

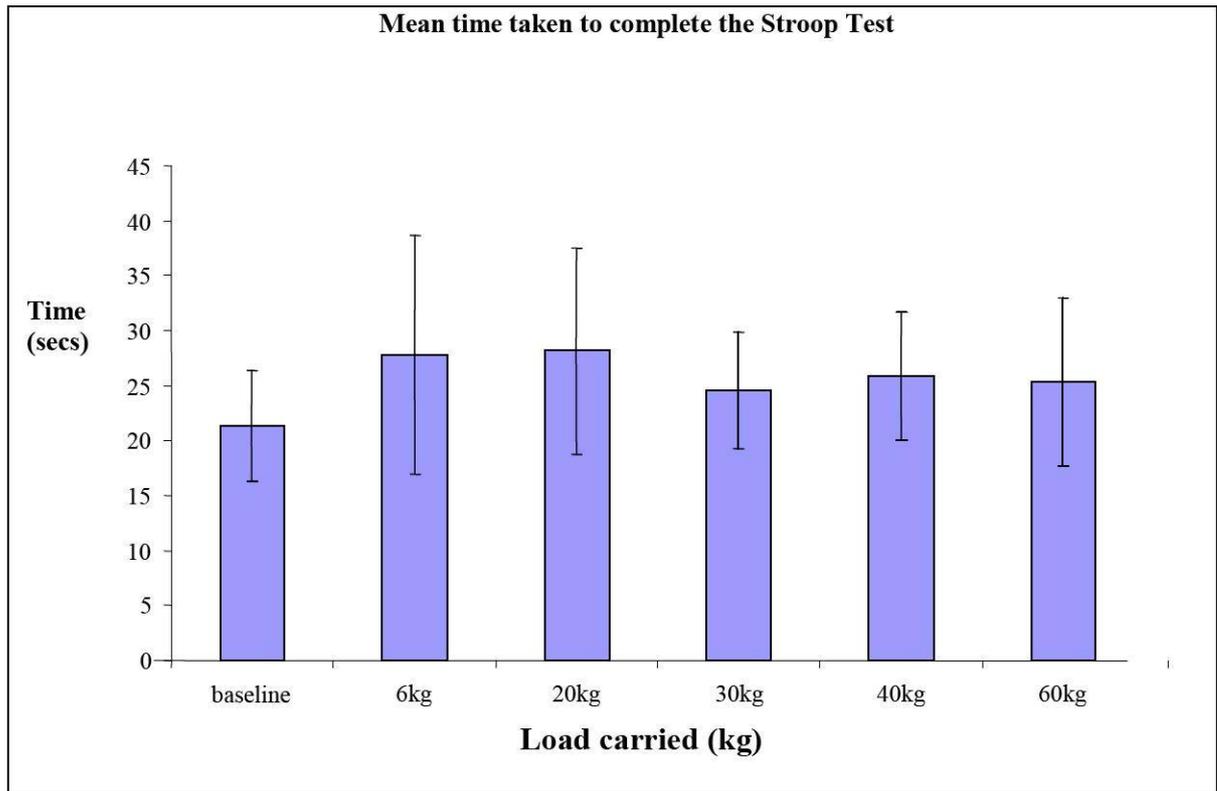


Figure 10: Mean time to complete the Stroop Test, for each load condition. Baseline was before any exertion.

