Verification and Reliability Assessment of the Common Battlefield Test Facility (CBTF): A Scientific Tool to Assess Agility and Mobility During Individual Soldier Performance

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Executive Summary

This report summarises the verification and reliability assessment of the Common Battlefield Test Facility (CBTF). This assessment was conducted in support of Dismounted Soldier System Integration development objectives of DE&S STSP[1]; that is to understand the effect of military clothing and equipment on the effectiveness of the soldier through scientifically robust and repeatable test and evaluation methods.

The CBTF is a purpose-built bespoke facility comprised of a series of obstacles designed to represent current and future theatres of operation, with a particular focus on urban environments. Moreover the CBTF has been designed as a scientific tool to measure agility and mobility for individual soldier performance against discrete tasks.

The aims of this assessment were fourfold:

1. To conduct a Subject Matter Expert (SME) workshop in order to validate the rationale for the inclusion of the CBTF obstacles and set performance criteria for the obstacles.
2. To determine the test-retest reliability of the CBTF in terms of individual measures of performance.
3. To verify the use of the CBTF, define and write its operating and data capture standardisation procedures.
4. To identify and define acceptable performance metrics for agility and mobility, in order to inform future Systems Requirements for equipment procurement.

Method
Fifteen male serving soldier participants completed the CBTF in three load configurations (A - unencumbered at 9.7 kg; B - Assault Order at 29.8 kg and C - Patrol Order at 39.8 kg). Each configuration was repeated three times for the determination of reliability. These configurations were selected specifically because they demonstrate a clear discrimination in load carriage and bulk.

Results
The assessment results demonstrate a clear statistical discrimination between the three configurations, with the unencumbered configuration producing the fastest overall time to complete and individual time to complete each obstacle.

Specifically, individual time to complete showed acceptable repeatability for all obstacles in all configurations; with the exception of the Window and Mouse-Holed Wall, and Fire & Manoeuvre (F&M) for the encumbered configurations only.

Overall time to complete yielded unacceptable differences between the repeated runs for configurations B and C, repeat 3 was significantly faster than repeat 1.

Subjective questionnaire ratings and quality of task performance degradation all increased with mass and demonstrated an acceptable level of reliability with statistically significant differences.

[1] Defence Equipment and Support, Solider Training and Special Programmes, conducted under The Close Combat Systems programme, contract number TSSP/077.

Conclusions and Recommendations

The CBTF and its set of standardised procedures have successfully been verified as reliable through demonstration of clear discrimination between three load configurations. Subjective feedback and individual time to complete 8 of 10 obstacles demonstrated acceptable levels of reliability. The two obstacle exceptions were the Window and Mouse-Holed Wall and F&M, which both had more variable time to complete.

The effect on performance of the configuration had a larger impact than the repeated run effect. Furthermore, the encumbered configurations (B and C) produced more variable times to complete all obstacles than when unencumbered; attributable to factors such as: participant fitness, strength, motivation, experience and potentially learning effect.

CBTF was used here to discriminate between load configurations with gross mass and bulk (10-20 kg) differences; however it is important to recognise that there may not always be a clear discrimination between configurations with smaller mass/bulk differences. Where this is the case further in-depth Human Factors analysis should be conducted with a careful selection of the appropriate obstacles, focusing the measures of performance on quality of task and collection of subjective data.

The following key agility and mobility metrics were identified as useful for equipment capability System Requirements: quality of task, physical effort experienced during obstacle course, impact of equipment on task performance (rigidity, mobility, mass, bulk), equipment integration and overall discomfort. Bespoke pass/fail cutoff values determined relevant to the equipment under assessment should be specified in each SRD.

It is recommended that subjective feedback should be incorporated in all future equipment trials. This highlights the importance of recruiting the right participants (varied sizes/fitness levels/gender/role appropriate) and having a fully trained SME to identify the quality of task performance consistently.

Whilst the CBTF measures individual agility and mobility, it is only one of a number of tools available that can be conducted to understand soldier performance, therefore the CBTF should generally be applied as part of a wider assessment framework as required. To be effective the CBTF should be used in combination with the Dstl Human Factors Analysis Framework (HFAF)[2] and its standardised set of procedures to ensure that scientifically robust and reliable data is captured to best support procurement decision making. Any deviation in the use of the standardised procedures will reduce the scientific integrity of the data and would not be recognised by UK and International scientific standards.

[2] HFAF is a tool that provides a technical approach for Human Factors (HF) practitioners to gather HF data needed to support the assessment of clothing and equipment.

A CBTF operating protocol[3] has been produced to provide a standardised approach, to the planning, procedures, data collection and evaluation methods that should be adopted when using the CBTF.

[3] PARISH, EC: CBTF operating protocol: CBTF conduct, data capture and evaluation: 2016 DSTL/CR097508 1.0.

Table of contents

List of tables

List of figures

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1 Introduction

1.1 Work Programme Overview

This work was conducted under the Close Combat Systems Programme and supports the Dismounted Soldier System Integration development objectives of Defence Equipment and Support, Solider Training and Special Programmes (DE&S STSP), under contract TSSP/077. The aim of this contract is to understand the effect of military clothing and equipment on the effectiveness of the soldier through robust, sensitive and repeatable test and evaluation methods.

1.2 Report Overview

This document has been prepared as a technical report. Given the exploitation of this work, it is recognised that it may be read by a technical and lay audience. With this in mind, the appropriate level of technical detail has been provided, with definitions throughout to ensure that key concepts can be understood by all readers. It is intended that this report form part of an audit trail for the CBTF, providing evidence of decisions made in the development of the supporting procedures. A separate document has been produced detailing the planning, operating procedures and data collection methods for the CBTF [1].

1.3 Aim

The aims of this assessment were fourfold:

1. To conduct a Subject Matter Expert (SME) validation workshop in order to validate the rationale for the inclusion of the CBTF obstacles and set performance criteria for the obstacles.

2. To determine the test-retest reliability of the CBTF in terms of individual measures of performance (time to complete the entire course, time to complete individual obstacles, subjective and observational feedback).

3. To verify the use of the CBTF, define and write its operating and data capture standardisation procedures.

4. To identify and define acceptable performance metrics[4] for agility and mobility, in order to inform future Systems Requirements for equipment procurement.

[4] A number of requirements in the VIRTUS Systems Requirement Document (SRD) relate to the requirement for agility to be maintained while wearing clothing and equipment. Soldiers must successfully be able to perform actions such as running, crawling, negotiating obstacles and operating in confined spaces. Currently the systems requirement for VIRTUS is: "The system shall not adversely affect the ability to negotiate obstacles when undertaking tactical manoeuvres and military tasks." It is envisaged that an output from this trial will be the identification of acceptable pass/fail cutoff values for agility and mobility domains to inform the SRD with a quantifiable benchmark for a standard level of acceptability of performance that the PPE being tested must meet if it is to be taken forward to the next phase of testing/development.

2 CBTF Overview

2.1 Background

Dstl have previously developed a series of bespoke militarily representative obstacles for a proof of concept Study to determine whether obstacle courses were a useful tool to assess the agility and mobility of individual soldier performance. These obstacles were tested in conjunction with a set of standardised procedures [2] whereby the authors confirmed that obstacle courses were a useful tool for Personal Protective Equipment (PPE) assessments, when used in combination with standardised procedures.

In the initial development stages of the CBTF, several obstacle courses were reviewed (including the United States Marine Corps Load Effector Assessment Program (MC LEAP)) to determine if they could meet or inform the UK requirements. Following this review, it was agreed that a bespoke obstacle course would be the most suitable approach for UK assessments. This decision was based on the following:

- There was a requirement for the UK course to be focussed on the challenges of future operational environments as opposed to existing operational environments.
- There was a requirement for the UK course to be located outside at ITDU and thus had to be weather proof.
- Existing courses had not been validated through physical testing and the reliability of the measurement equipment associated with existing courses had not been demonstrated at the time of review.
- There was a requirement for a short course to enable participants to work at best pace and avoid self-pacing.
- Cost benefits analysis of CBTF vs other obstacle courses.

Following on from the work conducted by [2], DE&S, Infantry Trials development Unit (ITDU) and Dstl collaboratively developed ten obstacles for the CBTF. These obstacles were designed to be used as a whole sequence or as discrete obstacles to address specific research requirements. Additional tasks can be added pre- or post-CBTF: such as range of motion, electronic marksmanship task, patrol tasks, manual dexterity, donning/doffing, casualty evacuation (CASEVAC), vehicle tasks depending on the research requirement.

The CBTF sponsor is DE&S STSP and it is located at ITDU Warminster where it will be managed by DE&S and run by appropriately Suitably Qualified and Experienced Personnel (SQEP) individuals.

The designs[5] of the CBTF were based on recent operational conditions, as experienced and reported by UK armed forces, and in anticipation of the obstacles that may be encountered in future conflicts, which may present a multi-dimensional challenge. For example street level, roof tops, sewers and tunnels, riverine, surface and subterranean environments [5]. The design of some of these obstacles was

[5] Designs were approved by military staff at ITDU and the Integrated Soldier System Executive (ISSE)

modified by STSP after the initial design was agreed. Thus an SME workshop [5] was conducted as part of this work (aim 1) with Dstl, DE&S and ITDU to gather evidence to endorse the final design and provide the rationale and relevance of each obstacle to current and future operations. This also informed the instructions for how participants were advised to negotiate each obstacle and to set performance criteria.

2.2 Exploitation and Use of the CBTF

The CBTF is a purpose built bespoke obstacle facility, designed to represent current and future theatres of operation, particularly focusing on urban environments which are expected to be increasingly prevalent and known to be one of the most challenging environments in which UK forces will operate over the next 20 years [7]. Unlike the standard Military assault courses, which are designed to test battlefield skills, confidence and teamwork, as much as physical ability, the CBTF has been designed specifically as a scientific tool to measure agility and mobility for individual soldier performance against discrete tasks. To be effective, as a scientific tool the CBTF should be conducted in accordance with a standardised procedure and in combination with the Dstl Human Factors Assessment Framework (HFAF)[2].

It is aspired that the CBTF will test systems requirements related to agility and mobility as per aim 4 of this assessment.

The intended use for the CBTF is as follows:

- *Equipment Trials* – in combination with HFAF assessment, CBTF can provide a quantified measurement of the effect of wearing specific clothing and equipment, on soldier agility and mobility, informing future equipment procurement by supporting, de-risking and down selecting of equipment.