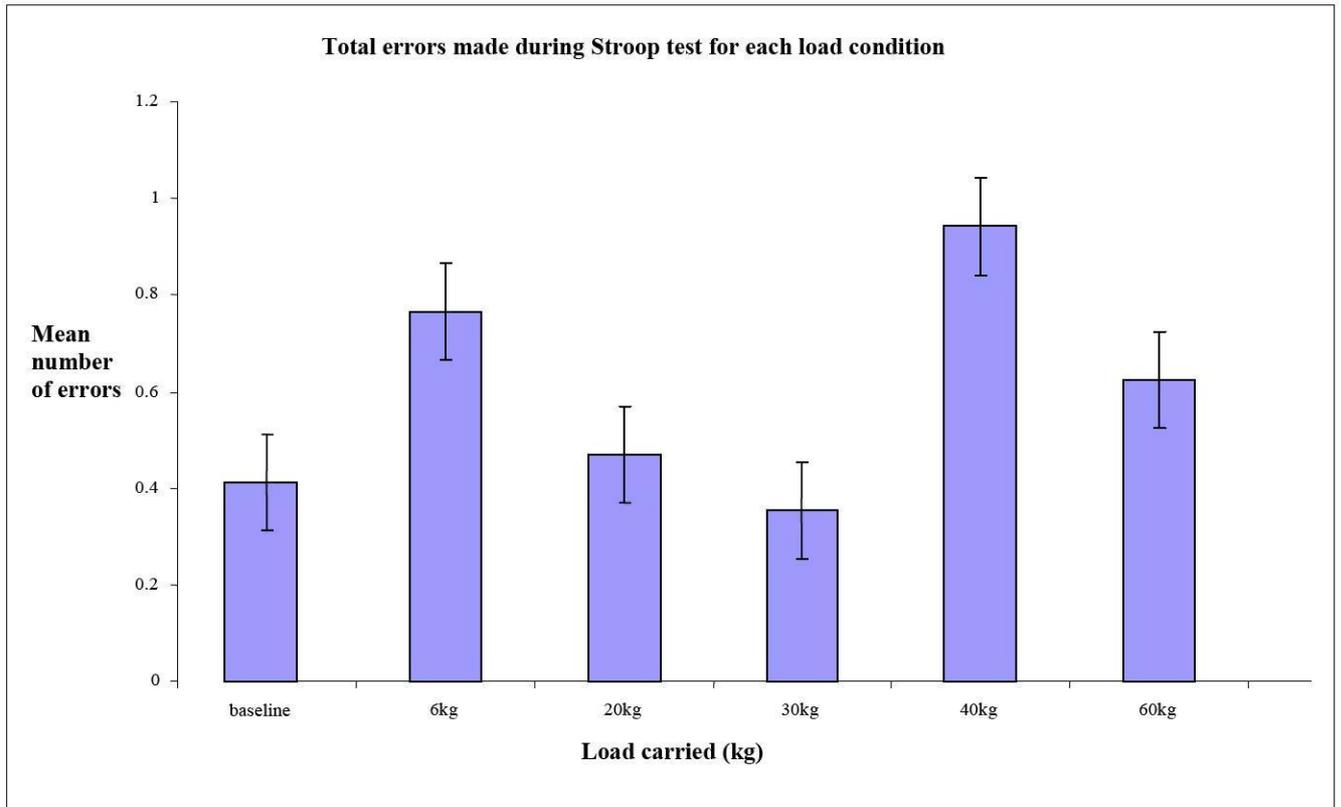


Figure 11: Total errors made during Stroop test for each load condition

3.6 Burden vs Agility (Part 1) – Fire & Manoeuvre and Zig Zag run

3.6.1 Heart Rate (morning recordings)

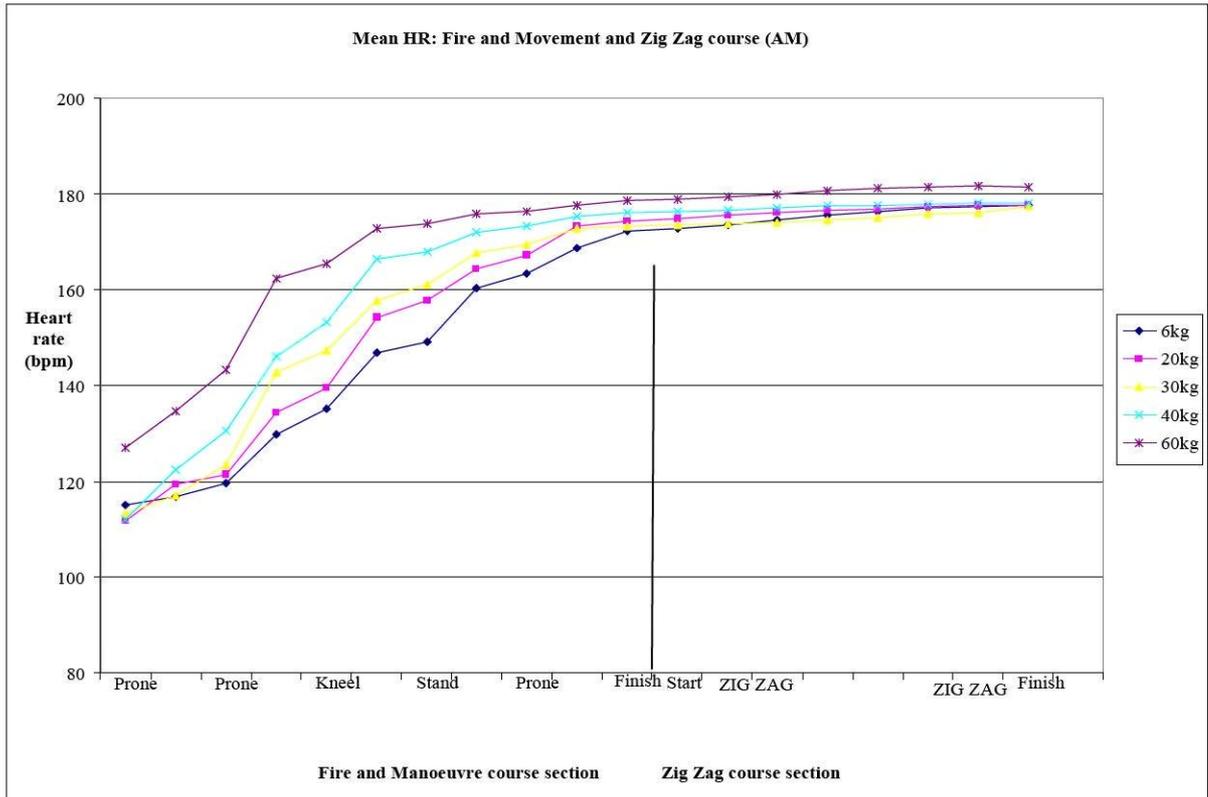


Figure 12: Mean heart rates during simulated fire & manoeuvre activity and zig zag run in each load condition.