- *Research Activities*– when specialist measures of human performance (physiological/biomechanical measurements) are required during simulated military tasks.

- *International Research Collaboration (IRC)* – Data collected during CBTF trials can be shared with other nations through Technical Cooperation Program (TTCP). The TTCP JT TP1 panel have conducted a collaborative project to develop a standardised methodology that can be applied to all nations regardless of what obstacles they have, informing procedures such as training and familiarisation and data analysis [3].

2.3 Research Requirement

The CBTF has been designed for the assessment of existing and new clothing and equipment, to inform future procurement. The CBTF provides a common platform for a standardised repeatable assessment, however a standardised set of procedures has been developed for the CBTF to ensure that scientifically robust and reliable data is captured to best support procurement decision making [1].

For the CBTF to be used as a scientific tool, it must be subject to appropriate levels of validation and verification [4]. Therefore a test - retest reliability trial and accompanying validation workshop have been conducted to enable this verification process.

2.4 Why Use Obstacle Courses for performance assessments?

"A challenge in fielding new soldier equipment lies in assessing how to trade off the increased combat effectiveness provided by the equipment with the decreased mobility associated with increasing the load carried by the soldier" [8].

A soldier must not only carry loads to a battlefield, but must sprint between and across obstacles on the battlefield while under fire. The ability to react with agility and speed under fire, encumbered with heavy loads, is a pivotal infantry task [10], and is an important component of both individual survival and the effectiveness of the fighting unit. The user's survivability on the Battlefield is derived from a number of factors including physical protection, agility and situational awareness. The physical burden and poor integration of equipment contributes significantly to reduced agility.

An obstacle course requiring movements similar to those on a battlefield presents various physical challenges not characteristic of road marching. A soldier's performance on a well-designed obstacle course is a good indication of the ability to get across a real battlefield quickly [11]. A study looking at the utility of obstacles courses and their application concluded that measurements such as time to complete and subjective feedback taken during their obstacle course can be used to assess combat clothing and personal equipment and were able to discriminate between different armour configurations [2].

2.5 Soldier Burden, Mobility and Agility

Soldier burden is defined as the cumulative effect of internal and external stressors on the soldier that are oppressive and difficult to bear. Notwithstanding the significant redundancy within the soldier system this may elicit a reduction in the performance of military tasks[6] .

When considering the impact of load carriage on soldier burden, the effect of increasing the load mass tends to be given the greatest consideration. However, other load characteristics such as distribution, bulk and stiffness also have an impact on soldier performance [12] and combat effectiveness. Soldiers who are laden with excess bulk will have difficulty traversing and manoeuvring through small openings and tight quarters, whereas soldiers who struggle with a lack of flexibility caused by the stiffness of worn equipment and protective gear will have trouble with agility and getting into required postures and positions.

Mobility is a broad and widely used term to describe 'the act or process of moving effectively or of changing position' [13] incorporating flexibility, balance and coordination. However, within the military-based literature the term mobility appears to be used with reference to performance of strength, power and endurance tasks. Agility involves functional movements, various joint specific ranges of motion tasks

[6] The definition of dismounted burden provided in this report was derived by NATO research task group 238 "Reducing the burden on the dismounted soldier".

and completion of obstacle courses that are thought to reflect mobility requirements on the battlefield [14].

Agility is a difficult capability to define, however it incorporates elements of movement speed as well as the ability to coordinate changes in direction and modification of the normal locomotion posture [15].

The use of appropriate measures of mobility and agility performance during human performance assessments is critical in making informed decisions about the protection burden trade-off. The speed at which a soldier can perform a task can greatly affect the outcome of battle; therefore one means of evaluating the effect of burden on the soldier is to time how long it takes the soldier to complete challenging tasks while using the equipment.

Previous work has identified that time to complete an action that requires great exertion over short periods (such as the CBTF), involving tactical movement with (simulated) engagement, is an appropriate measure of mobility/agility performance [8][2]. And is sensitive to differences in load [16] [17] [18] [19]. As such, the time to complete each obstacle and total time to complete the CBTF was considered the primary form of objective data.

Questionnaires recording feedback from participants and observers have also proved to be invaluable methods of assessing the performance of soldier equipment [2]. It is often this data that has the biggest impact when reporting the results of research trials to Military customers. Subjective feedback received in questionnaires has also demonstrated sensitivity to the armour characteristics where other measures have not [20].

2.6 Reliability and Validity

Measurements are almost always prone to various forms of error, which cause the observed value of a measure to differ from the true value. Two of the most important aspects of measurement error are considered to be concurrent validity and test-retest reliability [21].

Concurrent validity concerns the agreement between the observed value and the criterion value of a measure [22], which for the CBTF means: does it actually measure what it intends to measure? The analysis of validity is complex; for the CBTF or any Military obstacle course to be deemed valid it would need to correlate with a criterion measure, and in this case the criterion measure would be the operational environment. Although the CBTF is representative of the tasks that would be encountered in operational environments, it does not fully resemble operational performance (further work would be required to draw conclusions on operational performance) closely enough, therefore assessing its validity through scientific trials is not possible.

There are, however, different categories of validity. It is possible to assess validity based on subjective judgement that a test represents the domain being assessed [22]. This method is known as face or content validity [23], even though face or content validity is a scientifically inferior method (compared to concurrent validity), it serves an important purpose. With this in mind an SME validation workshop was conducted prior to this reliability trial, whereby a panel of military experts[7] reviewed the obstacles within the CBTF to determine their relevance to current and future operating environments.

Test-retest reliability concerns the reproducibility of the observed value when the measurement is repeated [23]. Assessing the test-retest reliability of the CBTF is a matter of repeating the measurements on the same individuals, a reasonable number of times using a reasonable number of individuals. Reliability is also dependent on multiple factors: the testing procedure being one, where the reliability between investigators (*i.e*. inter-rater reliability) is essential, since military testing must be executed on site at several different locations or by several different investigators.

The assessment of the test-retest reliability will allow a measure of the change in performance to be determined from repeated tests, which can then be attributed to the equipment being tested or the ‘normal biological variation’ that may be expected from repeated measurements. This test-retest reliability assessment must be conducted under scientifically controlled conditions, where the only variable to change is the equipment configuration.

[7] DE&S, ITDU, Dstl, DI Training.

3 Overview of the CBTF obstacles

3.1 CBTF Conduct

The conduct of the CBTF was established through a SME validation workshop [4] whereby information was captured on how military users should optimally negotiate each obstacle. Criteria were also identified for quality of task performance for each obstacle as assessed by a military SME[8], observing the ability to negotiate the obstacles in accordance with the given instructions or adopting alternative procedures in a given configuration. A CBTF operating protocol [1] has been produced to provide a standardised approach to the planning, procedures, data collection and evaluation methods that must be adopted when using the CBTF.

The method for the SME validation workshop along with photographs and the rationale for the inclusion of each obstacle have been provided in Appendix A. The instructions for negotiating the obstacles have been provided in [1] since they were modified during this assessment and now form part of the standardised set of procedures associated with the CBTF.

3.2 Overarching Scenario for the CBTF design[9]

The UK Armed Forces have historically sought to avoid congested battlespace when trying to achieve freedom to manoeuvre. Over the next twenty years, the future operating environment is likely to be shaped by increasing urbanisation. Cities will be more physically complex, the key hubs of human activity, where the majority of the World's population live and where political and economic activity is concentrated [3]. For the UK Armed Forces, the urban environment will be one of the most challenging areas in which to operate, therefore the obstacles included in the CBTF have all been designed to meet the requirement to represent this future urban operating environment. Additional obstacles can be added to the sequence if needed.

Number	Obstacle
1	Tunnel Crawl
2	Wire Fence
3	High to Low Crawl
4	Balance Beam
5	Stairs and Ladders Climb
6	Ditch Climb
7	Window and Mouse - Holed Wall
8	High Windowed Wall
9	Courtyard Wall
10	Fire and Manoeuvre

Table 1.0 CBTF obstacles. The Ditch climb has been highlighted due to a fault with the obstacle during the current trial, it was therefore withdrawn. This obstacle will be up and running for future trials.

[8] The military SME responsible for directing participants through the CBTF is named the Test Conducting Officer (TCO); the TCO is responsible for controlling each test serial, this will be an experienced military person.

[9] This overarching scenario was established and agreed at the SME workshop [4].

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4 Method

4.1 Ethics

Ethical approval was obtained from the Ministry of Defence Research Ethics Committee (MODREC) under protocol number 290/PPE/11 "Development of Test Methodologies for the Human Factors Assessment of Current and Future Personal Protective Systems"[10]. An ethical protocol was deemed necessary for this trial, where the scientific data was being captured and analysed (repeated measure) classed it as a research trial rather than an equipment trial.

4.2 Participants

An effective sample size calculation for estimating standard deviation has been used to determine the number of participants and number of repeats required for the current trial (power[11]). This method estimates variation using precision calculations from standard deviations.

Fifteen participants took part in the trial. The mean (±SD) age was 28 (±3.3) years; stature 1.81 (±0.1) m and body mass 79.1 (±12.4) kg. All were serving military male personnel[12] from a cross section of units. They were provided with a full trial brief, passed as medically fit by Dstl Medical Officers[13] and written informed consent was obtained from each participant prior to being accepted on to the trial.

The number of participants used in this assessment gave a high enough statistical power to allow for the assessment of reliability.

4.3 Participant characteristics

Participant characterisation was performed to help explain any performance differences; they provide investigators with a tool to determine if certain characteristics have influenced their performance during the CBTF. It also allows for the comparison of the military participants and comparison between other studies in the literature.

Three different assessments were conducted for characterisation, which included Anthropometric measurement, the Multi-stage Fitness Test (MSFT) and Strength assessments:

4.4 Anthropometric measurement

Anthropometric measurements were used to characterise participants in relation to their size. Body mass, height, skin-folds and body girths were measured to determine BMI, lean body mass and body fat percentage. These measurements were

[10] This protocol has been granted an extension by MoDREC until October 2016
[11] Studies with a high statistical power have less chance of falsely concluding that there is no difference between variables
[12] Although the RAAT bid requested infantry personnel, the volunteers sourced were mounted and performed roles such as clerks, signallers, drivers, mechanics
[13] All participants completed an entry medical before being accepted onto the trial.

conducted by an accredited investigator trained to undertake these procedures in accordance with best practice as detailed by The International Society for the Advancement of Kinanthropometry (ISAK) [24].

- Body Mass: participants were weighed using scales (Seca, Hamburg, Germany) in shorts and t-shirt to the nearest 0.1 kg.

- Height: participants removed their boots before standing on the stadiometer (Invicta, England) with both feet together. Feet, buttocks and scapulae were in contact with the back of the stadiometer, and the volunteer looked directly ahead. Height was measured to the nearest 0.1 cm.

- Skinfolds: Skinfolds were measured at 8 sites (bicep, tricep, sub-scapular, supraspinale, iliac crest, abdominal, thigh and calf) with Harpenden callipers (BodyCare, UK), according to the method of ISAK. Two measurements were made to the nearest mm, and the mean determined for each site.

- Body Girths: Girths were measured at the upper-arm, chest, waist, hips, thigh and calf using a Lufkin metal tape (Rabone Chesterman, England). These measurements, in combination with the skinfold measurement, were then used in the estimation of fat free mass, fat mass and percentage body fat.

4.5 Multistage fitness test (MSFT)

The MSFT (also known as the bleep test) is a standard field measure for the estimation of maximum aerobic power [25]. The test enables the comparison of the participant's fitness level to military fitness standards and population norms. This test involved running back and forth on a 20m course in time with a bleep that sounds at progressively shorter intervals. Participants either continued until volitional exhaustion or until the test was terminated by the investigator (when they failed to complete three consecutive shuttles in time with the bleep). Participants performed the test wearing running shoes and sports clothing. Heart rate was monitored throughout the test by a telemetric heart rate monitor for determination of maximal heart rate (HRmax). HRmax was used at a later stage in the trial in order to calculate the percentage of HRmax that the participants were working at during the required tasks. The maximum aerobic power was calculated from the level that the test was terminated on.

4.6 Strength Measurements

Measures of body strength were also taken as many of the obstacles are related to upper body strength, such as the walls and window clearance.

The measurements used in Military Annual Training Test 2 (MATT-2) [25] for assessing upper body strength were used in this trial. This involved measuring the number of a sit-ups and press-ups that can be conducted in two minutes. The procedures are provided below.

Press-up test: Each participant was asked to complete as many press-ups as possible in two minutes. Participants worked in pairs starting by lying flat on their stomach / chest with their legs straight. Feet were positioned no more than 30 cm apart and hands with palms down in a comfortable position. One complete press-up involved straightening the arms until they were fully locked at the elbows, then lowering the body using the toes as a pivot until the chest touches a partner's fist. Participants were instructed to maintain a rigid body posture, generally in a straight line, moving as a single unit. Participants were allowed to rest during the test and restart from the start position.

Sit-up test: Each participant was asked to perform as many sit-ups as possible in two minutes. Participants worked in pairs starting lying flat on their back with their knees bent to an angle between 70 º and 110 º. Forearms and hands were crossed across the chest and elbows tucked in throughout. Participants initiated the sit-up by raising their body up to, or beyond the vertical position (base of their neck will be in a position directly above the base of their spine), maintaining a straight back at all times. Once this position was reached they lowered their body until they touch the mat with the bottom of their shoulder blades. Their feet were held in place by their partner and they were allowed to rest during the test restarting from the start position.

4.7 Study Design

4.7.1 Configurations chosen for investigation

In order to assess the test-retest reliability of the CBTF and verify its procedures, three dress configurations were chosen[14]. UK Military Personal Load Carrying Equipment (PLCE) is divided into three orders of dress: Assault Order, Patrol Order and Marching Order (fight light doctrine[15]). A decision was made and agreed by SMEs at ITDU and DE&S to include Assault and Patrol order only; this was based on the fact that personnel should only carry into battle, loads commensurate with the task. Marching order was therefore discounted from these options given that it would ordinarily be dropped prior to negotiating such obstacles. These load configurations have also demonstrated a clear discrimination between different testing options in previous research, and were therefore appropriate for use in a validation study.

Each participant was asked to complete the obstacle course in the following three dress configurations using VIRTUS Pulse 1 equipment[16], repeating each configuration three times. Participants were fitted for the three configurations and trained in the use and fit of the VIRTUS pulse 1 kit by a military advisor. The mass of the three configurations have been provided in table 2.0, all configurations include the following safety items: helmet, gloves, kneepads and eyewear spectacles (full details of the three dress configurations items have been described in Appendix B).

A. Unencumbered[17] (Weapon and Helmet)
B. Assault Order[18] (Weapon, Helmet, Webbing, Body Armour)

[14] A joint decision was made by DE&S ITDU and Dstl at the validation workshop

[15] Fight light doctrine INFBS-PCD-Project PAYNE 2014.

[16] All VIRTUS items were supplied to the participants and all participants wore the same clothing and equipment in their given size.

[17] Standard dress (boots, Under Body Armour Clothing System (UBACS) and Personal Clothing System Trousers (PCS) plus weapon (SA80 A2) and safety items.

C. Patrol Order[19] (Weapon, Helmet, Webbing, Body Armour, Daysack)

	A	B	C
Total Mass (kg)	9.7 (± 0.5)	29.8 (± 0.3)	39.8 (± 0.7)

Table 2: Mass of the three configurations under investigation, reported as mean and SD.

Unencumbered configurations represented the baseline for the trial. The mass and bulk[20] increased through the configuration options order to assess their effect on the participant's ability to negotiate the obstacles. Beyond replicating PLCE orders of dress, the exact selection of equipment and configuration is irrelevant other than it provides distinct increments in bulk, mass and mobility offered. For the purposes of validation such as this trial, configurations of known difference should be used. If CBTF were unable to distinguish difference between these configurations of obviously increasing difficulty, it will be unable to detect more subtle differences between equipment.

The order in which the configuration options were worn was initially counterbalanced in accordance with a Latin Square design to avoid bias. However the Wet Bulb Globe Temperature (WBGT) [21] was measured daily by the PTI, as taken from the ITDU gymnasium, and on the first testing day the index rating was exceeded for configuration C. Therefore the Latin square had to be adjusted so that configuration C was not used. All participants performed each configuration three times and completed a maximum of two runs each test day. The rest period between repeats was at least two hours (>2hrs).

[18] Assault order is the minimum load required to close with and kill the enemy. It consists of only the essentials required to conduct the assault, from crossing the line of departure to the reorganisation.

[19] Patrol order is assault order plus additional equipment, rations and water required for the mission, typically allowing a soldier to operate for 24 hours without his rucksack. The items are carried inside a rucksack side pouch or daysack.

[20] Although bulk was not measured due to time constraints the addition of webbing and webbing plus daysack will increase the bulk. Bulk should be measured in future studies where possible.

[21] The measurement of Wet Bulb Globe Temperature (WBGT) provides a useful indicator of the thermal strain that may be experienced by the participants. The WBGT index rating exceeded the safe limit for configuration C due to extreme temperatures

	TD1	TD2		TD3		TD4		TD5	
	AM	AM	PM	AM	PM	AM	PM	AM	PM
Participant	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9
2	B	C	A	B	C	A	B	C	A
3	A	C	B	C	A	B	C	A	B
4	B	A	C	A	B	C	A	B	C
5	A	B	C	B	C	A	B	C	A
6	B	C	A	C	A	B	C	A	B
7	A	B	C	A	B	C	A	B	C
8	B	C	A	B	C	A	B	C	A
10	A	C	B	C	A	B	C	A	B
12	A	C	B	C	A	B	C	A	B
13	B	A	C	A	B	C	A	B	C
14	A	C	A	B	C	A	B	C	A
16	B	C	A	C	A	B	C	A	B
18	A	B	C	A	B	C	A	B	C
19	B	C	A	B	C	A	B	C	A
20	A	C	B	C	A	B	C	A	B

Table 3, Modified Latin square to take into account the restrictions of the WBGT index on test day one. TD= Test Day (AM:PM), TS = Test Serial (1 -9), A, B, C = unencumbered, assault order, patrol order respectively.

4.7.2 Instructions for negotiating the obstacles

The participants were instructed to negotiate the obstacles according to a set of instructions that were developed during the SME workshop [4] and were then further modified during the pilot trial of this assessment by the TCO and PTI. The instructions were developed for the unencumbered configuration and the exact techniques were found to be dependent on configuration being worn and the physical characteristics of the participant (*i.e*. height, limb length, weight).

The full instructions have been provided in the accompanying document [1].

4.8 Study Overview

4.8.1 Environmental Conditions

All testing was conducted outside during the month of July at ITDU Warminster. Mean temperature was 26 ± 1°C, and WGBT index ranged from 19 to 24. Days one to three were dry and sunny, with days four and five experiencing light rain. Participants waited in a room supplied with water and food until their test serial.

4.8.2 Familiarisation and Training

Participants were briefed on all elements of the trial to familiarise themselves with the CBTF, subjective questionnaires and ratings scales. Participants initially walked through the obstacle course in configuration A, one by one with a TCO providing instruction on how to negotiate the obstacles[22].

The following day the participants were then trained to a "plateau performance" on the CBTF whilst wearing configuration A, this was to reduce the learning effect associated with repeated runs. Plateau performance was assessed using total time to complete[23], where four repeated runs of the obstacles course were performed. [24] Participants were then given a chance to familiarise themselves with the obstacles in configuration C and were critiqued through these practice runs by the TCO. The participants were given the chance to practice individual obstacles until they were deemed to be fully competent by the TCO and PTI.

Training in the use of the questionnaires was conducted for each individual with an assigned investigator[25].

4.8.3 Pre-test Procedures

Prior to the start of the run, participants were weighed in their underwear to determine "nude weight" and then redressed into their standard dress[26]. Participants then performed a standardised warm up[27], in pairs just prior[28] to their test run which included the following:

- 120m self-paced walk to a coned activity area.
- 60m jogging in-between 4 cones (spaced 15m apart) alternative side stepping at each cone. 60m jog back to start point.
- Repeat above with 5 squats at each cone.
- Repeat with 1 burpees at each cone.
- Walk back to dressing area.

Following the warmup participants immediately donned the VIRTUS configuration under investigation. Participants were then re-weighed to determine "dressed weight".

4.8.4 CBTF Test Procedures:

A flow diagram of the CBTF test serial has been provided in figure 1. Following the warm up participants were asked to move as quickly and as accurately as possible whilst still maintaining form (TTPs) between obstacles, without stopping unless medical assistance was required. Participants were instructed in the safe correct manner in which to complete the course by the physical training instructor (PTI).