- 3.6.2 Figure 12 shows mean HR for the first Fire & Manoeuvre and zig zag tasks (morning, pre-4.5km march) in each load configuration. Mean HR increases as the participant moves through the course. The increase is from 115 to 169 bpm for the 6kg load, and 127 to 177 bpm for the 60kg load. During completion of the zig zag run, mean HR peaks for all weight configurations, from a mean of approximately 176 bpm to 181 bpm for the 6 and 60 kg loads respectively. This represents approximately 90% of maximum exercise capacity.
- 3.6.3 When mean HR for the 60kg condition is compared to all other load configurations, during the period when the subjects are running and taking up fire positions, it is significantly higher than for the lighter loads in 25 out of a possible 28 comparisons ($P < 0.05$). During the zig zag run, there is no significant difference between mean HR values for any of the load configuration comparisons, with it being near 90% of maximum in all conditions ($P > 0.05$).
- 3.6.4 Comparing mean HR for the fire & manoeuvre task before and after the 4.5km march, there was little variation with HR being no different in 76 out of a possible 80 comparison points. The HR data for the task completed in the afternoon is therefore omitted from this report.

3.7 Time to complete Fire & Manoeuvre and Zig Zag course in each load condition (before (a.m.) and after (p.m.) the 4.5km march)

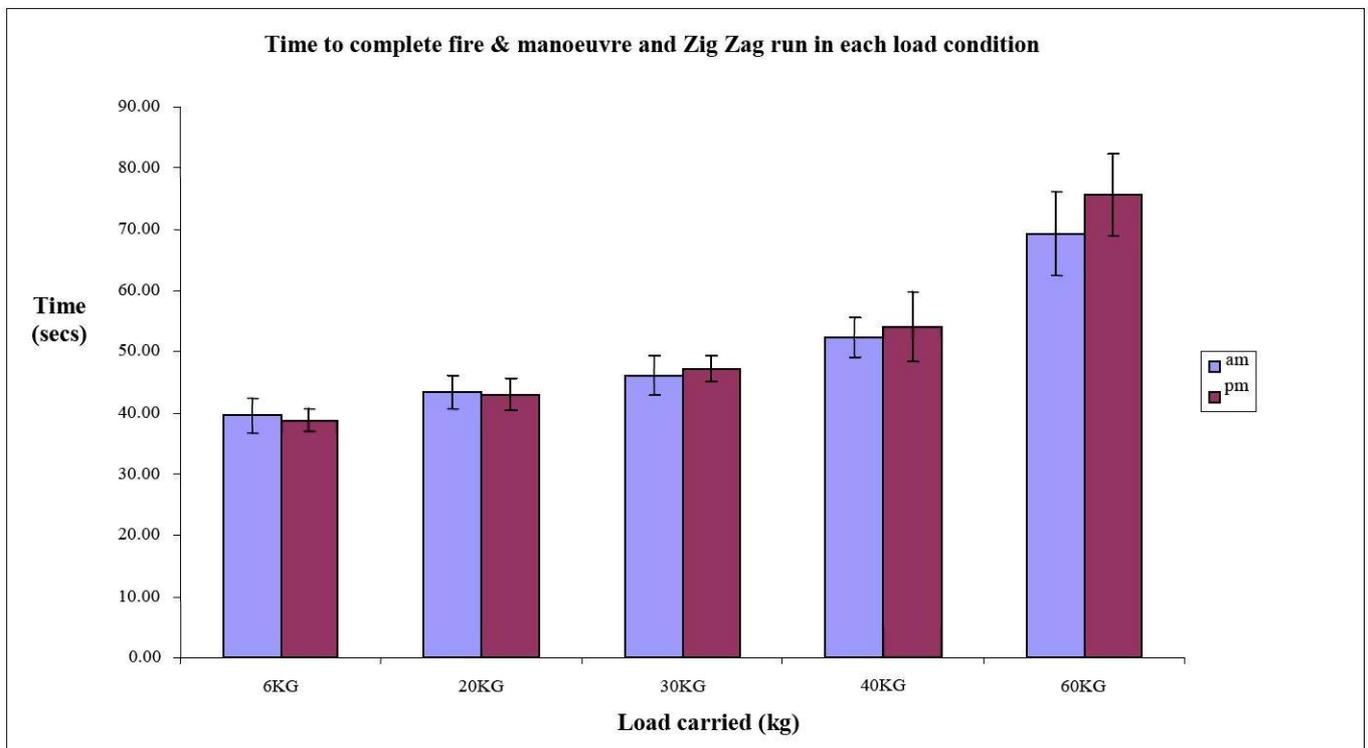


Figure 13: Mean total time, to complete fire & manoeuvre and zig zag run (a.m. – before 4.5km march, p.m. – after 4.5km march).

3.7.1 Figure 13 shows the mean total time to complete the Fire & Manoeuvre and zig zag run tasks in each load condition, before and after the 4.5 km march.