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[22] Instructions for negotiation were determined at the SME workshop and during the pilot testing with the TCO and PTI.
[23] See section 6.2 for data analysis details.
[24] Due to time constraints and to minimise fatigue a maximum of four training runs were performed.
[25] It is important to ensure that all investigators are trained in all the trials procedures prior to the assessment. Refer to [1] for full details of expected training.
[26] Boots, UBACS and PCS trousers.
[27] The warm up was prescribed and directed by a qualified Army Physical Training Instructor.
[28] Approximately 5 minutes before the test run started.

Each participant was required to complete 3 runs in each of the three configurations over the duration of five days; each run was separated by a rest period of no less than 2 hrs. A maximum of two runs were completed each day for each participant to minimise the risk of injury and onset of fatigue.

Prior to the start of the test serial participants were asked to rate their perceived exertion (BORG) [27] thermal sensation (ASHRAE) [28] and thermal comfort (BEDFORD) [29].

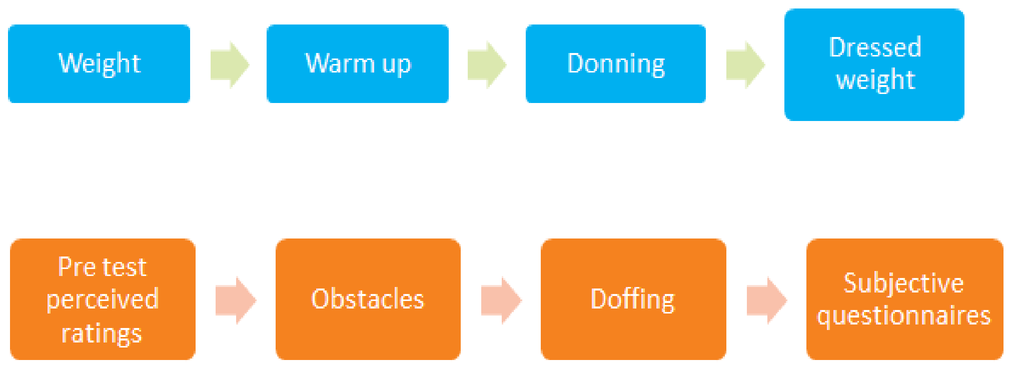

Figure 1: CBTF test serial flow diagram.

4.8.5 Measurements of performance

4.8.5.1 Timing:

Time to complete was measured by an electronic timing system (MYLAPS ProChip timing system), which allowed the dual measurement of time to complete each obstacle in addition to total time to complete.

Each participant was given a separate timing transponder to ensure that the runs of different participants were recorded separately. For each run, the investigator recorded the participant number, run number, and a pre-determined reference to denote the equipment being carried.

The transponder was attached to the participant around the ankle and was carried in the same location on every run.

The F&M obstacle was split into three elements:

1. Approach wall, adopt standing fire position.
2. Move to next wall, adopt kneeling fire position.
3. Move to next wall, adopt prone fire position (finish).

For the purposes of this trial these splits were timed by an investigator using a stopwatch, in order to understand whether split times for individual elements of this obstacle were useful. The standardised method of recording the split times has been provided in [1].

4.8.5.2 Quality of Task Performance:

Subjective feedback was also collected from the TCO (Dstl MA) who observed the participants going over the obstacles. This quality of task assessment was conducted on the five point scale provided in Table 4 that had previously been used on a previous HFAF level two trial [2] a copy of the questionnaire has been provided in Appendix C. This questionnaire was also given to the participants for self-assessment after they had completed each repeat of the CBTF.

1	Catastrophic degradation of task performance
2	Severe degradation of task performance
3	Noticeable degradation of task performance
4	Minor degradation of task performance
5	No degradation of task performance

Table 4: Scale used to assess quality of task

4.8.5.3 Heart Rate

Heart rate was measured using Garmin Forerunner 305 for verification that the participants were working at best pace. Participants were asked to wear a chest strap and wrist watch to record heart rate. Previous studies have shown that heart rate has less utility for discriminating between body armours during best paced, high intensity exercise[2][16][18] but is a useful measure to ensure participants are operating close to maximum heart rate throughout trial activities.

4.8.6 Post-test Measurements

4.8.6.1 Subjective Rating Scales

Immediately after completion of the obstacle course the participants were asked to provide ratings of perceived effort, thermal comfort and thermal sensation using the scales developed by Borg [27], ASHRAE [28] Bedford [29].

4.8.6.2 Subjective Questionnaires

Participants were then asked to rate their perception of their performance for the following categories:

1) Level of physical effort experienced during each obstacle.
2) Impact of the equipment worn based on: Rigidity, Mobility, Weight, Bulk, and Discomfort.
3) Quality of task performance (self-assessed).

4.9 Statistical Analysis

Statistical analysis was carried out using R v.3.1.1; the packages used were MASS, HH, AER, lsmeans, lme4, ggplot2, and Paired Data. Statistical testing was used as an objective method of interpreting the data. Statistics were used to describe the characteristics of the data.

The data was assessed for a configuration effect, a repeat effect and a configuration against repeat effect. Any configuration vs repeat effect will mask any repeat effect – i.e. be more important than it. However if there is a repeat effect and not a configuration vs repeat then this means that it's accounting for variation within the model.

Proportional odds logistic regression was used on ordinal scale data (Quality of task data and the subjective ratings); participant was included in the model to account for this random effect.

Linear mixed-effects models were run on the continuous data (NASA TLX data, timings data, and heart rate data), with participant included as a random effect. The data was checked for normality and was log-transformed into a log scale if normality assumptions on the raw data were violated.

The data from the ditch climb obstacle prior to it being removed from use was excluded from the analysis to ensure that like for like data was being analysed.

The subjective questionnaire data was investigated both using the original continuous data, then as converted ordinal data.

Data were accepted as significant at the 95% confidence level (α level of 0.05). However the higher level of confidence (99%, α level of 0.01) has been reported for data that gave this higher significance level.

Coefficient of variance (CV)[29] was performed on overall time to complete, between run three and four for the plateau in performance data.

[29] CV is a measurement of variability

5 Results and Discussion

5.1 Participant Characterisation

Individual data for anthropometrics, MSFT and strength measurements are presented to identify where they may have influenced the participants performance during a run. These data will also have utility for comparing data between different studies.

5.1.1 Participant Experience

No participants had experience with wearing the VIRTUS kit and only 7 out of the 15 subjects had operational experience. All participants had completed phase 1 and 2 training. The participants were from mounted regiments and not previously familiar with the VIRTUS kit used in this trial. Additionally their roles included clerks, mechanics, signallers and drivers.

5.1.2 Anthropometrics

The anthropometric characteristics of the participants are presented in Table 5. Fat Free Mass Index (FFMI) was calculated as an indicator of lean body mass[30] (the measurement of which is impractical during field studies). Although the terms fat free mass and lean body mass are used interchangeably in the literature, FFMI is approximately 3% less than lean body mass[31]. Although anthropometric measurements are useful for participant characterisation, there is no requirement for these to be included as an SRD metric, unless specifically relevant to the bespoke research question.

[30] The gold standard procedure for measuring lean body mass is by CT scan.

[31] Lean body mass contains a small percentage of non-sex specific essential fat equivalent to approx 3% of body mass. Fat free mass represents the body mass devoid of all extractable fat (fat free mass = body mass - fat mass).

Participant[32]	Height (m)	Weight (kg)	BMI	Fat (%)	Fat Mass (kg)	FFMI (kg)
2	1.84	66.20	19.55	7.45	4.93	61.27
3	1.85	73.80	21.59	7.43	5.49	68.31
4	1.80	84.00	26.04	18.78	15.77	68.23
5	1.78	72.20	22.89	8.89	6.42	65.78
6	1.90	75.40	20.95	12.27	9.25	66.15
7	1.83	75.20	22.46	9.45	7.11	68.09
8	1.75	76.00	24.79	10.15	7.72	68.28
10	1.79	81.00	25.34	15.20	12.32	68.68
12	1.70	73.40	25.40	13.82	10.15	63.25
13	1.70	73.60	25.47	9.72	7.16	66.44
14	1.83	101.40	30.15	20.30	20.59	80.81
16	1.80	80.60	25.02	12.79	10.31	70.29
18	1.97	106.60	27.61	15.74	16.78	89.82
19	1.85	89.00	26.15	10.06	8.95	80.05
20	1.71	58.80	20.11	6.22	3.66	55.14
Mean	1.81	79.15	24.23	11.89	9.77	69.37
SD	0.07	12.35	2.93	4.20	4.77	8.48

Table 5: Anthropometric Characteristics of the Participants. FFMI = fat free mass index, BMI = body mass index.

5.1.3 MSFT and Strength Tests

The results from the MSFT are presented in Table 6. Predicted $\dot{V}O_{2max}$ was determined using [25]. All the participants were ranked as having a "Fair" fitness level or above when their age and $\dot{V}O_{2max}$ were compared to the normal population [30]. The minimum fitness standard identified in the MATT2 fitness test for men aged 29 or less is a minimum of 44 press ups and 50 sit ups in two minutes [26] The HRmax achieved during the MSFT was assumed to be the participant's maximal heart rate value and used for the retrospective analysis of heart rate data presented in section 6.8. Although fitness and strength measurements are useful for participant characterisation, there is no requirement for these to be included as an SRD metric, unless specifically relevant to the bespoke research question.

[32] Participants 1,9,11,15,17 were either voluntary withdrawals or medically withdrawn prior to or during the trial.

Participant	Age (yrs)	MSFT Level	HRmax (beats.min-1)	Fitness Level	$\dot{V}O_{2max}$ (ml.kg.min-1)	Sit ups	Press ups
2	25	10,2	183	average	47.4	59	45
3	26	12,1	188	good	54.0	65	74
4	27	9,1*	182	average	43.6	54	70
5	28	10,1*	197	average	47.1	77	64
6	29	11,2	182	good	50.8	70	61
7	33	10,1*	187	good	47.1	55	50
8	21	11,1	194	average	50.5	65	70
10	27	9,9*	199	average	45.8	60	55
12	29	8,11*	197	fair	43.3	60	55
13	29	12,7	193	good	55.7	59	49
14	32	8,7*	183	fair	42.1	55	46
16	31	11,8	199	good	52.5	65	51
18	23	8,7*	197	fair	42.1	70	50
19	30	10,3	182	average	47.7	62	61
20	30	10,2	185	average	47.4	75	50
Mean	**28**		**190**		**47.8**	**63.4**	**57.6**
SD	**3.3**		**6.9**		**4.2**	**7.1**	**9.1**

Table 6: Results from MSFT. * indicates participants who failed to meet the minimum fitness standard for the MSFT. HRmax = maximum heart rate achieved during the test.