3.7.2 Time elapsed for all values differs in order of weight configuration, at every distance point. Mean total time taken to complete both tasks ranges from 39.6 seconds for the 6kg load to 69.2 seconds for the 60kg load condition. There was a significant increase for the time taken between all load conditions as load increased ($P < 0.001$ between all conditions except between 20-30kg where $P < 0.05$). For the 6kg and 20kg conditions, mean time to complete the course decreased slightly from morning to afternoon (39.6 sec to 38.7 and 43.4 to 43.0 respectively). For all other load conditions, mean time to complete the course was slower following the march than before. The largest decrement in performance was in the 60kg condition where mean time to complete the course increased from 69.2 sec before the march to 75.64 sec after the march ($P < 0.01$).

3.8 Shooting Scores before (a.m.) and after (p.m.) the 4.5 km march in each load condition

3.8.1 Shooting scores and group size¹⁴ before and after the 4.5km march are shown in Figures 14 and 15. For shooting scores, there were significant differences between conditions in both the a.m. ($P < 0.001$) and p.m. ($P < 0.001$) shooting sessions, but there was no obvious

¹⁴ The spread of shot between the two furthest apart hits on the target

pattern to the changes in shooting scores related to load condition. However, shooting scores decreased consistently across all loads following the 4.5km march (mean scores 26.2 vs 22.3, $P < 0.05$).

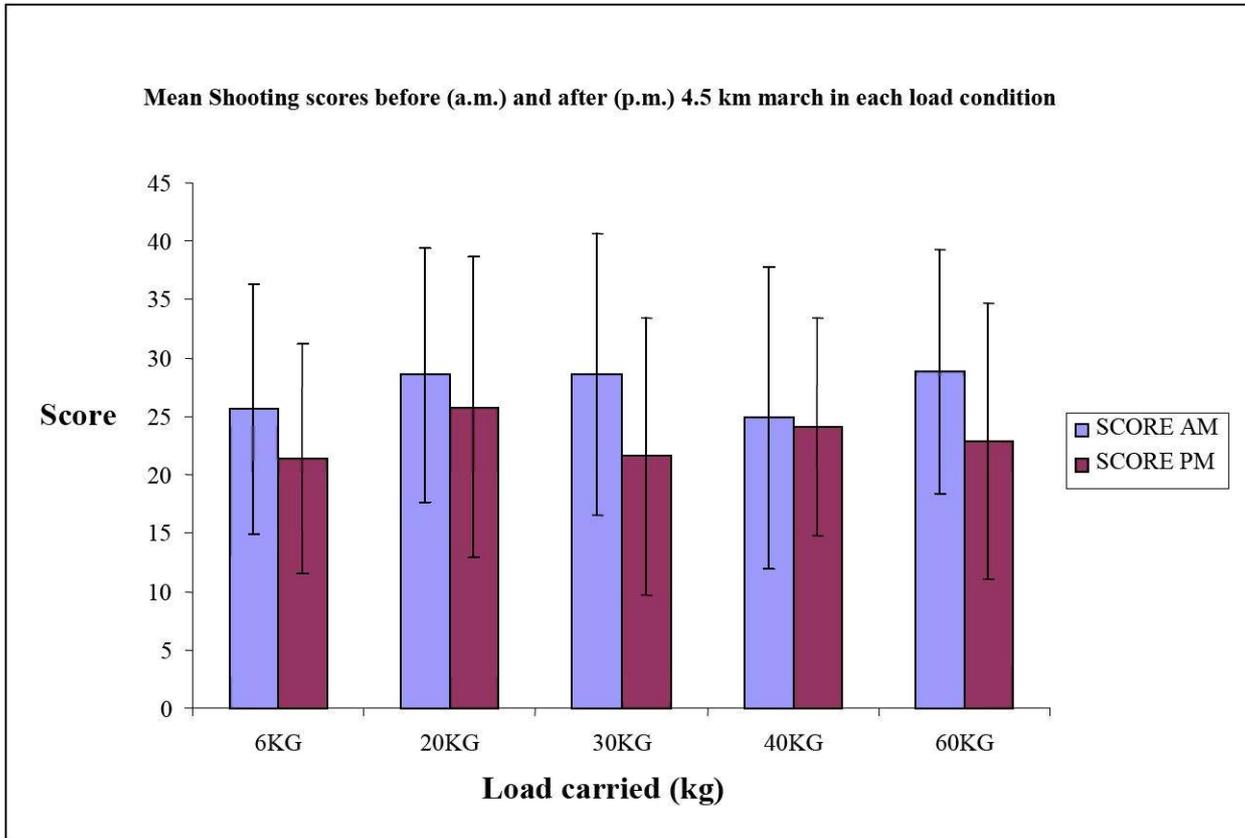


Figure 14: Mean shooting score for each weight configuration (in kilograms) during live firing, before and after the 4.5km march.

3.8.2 There were no significant differences ($P > 0.05$) between group size between load conditions (Figure 15). However, total mean group size across all load conditions increased consistently following the 4.5km march (19.0cm vs 23.8cm, $P < 0.001$).