Plateau performance was assessed using total time to complete, where four[33] repeated runs of the obstacles course were performed in configuration A only, in order to reduce the 'learning effect' associated with negotiating obstacles on multiple occasions.

Coefficient of variance (CV)[34] was performed on overall time to complete, between run three and four with the mean CV being 3.4% (± 2.5%).

Additionally paired t-tests were carried out on run 1 vs run 2 and run 3 vs run 4 in order to identify the plateau. No significant differences were found between the runs for the overall time ($p > 0.05$) however when the individual obstacles were analysed the courtyard wall identified a significant difference between the runs ($p < 0.05$), suggesting that the participants were still improving by run four and were not fully trained on this obstacle.

These findings indicate that for overall time to complete the participants were trained to a plateau in performance for configuration A.

5.2 Obstacle Course Measurements

5.2.1 Heart Rate

Heart rate was monitored to confirm how hard the participants were working while negotiating the obstacles. Heart rate was between 94 and 95% of HRmax achieved in the MSFT. This provides confirmation that participants were working at best pace

[33] Due to a limited timeframe no more runs could be performed, however a maximum of 5 runs would have been run in order to identify the plateau.
[34] CV is a measurement of variability

during the course. No differences between the repeats were evident, meaning that heart rates were consistent throughout all three runs regardless of the configuration being worn. As the participants were working at best pace in all the configurations, there were no significant differences between the configurations. These results agree with previous research [2][8][16] and confirm that that the instructions and training given to the participants was sufficient to ensure that they exerted the same amount of effort with each repeat. As such, heart rate is not considered a required metric for use of CBTF.

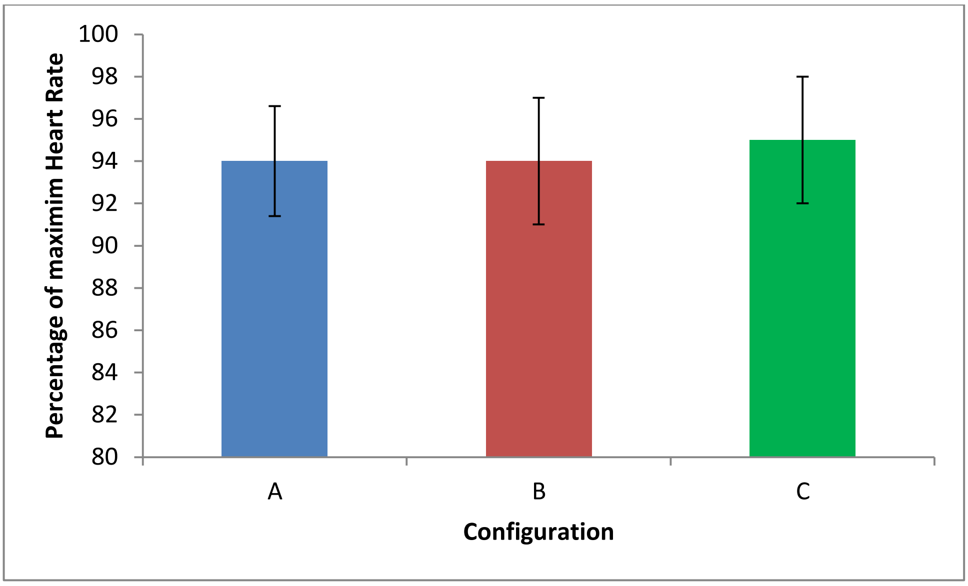

Figure 2: percentage of maximum heart rate for each configuration. Mean and SD

5.2.2 Total Time to Complete

Data from the Ditch climb obstacle was excluded from the total time to complete analysis as this obstacle broke on test day 2.

Overall, configuration A gave a significantly faster time than both configuration B and C ($p = <0.01$). Configuration B gave a significantly faster time than C ($p < 0.01$). As expected the lightest configuration produced the fastest times, with the CBTF showing a clear discrimination between a load of 10kg, 30kg and 40kg when using time to complete as a performance metric. These findings are consistent with the literature which has also shown that total time to complete is sensitive to differences in load [16][17][18][19].

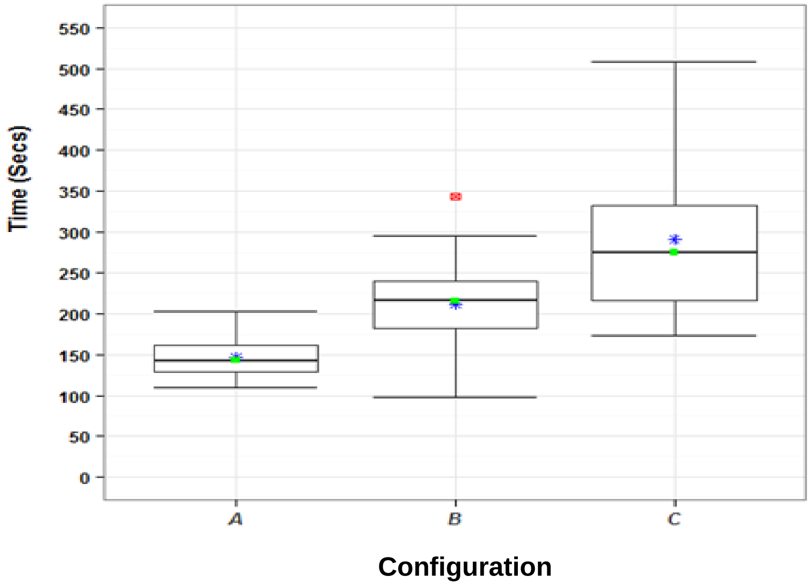

Figure 3: Boxplot for total time to complete for configurations A-C. Mean (blue star), median (green circle), interquartile range (whiskers) and outliers (red square) are reported. The outlier in configuration B was due to the rifle getting caught on the participants webbing during the Mouse-holed wall causing a delay.

Configuration A for all three repeats gave a significantly faster time to complete than configuration B and C for all three repeats. Configuration B, repeats 2 and 3 showed a significantly (p= <0.01) faster time than for configuration C for all repeats. Configuration B repeat 1 was significantly faster than configuration C repeat 1 and 2 but not repeat 3. This may indicate that there was still a learning effect for configurations B and C due to the variability associated with carrying external load. Data can be seen in figure 4 below.

When repeatability (test-retest) for each configuration was considered there were no significant differences between the repeated runs for configuration A, with all three repeats producing a significantly faster time than for configuration B and C all three repeats (p= <0.01). These findings indicate that the ‘training to plateau to performance’ conducted during the pre-trial tests prevented a learning effect or evidence of fatigue for this configuration and that the CBTF repeatedly produced consistent results for this configuration.

However significant differences were identified between the repeated runs for configurations B and C, with repeat 3, showing a significantly faster time than their respective repeat 1 (p= <0.01).

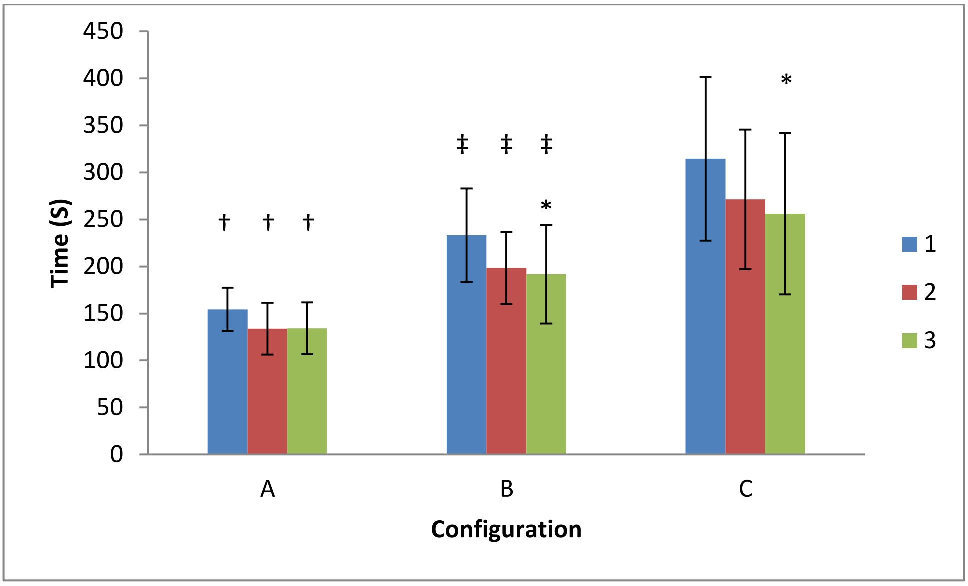

Figure 4: Time to complete the CBTF in configurations A - C. Data for repeats 1-3 are reported as mean and SD. † indicates significantly faster time to complete than B and C for all repeats. ‡ indicates significantly faster time than C.* indicates significantly faster time than repeat 1 within the same configuration.

Configuration	Time (s) ± SD			Time (s) % diff
	Repeat 1	Repeat 2	Repeat 3	Difference 1vs 3
A	154.3 (±23.0)	133.7(±27.6)	134.3 (±27.6)	20 (13.0%)
B	233.3 (±49.7)	198.4 (±38.4)	191.8 (±52.4)	41.5 (17.8%)
C	314.6 (±87.1)	271.3 (±74.3)	256.2 (±85.9)	58.4 (18.6%)

Table 7 mean (± SD) total time (s) for all three configurations and 3 repeated runs. The decrease in time to complete (s) and (% diff) between repeat 1 and 3 has also been shown.

The variability between the participants times to complete, as indicated by the increased standard deviations becomes more evident as the load increment increases, perhaps influenced by factors such as participants' individual characteristics, experience, fitness, strength and motivation. This reflects the importance of capturing these participant characteristics and using participants that are suitably fit and appropriate for the given tasks.

Perhaps of more military importance than the statistical difference identified between configurations B and C, is the increased percentage difference identified across the repeated runs for the heavier configurations (B and C). The difference in the data across these repeated will, and is expected to, increase as the mass of the configurations increases. Again it is likely that factors such as participant's size, fitness and experience may have caused some degree of differences in the time to complete the obstacles in these two configurations. Of course the differences between the repeated runs also indicates evidence of a potential learning effect for configuration B and C, and perhaps if they had completed more runs in these configurations during training this differences would have decreased. Whilst participants were all familiarised[35] in configuration B and C they were not trained to the extent of a 'plateau in performance' like they were for configuration A. Furthermore the load increment between B and C was 10kg whereas the load increment between A and B and A and C was 20kg and 30kg respectively, so you would expect to see a greater difference as the configuration mass increases.

Despite the reduced repeatability between runs in the heavier loads, statistically significant differences were still observed between the configurations. This indicates that when the test configurations are sufficiently different (in terms of mass), time to complete will be a useful metric to identify differences in agility and mobility. However, the same may not hold true for smaller weight or bulk increments. A similar trial found that flexible body armour options with much smaller load increments showed no statistical differences in time to complete [2]. When smaller additional pieces of kit are being assessed, it may be more important to assess the impact of the bulk/rigidity/positioning/location on the body using questionnaires rather than using total time taken. As such, overall time to complete may be included as a metric for use with CBTF where appropriate and with understanding of its limitations, which include: the limited reliability of total time to complete, the sensitivity of the measure with more similar clothing configurations, and the required participant familiarisation with the obstacles.

These findings highlight the importance of training and familiarisation in order to capture reliable data. Further training and familiarisation is recommended in all configurations prior to live testing. To mitigate any bias of wearing a particular piece of equipment, a similar mass and bulk prototype item should be worn during familiarisation where possible. This should help ensure that participants are familiarised with the obstacle course, but do not develop biases or opinions about the actual kit to be tested.

5.2.3 Time to Complete Individual Obstacles

The time to complete each obstacle individually was measured, data is provided in Appendix D.

For all obstacles, configuration A gave a significantly faster time than both configuration B and C ($p = <0.01$). Configuration B gave significantly quicker time than C. As expected, the lighter and less bulky options produced faster times. These findings agree with previous research, [2] which measured agility and mobility using 8 obstacles. Differences in time to complete were observed for 7 of the 8 obstacles used. This is encouraging for future CBTF studies given that the configurations tested in previous research [2] were more similar in bulk and mass, and suggests that time to complete each obstacle would be an appropriate measure to identify differences in agility and mobility between configurations that were similar in design.

For all the obstacles regardless of the configuration worn, repeat 3 was significantly faster than repeat 1, showing a difference due to familiarisation getting over the

[35] Familiarisation included wearing the configuration and walking over the obstacles and repeating specific obstacles which posed particular problems.

obstacle. Additionally, there was a repeat effect for repeat 2 vs 1 and 3 vs 2 as shown in table 8 below:

Obstacle	Repeat		
	1 Vs 2	1 Vs 3	2 Vs 3
Tunnel Crawl		* (p= <0.01)	
Wire Fence	‡(p= <0.01)	*(p= <0.01)	
High to Low Crawl	‡(p= <0.01)	*(p= <0.01)	
Balance Beam	‡(p= <0.01)	*(p= <0.01)	
Stairs and Ladder Climb		*(p= <0.01)	†(p= <0.05)
Window and Mouse-Holed Window	‡(p= <0.01)	*(p= <0.01)	†(p= <0.05)
High Windowed Wall	‡(p= <0.01)	*(p= <0.01)	†(p= <0.05)
Courtyard Wall		*(p= <0.01)	†(p= <0.05)
Fire and Manoeuvre	‡(p= <0.05)	*(p= <0.01)	†(p= <0.05)

Table 8 repeated runs effect for each obstacle

*indicates that repeat 3 was significantly quicker than repeat 1
‡indicates that repeat 2 was significantly quicker than repeat 1
†indicates that repeat 3 was significantly quicker than repeat 2

When the repeatability for each load configuration was considered the only obstacles that showed a significant difference in time to complete were the Window and Mouse-Holed Wall, and F&M for configurations B and C only. This variance may be attributable to the fact that they are more complex obstacles and external load may have a greater impact on the participant when negotiating these obstacles. As such, these obstacles may be more likely to highlight any changes in performance due to the equipment being worn. Moving under, over and through an obstacle and going from prone to standing with a heavy load is likely to be more variable each time the action is repeated as opposed to repeating the action in standard dress with minimal load and bulk.

A previous trial [19] looking at agility vs burden with loads up to 60kg found that over a short distance fire & manoeuvre and zig zag run course, participants found it more difficult to manoeuvre and took a longer time to negotiate the course as the loads increased. Another trial looking at the effects of marksmanship and load [18] has found that mass can adversely affect balance, strength and endurance, exacerbated by the effects of poor equipment integration; which in turn affects the stability of the fire position long enough to degrade a firer's ability to acquire, engage and ultimately hit the target.

The window and mouse-holed wall showed significant differences (p= <0.01) in configuration vs repeatability as shown in figure 5. Configuration A, all repeats gave a significantly faster time than configuration B and C for all repeats. Configuration B repeat 2 and 3 gave a significantly faster time than repeat 1. Configuration C repeat 3 gave a significantly faster time than repeat 1, indicating an improvement each time

Configuration B, repeats 2 and 3 showed a significantly (p= <0.01) faster time than for configuration C for all repeats. Configuration B repeat 1 was significantly faster than configuration C repeat 1 and 2 but not repeat 3, again indicating that the load was becoming more familiar.

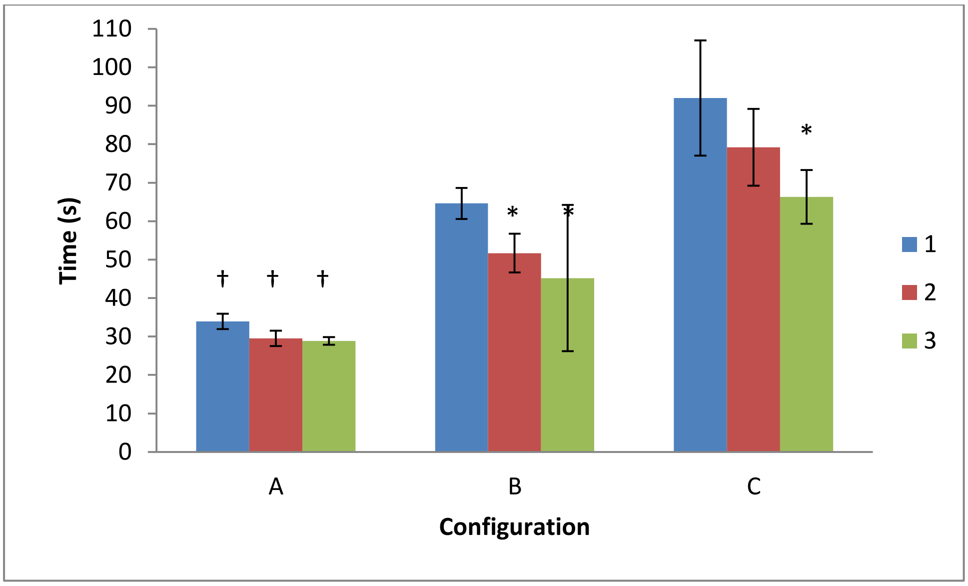

Figure 5: Window and mouse-holed wall.† indicates significantly faster time to complete than B and C for all repeats. *indicates significantly faster time than repeat 1 within the same configuration.

For the F&M (prone to finish element) there were numerous significant differences between the configuration and repeat which indicates that the times for this portion of the obstacle were not reliable, perhaps due to the use of a stopwatch for this obstacle rather than the timing mat. However, the use of timing mats is not possible for this obstacle as each section starts/finishes with a verbal command from the TCO and is about body posture rather than movement across space. Therefore the inaccuracy of stopwatch use should be a consideration for the F&M obstacle.

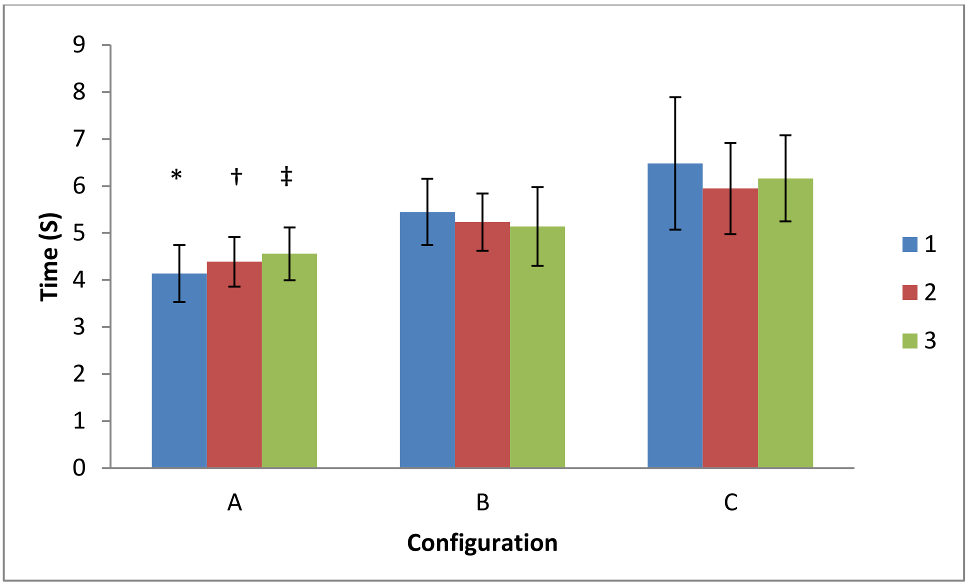

Figure 6 fire and manoeuvre (prone to finish).*indicates significantly quicker time than B and C (all repeats) †indicates significantly quicker time than B (repeats 1 and 2) and C (all repeats) ‡ indicates significantly quicker time than B (repeat 2 and 3) C (all repeats)

All other obstacles showed no significant difference in time to complete for configuration vs repeated run, in A, B or C, indicating that time to complete for individual obstacles was repeatable for all obstacles except the Window and Mouse-holed Wall and F&M (prone to finish element). As such, time to complete individual obstacles may be included as a metric for use with CBTF where appropriate and with understanding of its limitations (see section 5.2.2). Importantly, it should always be measured in parallel with military TCO quality of task performance, which will help to explain any discrepancies in timings.