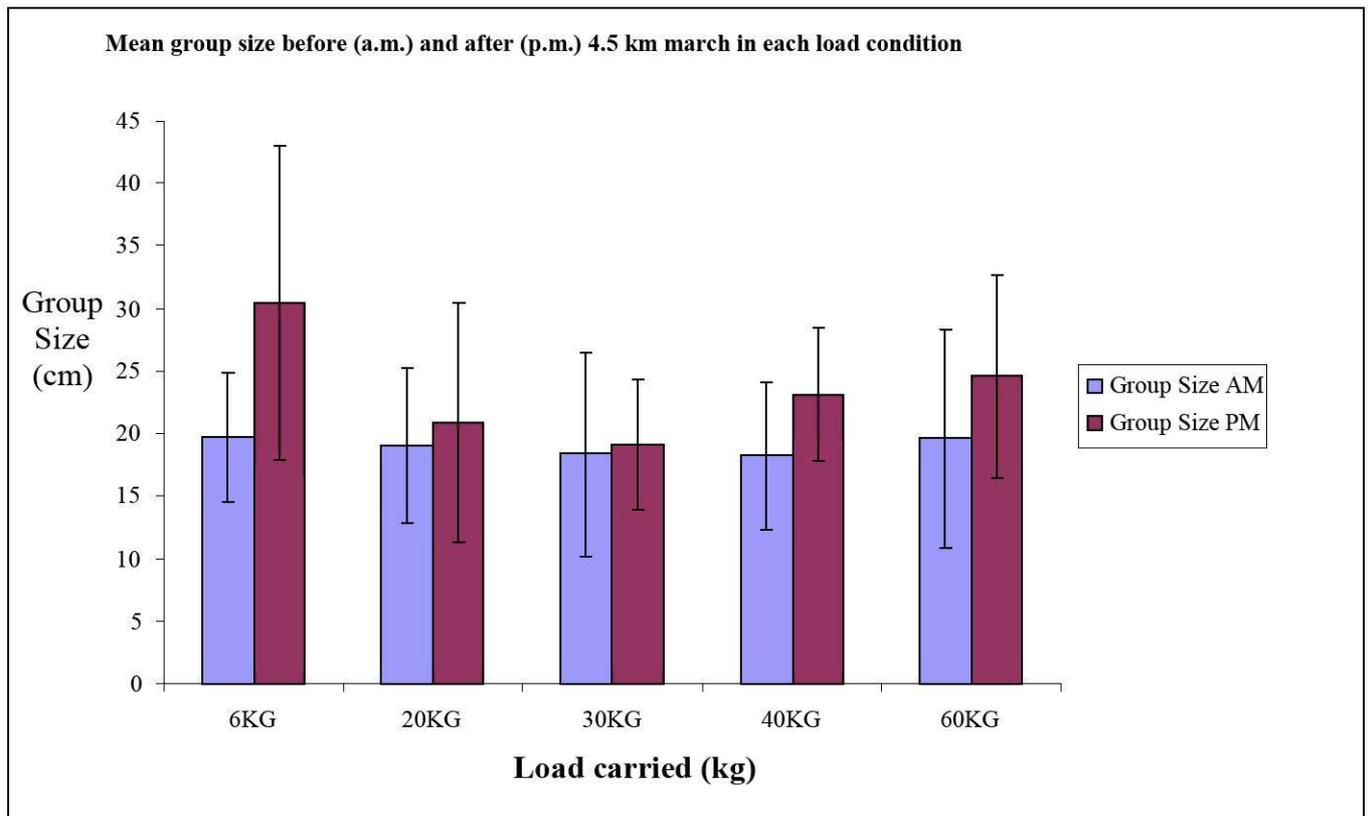


Figure 15: Mean group size for each weight configuration (in kilograms) during live firing before and after the 4.5km march.

3.9 Part 2 Agility vs Vulnerability

3.9.1 There were two shooters during the TES exercise. The mean number of hits was recorded for both shooters together and for each individually. The mean number of hits increased as the load carried increased. For the 6kg and 20kg loads, the mean number of hits was 3.4 and 3.1 respectively. For heavier loads carried, the number of successful hits increased almost two-fold to 5.8, 5.8 and 6.6 respectively for 30, 40 and 60 kg. There were significant differences between successful hits across all load conditions ($P < 0.01$). There was no significant difference ($P > 0.05$) in the mean number of hits achieved with 6 and 20 kg loads (3.1 and 3.4 respectively) but the difference between mean hits (5.8, 5.8 and 6.6) for the heavier loads of 30, 40 and 60kg was significantly higher when compared to the 6 and 20kg conditions ($P < 0.01$).

3.9.2 The performance variation between the two shooters was considerable, with one shooter scoring an overall average of 4.0 hits throughout the exercise and the other scoring an average of 6.0 across all load conditions. If only the better shooter's data is used, the relationship between number of TES hits and increasing load becomes almost linear. (The data for this better shooter is not presented on its own in this report.)