5.3 Subjective Questionnaires

5.3.1 Physical Effort:

The questionnaire previously developed by [2] was modified for this current trial in order to determine self-assessments of performance and the impact of the configurations tested during the CBTF. The participant's responses to the questionnaire indicated differences in self-assessed performance between the three configurations.

Subjective ratings of physical effort increased with mass, with the mean effort rating being minimal for the lightest configuration and high/extreme for the heaviest.

The obstacles with the highest number of high and extreme ratings for physical effort were: tunnel, high to low crawl, stairs and ladders climb, window and mouse holed wall, high windowed wall. Data is shown in Appendix E.

There were no significant differences between the repeated runs and configuration worn for the ratings on physical effort indicating that the physical effort was consistent over the repeated runs and highlighting the reliability of the questionnaires to generate consistent responses for repeated attempts in the same configuration.

Subjective ratings of Physical Effort is therefore recommended as a potential metric to include in assessments using CBTF.

5.3.2 Rigidity, Mobility, Weight, Bulk, Discomfort

Subjective ratings for rigidity, mobility, weight, bulk and discomfort were all lower in configuration A than B and B than C, as would have been expected as the weight, bulk and rigidity all increased with the testing configurations. The repeated runs vs configuration showed no significant differences for rigidity, mobility, weight, and discomfort, however there were significant differences identified in relation to bulk.

Bulk was found to have a configuration vs repeated effect, with configuration A repeat 1 and 3 having a significantly lower (p= <0.01) impact on bulk than all other combinations of configurations and repeats, and repeat 2 having significantly lower (p= <0.01) impact on bulk than configuration B and C all repeats. As expected configuration A identified the lowest level of bulk. Configuration B repeated run 1 having a significantly lower (p= <0.01) impact on bulk than configuration C repeat 1.

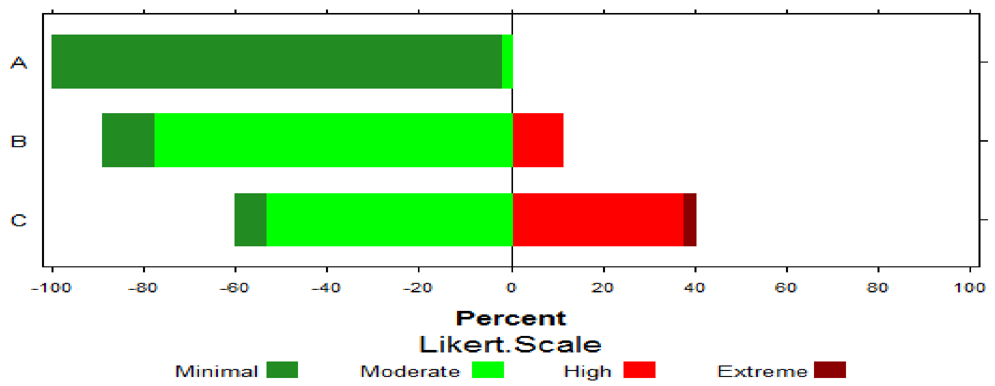

Figure 7: showing the impact of Bulk of configuration on performance, the mean rating for configuration A, and B was minimal and moderate respectively. The highest number of ratings for high and extreme were for configuration C as expected.

When participants were asked to rate the acceptability of their task performance using the configuration under test, configuration C received the highest number of not acceptable responses compared to both A and B (p= <0.01), and configuration B identified a significantly higher rating of not acceptable than A (p= <0.01). Configuration A received the highest number of acceptable responses. There were no repeated run differences for this question. The data is shown in Appendix F.

In summary the bespoke questionnaires proved to be a reliable method of discriminating between testing options and should be used for all future equipment assessments. As such, subjective ratings of rigidity, mobility, weight, bulk and discomfort are therefore recommended as potential metrics to include in assessments using CBTF.

5.4 Quality of Task Performance

Results from the quality of task questionnaire[36] identified that performance degradation as rated by the TCO was significantly lower ($p= <0.01$) in A than B and C and significantly lower in B than C. The mean observed ratings for configuration A, B and C was none, minor or above and noticeable or above respectively, which again confirms the clear discrimination between the configurations using subjective observational measures.

Minor (4) degradation in performance was associated with adopting a different position to negotiate the obstacle, severe (2) and noticeable (3) were generally associated with 1 or 2 failed attempts over the obstacle and or equipment hindrance. Catastrophic (1) was associated with 3 failed attempts at the obstacle.

Obstacle	Degradation of task performance [37]		
	A	B	C
Tunnel Crawl	None*	Minor or above	Noticeable*** or above
Wire Fence	None	Minor or above	Noticeable or above
High to Low Crawl	None	Minor or above	Noticeable or above
Balance Beam	None	Minor or above	Minor** or above
Stairs and Ladders Climb	None	Minor*** or above	Noticeable or above
Window & Mouse Holed Wall	Minor or above	Catastrophic	Catastrophic
High windowed wall	None	Minor or above	Noticeable or above
Courtyard Wall	None	Noticeable or above	Noticeable or above
Fire & Manoeuvre	None	None***	Minor or above**

Table 9 quality of task performance as observed by the TCO

*one participant was rated as being minor
**one participant was rated as being noticeable
***one participant was rated as being severe

The Window Mouse-holed Wall was the only obstacle rated as catastrophic or above for both configuration B and C. This obstacle was clearly the most complex and gave the best discrimination between the configurations in terms of load and bulk.

Two obstacles were identified as having a significant difference between repeats: the courtyard wall and Fire and Manoeuvre repeats 2 and 3 were observed as having significantly lower degradation than repeat 1 ($p= <0.01$), attributable to the learning effect and increased confidence of moving over walls and between cover stances with heavier loads.

[36] The quality of task scale has been previously used under the HFAF by [2][16][18]
[37] Catastrophic degradation of task performance (1), Severe degradation of task performance (2), Noticeable degradation of task performance (3), Minor degradation of task performance (4), No degradation of task performance (5)

There were no repeated run differences for the configurations indicating that the observed ratings were consistent for all obstacles. These findings suggest that quality of task performance observations by a trained military test conducting officer can be used to reliably discriminate between different loads (10kg, 30kg and 40kg).

The contextual data from quality of task questionnaire proved invaluable at capturing observational data from the TCO such as identifying where equipment got caught, hindered performance or caused the participant to adopt an alternative method of negotiating the obstacle from the original instructions given at the start of the CBTF familiarisation phase. Many participants reported that their kneepads kept falling down and didn't stay in place during the tunnel crawl, the daysack and weapon got caught in entering the tunnel crawl, so alternative procedures were adopted for this obstacle. The daysack was a hindrance when climbing through the window obstacles and over walls.

Previous studies [2] have found that for smaller load increments, the quality of task performance questionnaire failed to discriminate between different armour systems, which indicate that it is most useful in studies where there is an obvious difference in mass. Therefore, subjective quality of task ratings are recommended as a potential metric to include in assessments using CBTF, particularly for large differentials in load. The TCO ratings are crucial to contextualise other data and any key issues with equipment, and should always be incorporated with use of CBTF.

Interestingly when the participants rated themselves on the same quality of task questionnaire they gave significantly higher performance degradation responses. This may be down to the scale used and in hindsight it would have been more appropriate to use the scale of acceptable to not acceptable for the participant self-assessed questionnaire. Data has been shown in Appendix E.

5.5 Subjective Ratings Scales

Data for perceived rating scales are provided in Appendix F. In summary significantly lower perceived ratings of exertion (Borg) , thermal sensation (ASHRAE) and thermal comfort (Bedford) were identified in configuration A than B and C, and for B than C ($p= <0.01$). No significant differences were identified for repeated runs within the same configuration indicating a consistent rating for all repeats

As expected pre-course ratings were significantly lower than post course ratings for exertion (Borg), thermal sensation (ASHRAE) and thermal comfort (Bedford). Post CBTF, participants rated perceived exertion as hard for configuration A and very hard for configuration C. Overall participants rated thermal sensation post CBTF as slightly cool for configuration A and very hot for configuration C.

The use of the perceived exertion scale may be useful in providing information on how hard the participants were working in the absence of heart rate monitoring. Numerous past research studies have found a positive correlation between heart rate and perceived exertion, so much so that some perception scales are on a scale from 6 to 20, to match typical heart rates during exercise of 60 to 200 beats per minute.[41] The thermal sensation scale gives an indication of the thermal effect of the equipment however the thermal comfort scale did not identify any differences in how comfortable the participants felt with the temperature. This was not a surprise given the short length of the course.

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6 Overall conclusions

The aims of this assessment were fourfold:

1. To conduct a Subject Matter Expert (SME) / Stakeholder validation workshop in order to validate the rationale for the inclusion of the CBTF obstacles and set performance criteria for the obstacles.

2. To determine the test-retest reliability of the CBTF in terms of individual measures of performance (time to complete the entire course, time to complete individual obstacles, subjective and observational feedback) and define systems requirement metric from the trial.

3. To verify the use of the CBTF, define and write its operating and data capture standardisation procedures.

4. To identify and define acceptable performance metrics for agility and mobility, in order to inform future Systems Requirements for equipment procurement.

The current study has successfully verified the CBTF and its set of standardised procedures by demonstrating a clear discrimination between the three chosen configurations.

The reliability of the CBTF was variable depending on the configuration and parameters used, with time to complete individual obstacles being the most reliable objective metric (with the exception of two more complex obstacles requiring a greater amount of negotiation with external load). Total time to complete the whole obstacle course was repeatable for configuration A but not for B and C, indicating that the heavier configurations caused a more varied time to complete perhaps due to factors such as individual characteristics, fitness, strength, motivation and experience, or that a potential learning effect was still occurring through the repeats. Incorporating further training and familiarisation for configurations B and C may have helped to reduce this variability.

Whilst it was important for the participants to be trained to a plateau in performance in the baseline configuration, in order to detect any changes when using alternate configurations; the differences identified in configuration B and C for time to complete still remain of value, as they can be attributed to the impact of the equipment configuration being tested.

The subjective questionnaires and quality of task performance observations conducted by the TCO proved to be the most reliable parameters for discriminating between the different configurations and should be incorporated in all future equipment trials. This highlights the importance of recruiting the right participants (varied sizes/fitness levels/gender/role appropriate) and having a fully trained TCO to identify the quality of task performance consistently. Furthermore observational and subjective feedback data captured through these two questionnaires can be fed back into the equipment procurement cycle for modifications and further development of clothing and equipment.