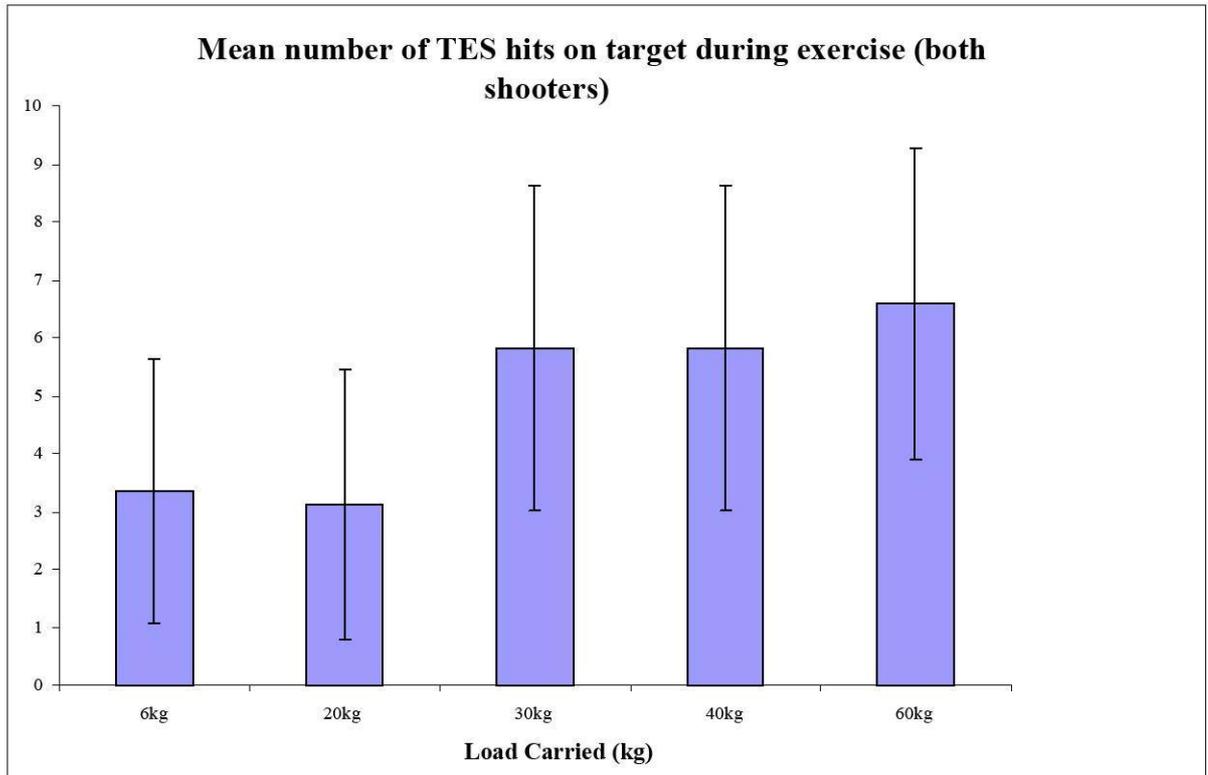


Figure 16: Mean number of TES hits for subjects in each load condition attempting to run between cover points.

4 Conclusions

4.1 Burden vs Agility

- 4.1.1 The relationship between increased load carried and physical performance over a short distance such as the fire & manoeuvre and zig zag run course follows an obvious path; the more the load increases, the more difficult the manoeuvre becomes and the longer it takes to negotiate a simple course. The videos taken of the subjects struggling to raise themselves from the ground under 60kg loads left an impression on all of the trials staff and observers. The heart rate (HR) data presented in Figure 12 illustrates the increased HR caused by the burden of higher loads. However, the times for completion of the fire & manoeuvre and zig zag course demonstrate the impact of load even more clearly. In the 6kg configuration, the mean time to complete the course was 39.6 secs, increasing to 69.2 secs for the 60 kg load. Considering that the whole course was only a total of 110m, this 56% increase in time to complete could have a devastating effect during combat operations when soldiers may have to cover significantly longer distances in order to reach safety. The data in Figure 8 also demonstrate the effect of added fatigue induced by a 4.5 km march, which extends the time to complete the agility course to 75.6 secs, from 69.2 secs in the 60 kg condition. An interesting point to note is that for the lighter loads of 6kg and 20kg, course completion times are marginally faster following the march than before. This is likely due to muscles being thoroughly warmed up by the march activity, allowing subjects to produce more power, with more confidence, during the second fire & manoeuvre and zig zag run tasks.
- 4.1.2 The HRs during the 4.5km march also give an indication of the workloads experienced with different load conditions. With loads from 6kg to 40 kg, and corresponding mean HRs of approximately 110 to 120 bpm in the first half of the march, this equates to a workload of 35-45% of maximum aerobic capacity. This level of work can be continued for many hours without undue fatigue. However, in the 60kg condition, mean HR was near 150 bpm, which represents a workload of approximately 65% of maximum aerobic capacity¹⁵. This level of work can be continued only for a limited period, perhaps an hour or two at the most. The higher mean HR (170+) and workloads (85% of maximum) observed during the march (Figure 3) on an incline would be absolutely unsustainable for more than very short periods and frequent rest stops would be required. More importantly, as trials staff and observers noted during the trials, the subjects with the heavier 60kg loads were less aware or even unaware of their surroundings, often marching with their heads low and their weapons swinging by the sling. The contrast to the relaxed and comfortable manner of those carrying lighter loads was remarkable and the photograph of subjects at the water stop (Figure 17) clearly shows the effect of the heavier loads resulting in subjects bending forwards to gain temporary relief from the discomfort of the heavier loads as soon as they stopped. The Stroop test was administered to try to quantify the decrement in cognitive performance induced by the fatigue of increasing burden. However, as can be seen from figures 5 and 6, the Stroop test did not detect any meaningful relationship between loads carried and subsequent

¹⁵ This is calculated using the Karvonen formula, assuming a maximum HR of approximately 200 bpm.

cognitive performance although it did detect a significantly reduced cognitive performance compared to baseline for all load conditions following the march. This presumably reflects the adverse effect of any physical exertion on cognitive performance, as assessed by the Stroop test. The decrement in awareness of subjects carrying the heavier loads was quite obvious to all trials staff and observers (Figure 18), with lighter loads allowing subjects to look around and be much more aware whilst the heavier load conditions resulted in heads down and weapons hanging from slings. However, the Stroop test may not have been sensitive to this difference. Also, the test instrument may not be sensitive enough to detect more subtle decrements induced by different loads. Further work is required in this area, perhaps with more militarily relevant tests of awareness and cognitive function administered during activities rather than, or as well as, immediately afterwards.



Figure 17: Subjects at the water stop (2.5km) during the 4.5 km march, with heaviest loads at the front of the column and lighter loads toward the rear.



Figure 18: Contrast between lighter (left) and heaviest (right) load conditions during the 4.5 km march.

4.1.3 The heart rate data during the 4.5km march (shown in Figure 8) indicates that the level of exertion required in the 60kg load condition is beyond that sustainable for any prolonged period of time, with mean perceived exertion rates of 17 and thermal comfort scores near maximum, even during pleasant, temperate weather conditions at Warminster, UK in April. The observations of the trials staff confirm that the impact of this load on the subjects' awareness was considerable with obvious discomfort being experienced by the majority of subjects. The additional time taken to complete the fire & manoeuvre and zig zag courses with the heaviest loads also gives a good indication of their adverse impact on soldier performance. This study did not assess the longer-term implications of musculoskeletal injury risk associated with the heaviest load, but observation of the struggle to change fire positions, especially from prone position, must raise concerns of increased injury risk in the longer term. Additionally, the slower movement and performance times in the heaviest load condition could have serious implications for soldier lethality and vulnerability as they would struggle to lay down effective suppressive fire and be slow to reach the safety of cover.

4.2 Shooting performance

4.2.1 There were significant differences between mean shooting scores for all load conditions for both morning (before exertion) and afternoon (following exertion) sessions. However, the differences between load conditions did not appear to follow any distinguishable pattern. The relationship between load, body armour and shooting performance is a complex one, with previous studies¹⁶ noting that some body armour and some load can improve shooting scores, presumably by increasing stability of the firing position. The high variability in group size (Figure 15) before and after exertion in the 6kg load condition appears to support this hypothesis.

4.2.2 However, the shooting scores demonstrated that any physical exertion significantly reduces shooting score and increases group size across all load conditions. This finding could have implications for training, requiring that soldiers train to shoot following physical exertion similar to that required during combat patrols. Through such training, it may be possible to reduce the decrement in shooting performance induced by any prior physical exertion and increase the soldier's potential lethality during operations.

4.3 Agility vs Vulnerability

4.3.1 The second part of the study aimed to quantify the increased vulnerability to enemy fire with increased burden.

4.3.2 The number of TES hits in the lighter 6kg and 20kg load conditions was 3.1 and 3.4 respectively and was not significantly different. However, the number of hits in all loads of 30kg and above was significantly higher (than the lower weights) at 5.8, 5.8 and 6.6 respectively for the 30, 40 and 60 kg conditions. Clearly, increased load causes an increased exposure time during dashes between cover and this translates into an increased probability of engagement, and an increased likelihood of being hit.

¹⁶ R J Edwards, H L Vicary, G Newell, T Powell, A Curtis, M Hayes and S Byfield. Personal Equipment Common Operational Clothing : Agility versus Protection Study. Summary Report DSTL/CR32151/1.0 10 November 2008

4.3.3 The TES equipment was difficult to set up, with an apparent random performance effect being present even when weapons were carefully zeroed and tested. The performance variation was attributed to receiver sensor location (shoulders, front and rear), presentation (only shoulders during side-on run) and masking (due to sensor construction and mounting). Even with the equipment in optimal configuration, some shots were apparently not being recorded as hits when the shooters were confident that they had been aiming on target. For this reason, the distance between shooter and target was reduced from 100m to 50m in order to achieve a more reliable hit rate. The equipment was also set to record multiple hits in order to increase the discriminatory potential between runs with different load conditions. The TES exercise was successful and demonstrated a clear relationship between increased exposure time and increased likelihood of being hit. Thus, the reduced agility observed in Part 1 of the trial translated into increased vulnerability in the TES exercise. Similarly, the reduced marksmanship performance after physical exertion across all load conditions would have implications for reduced soldier lethality. The combination of the above, added to potentially reduced awareness and reduced cognitive ability with any exertion, suggest that excessive loads are not conducive to soldier effectiveness, vulnerability and ultimately, survivability.

5 Recommendations

5.1 Consideration of Outcomes

- 5.1.1 It is evident from the results of this study that increases in the load carried by a soldier also decreases the quality of performance or increases the effort required during a variety of physical activities as follows:
- 5.1.1.1 The time taken to complete a fire and manoeuvre and zig zag course of 110m increased from 39.6sec for a 6kg load to 69.2 sec for a 60kg load and this was increased further to 75.6 secs following fatigue induced by a 4.5 km march;
- 5.1.1.2 During the 4.5km march the heart rate for the 60kg load condition was significantly higher than that for the other conditions at all 0.5km points during the march and equated to a workload of 60% of maximum on level ground and up to 85% of maximum on an incline. In contrast, the workload in the 6 & 20kg load conditions never exceeded 50% of maximum even on the incline;
- 5.1.1.3 The Perceived Exertion scores measured following the march equated to 'Very Hard' to 'Very Very Hard' for the 60kg load and to a score between 'Somewhat hard' and 'Hard' for the 40kg load. In contrast, mean RPE scores for the 6 & 20 kg load conditions were 7.4 and 9.7 respectively, equating to a description of 'Very Very Light' and 'Fairly Light'.
- 5.1.1.4 Similarly, thermal comfort immediately following the march was assessed to be 7.2 and 8.8 (scale maximum 9) for 40kg and 60kg loads respectively. Thermal comfort equates to scores between 4 and 6, which suggests that scores following marching 4.5km with 40 and 60kg loads represent thermal discomfort.
- 5.1.2 Although shooting scores were consistently and significantly lower after the march (22.3 after vs 26.2 before) and were different between load conditions this difference was unrelated to load per se.
- 5.1.3 In the trials assessing change in vulnerability with agility (load) there was a notable difference between the number of hits achieved for the 6kg and 20kg loads (3.4 and 3.1 respectively) and those for heavier loads where the number of successful hits increased almost two-fold to 5.8, 5.8 and 6.6 respectively for 30, 40 and 60 kg.
- 5.1.4 Considering some of these outcomes in combination it is evident that during the 4.5km march the heart rate for the 60kg load together with mean perceived exertion rates of 17 and thermal comfort scores near maximum, indicates that the level of exertion required in this condition is beyond that sustainable for any prolonged period of time even during pleasant, temperate weather conditions at Warminster, UK in April.
- 5.1.5 The evidence regarding the 6kg and 20kg loads suggests that they are perfectly manageable for the tasks used in this study. The evidence regarding the 30 and 40kg loads is less clear-cut. The 40kg load, for example, resulted in perceptions of between

‘Somewhat hard’ and ‘Hard’ exertion following the march as well as thermal discomfort. Both the 30kg and 40kg loads resulted in more successful hits during the agility vs vulnerability task which were significantly higher than those for the 6kg and 20kg load (5.8 and 5.8 vs 3.1 and 3.4 respectively).

5.2 Summary

- 5.2.1 Carrying a load of 60kg in tasks such as those used in this study results in excessive heart rate, high perceived exertion, and thermal discomfort. These findings indicate that, with such a load, performance is not sustainable for any prolonged period of time.
- 5.2.2 Carrying loads of 6kg or 20kg appears to be perfectly manageable for the tasks used in this study.
- 5.2.3 The results for carrying loads of 30kg and 40kg are less clear-cut although both were associated with a significantly higher number of hits than the 6kg and 20kg loads in the agility vs vulnerability tasks.
- 5.2.4 Thus for the militarily relevant tasks assessed in this study: a 60kg load will significantly degrade soldier performance; carrying loads of 6kg and 20kg will have little or no impact on performance; carrying loads of 30kg, 40kg (and higher) will result in progressive degradation of performance which may, in particular, affect vulnerability.
- 5.2.5 In order to achieve the lightest load with body armour (20kg) used in this study, lightweight armour plates were used. These lightweight plates offer a weight saving of approximately 3.3 kg over the standard Osprey plates. However, whilst webbing and day sack were worn, both remained empty to achieve this load 20 kg condition. This would therefore allow only 10kg of additional equipment to be carried even if the maximum load were to be 30kg. Thus, additional weight saving on all equipment is an urgent requirement if any significant load reduction is to be achieved.
- 5.2.6 The overall recommendation must be to reduce soldier load by any means possible, whilst maintaining adequately matched protection, as this will provide tangible benefits in terms of reduced workload, increased lethality and reduced vulnerability.

5.3 Further work

- further work to quantify the decrement in cognitive performance induced by the fatigue of increasing burden;
- quantification of the long-term musculoskeletal injury risk associated with heavy loads (e.g. 40-60kg).

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