The Window Mouse-holed Wall appeared to be the most complex obstacle when wearing configurations B and C, being rated as *catastrophic* by the TCO and being identified as more variable in the individual times for the same configurations, indicating that it is a useful obstacle to discriminate between configurations.

The effect on performance of the configuration had a larger impact than the repeated run effect. Furthermore, the encumbered configurations (B and C) produced more variable times to complete all obstacles than when unencumbered; attributable to factors such as: participant fitness, strength, motivation, experience and potentially learning effect.

However, it is important to acknowledge that there may not always be such a clear discrimination between different testing options, for any of the parameters discussed in this report, especially if the load/bulk increment is smaller and the conditions differ from the current study. Where this is the case further in depth Human Factors Analysis will need to be conducted with a careful selection of the most appropriate obstacles to be used, focusing the measures of performance on quality of task and collection/understanding of subjective data to allow for adequate understanding of equipment size/weight/bulk issues to inform areas of focus during more detailed user field trials.

When used in combination with the Dstl HFAF and its own standardised set of procedures, the CBTF can provide robust and reliable data to support military personal clothing and equipment procurement decision making.

This study has highlighted the importance of having a trained military TCO and data collection team who are familiar with the test procedures and the equipment being tested. The verified set of standardised procedures that should be conducted in accordance with the CBTF have been documented in the operating protocol [1]. The instructions for negotiating the obstacles as defined during the SME validation workshop have been modified and defined in [1] according to the configuration worn and individual characteristics of the participants (height, limb length, experience, weight). The SME workshop was crucial to the development of these instructions and procedures and the CBTF verification process.

6.1 Metrics for success for the systems requirement document (SRD)[38]

Based on the CBTF validity and reliability assessments determined in this report, the operating protocols produced for CBTF (Dstl/CR097508), and numerous past MoD and academic research studies developing subjective questionnaires for comfort, thermal sensation, quality of task performance and perceived exertion, a set of metrics have been compiled for use with CBTF and inclusion within SRDs.

Please note, assessment pass/fail cutoff values for objective and subjective measurements for each metric should be matched to the operational requirement of each piece of equipment tested and within each bespoke CBTF trial. Setting arbitrary time pass/fail values for obstacle/course completion may be inappropriate if

[38] This forms one of the customer outputs: to inform the SRD with useable metrics for the Human Factors agility and mobility domains.

assessing equipment where speed may not be the crucial factor, but mobility and comfort are more important. Alternatively, other equipment may prioritise agility and speed of movement over soldier comfort. The metrics for CBTF must be considered unique for each trial conducted, given the aims and requirements of specific equipment and the metric's operational relevance. For this reason, pass/fail cutoff values for each metric cannot be defined in this report.

When the CBTF is conducted under the set of scientific conditions and procedures described in this document the following metrics can be applied:

1. Quality of Task Performance as observed by a military TCO:

The system shall not degrade the quality of task performance. Specific pass/fail cutoff values should be set based on the particular equipment being tested, and relevant obstacles of interested can also be selected from the entire course. An SRD may, for example, state *'the system shall not degrade the quality of task performance any higher than '4 - minor' on a 5 point scale of 1 - catastrophic degradation of task performance to 5 - no degradation in task performance for the following obstacles: Tunnel crawl, Wire Fence, Low to high crawl, Balance beam, Stairs/ladders, Ditch, Buildings (mouse holes), Walls, Fire and manoeuvre walls'.*

2. Subjective Questionnaires:

The following metrics should be included and defined if relevant. An SRD may, for example state that:

'The following subjective metrics shall not be rated as greater than 'moderate' (on a scale of minimal, moderate, high, extreme):

- The level of physical effort experienced during the individual tasks and the whole obstacle course.
- The impact of the equipment on task performance (rigidity, mobility, weight, bulk).

'The system shall not be rated less than acceptable (on the scale of not acceptable, acceptable with modifications, acceptable) for:'

- The task performance.
- The integration of equipment.

'The following metric should not be rated as anything greater than mild (mild, moderate, severe, and unbearable):'

- Overall discomfort during the CBTF.

3. Time to Complete:

The time taken to complete a task, either total time or for individual obstacles, will be relative to each individual's baseline time to complete. If included in an SRD, time to complete should be used with caution given the variability and limited reliability identified in this report. Whilst time to complete has proved to be a useful parameter to discriminate between configurations, individual participant characterisation (height, weight, limb length), motivation, experience and fitness mean that it is not appropriate to give a generalised time pass/fail cutoff value for all personnel to meet. Therefore, if time to complete is included as a metric, a within-participant design should be used and SRD metrics could be chosen based on a time delta between an individual's unloaded / in-service equipment and the new configuration under assessment. This ensures that the time taken to complete a task will be relative to each individual's baseline time to complete.

Time to complete provides useful information in equipment trials; however it should be used in parallel with Military TCO Quality of Task Assessment and other subjective questionnaires which will help to explain any discrepancies in time. In addition, the emphasis on certain tasks should be on task quality rather than speed. Incorporating timing chips and timing gaits can often distract from the primary metric of quality if participants perceive the obstacle course to be a 'race'. Clear instructions and objectives must be provided to the participants to ensure they do not substitute quality for speed. In test examples where speed may be a priority over quality of task, the use of CBTF or alternative methods such as the Army Assault Course or other Dstl HFAF should be considered carefully.

6.2 Future Work and Development Areas

Whilst outside the scope of the current work summarised within this report, CBTF offers a number of future opportunities beyond its existing use. There are also areas for development which may help to improve the quality of results obtained from CBTF.

- Assessment of wider soldier effectiveness and soldier capability could be incorporated within CBTF. Whilst this would work beyond the scope of Dstl's HFAF level 1 or 2, incorporating specific pass/fail operational tasks prior to, after, or during CBTF in different equipment would broaden the scope of research opportunities. This would require a large amount of research and development to be incorporated within CBTF.

- Whilst CBTF is designed as an obstacle for individuals, procedures for CBTF could be developed to investigate beyond the individual soldier towards collective performance. Soldiers rarely operate as individuals in a combat environment, and obstacles could be set up and positioned to create a wider scenario or group task, such as casualty evacuation or larger equipment carriage. This would require a large amount of research and development to be incorporated within CBTF.

- The F&M task could incorporate a more objective method of acquiring the target. For example laser light modules attached to the weapon or live firing /TES for a trial that focuses particularly on marksmanship. This may not be required if marksmanship is not a primary metric and stopwatch use is sufficient. Alternatively, additional timing gaits could be added for the F&M task if deemed appropriate.

- The use of the WBGT index should be further explored for use in short duration tasks. This may allow testing to continue or not based on the duration of unique tasks. Participant safety must always be a paramount issue during CBTF trials and environmental conditions should be monitored to ensure the appropriate rest periods are provided and trial alterations as required.

7 Recommendations for using CBTF

- The standardised procedures as defined in the CBTF operating protocol [1], and should be followed to ensure collection of reliable and useful data for the assessment of future soldier systems.

- The TCO must be trained for the quality of task observations and understand the criteria for assessing participants using the 5 point scale on the questionnaire. The TCO must also be trained on the instructions for negotiating the obstacles and understand that heavier/more bulky configurations and different sized individuals may necessitate an alternative method of negotiating the obstacles. Alternative methods have been described in the CBTF operating protocol [1].

- Participants should be familiar with the equipment being tested to reduce any learning/training effect. The participants in the current study were mounted and not previously familiar with the VIRTUS kit used. It is also recommended that a range of participants (Male/Female, 5th and 95th percentile) be used in order to identify potential issues.

- The CBTF should be used as part of a wider assessment framework where the research requirement necessitates, as it is only one element of a series of available assessments that can be conducted to understand the impact of equipment on performance. The CBTF is optimised as an assessment within Dstl's HFAF levels 1 and 2 approach, where specific obstacles and additional add on tasks are selected for investigation.

- The configurations must be standardised and consistent for all participants; all participants must wear identical kit and should not be allowed to wear alternative options. Where possible, configuration loads and mass distribution should replicate combat loads and operation equipment usage.

- A standard/ baseline configuration or existing equipment configuration should be used for comparison purposes.

- Individual or groups of obstacles with the CBTF can be used to test specific equipment items and there is not always a need to use the whole course in its entirety, discrete tasks should be chosen depending on the research question or equipment being tested, with additional add on tasks pre and post obstacle course. It should be noted however, that the purpose of the CBTF is to identify unknown issues with equipment, and therefore care should be taken when discounting obstacles from the assessment. A case by case approach to using the CBTF is advised depending on the requirement.

- The warm up was devised by the PTI during the pilot study; this can be modified depending on whether additional tasks are being conducted prior to the CBTF, such as patrol type tasks.

- The subjective questionnaires should be tailored to the research question or particular equipment being tested.

- Time to complete the whole obstacle course and individual tasks whilst relevant to agility and mobility may not be needed for all trials where only a handful of obstacles have been chosen for the assessment and the focus is on subjective feedback, for example a level 1 HFAF.

- The F&M task should incorporate a more objective method of acquiring the target. For example laser light modules attached to the weapon or live firing /TES for a trial that focuses particularly on marksmanship.

- To be effective the CBTF must be used in combination with the Dstl HFAF and its standardised set of procedures to ensure that scientifically robust and reliable data is captured to best support procurement decision making. Any deviation in the use of the standardised procedures will reduce the scientific integrity of the data and would not be recognised by UK and International scientific standards.

- The use of the WBGT index should be further explored for use in short duration tasks.

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10 List of abbreviations

CBTF	Common Battlefield Test Facility
DE&S	Defence Equipment and Support
F&M	Fire and Manoeuvre
HFAF	Human Factors Assessment Framework
HF	Human Factors
HR	Heart Rate
ITDU	Infantry Trials Development Unit
ISAK	International Society for the Advancement of Kinanthropometry
PPE	Personal Protective Equipment
PCS	Personal Clothing System
PLCE	Personal Load Carriage Equipment
PTI	Physical Training Instructor
MSFT	Multi Stage fitness Test
MA	Military Advisor
RPE	Rate of Perceived Exertion
SME	Subject Matter Expert
STSP	Solider Training and Special Programmes
TCO	Test Conducting Officer

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APPENDIX A SME Workshop Method and Overview of Obstacles

Method

A selected group of SMEs[39] from DE&S (STSP), ITDU and Dstl attended the workshop on 14th January 2016 at ITDU. The SMEs worked through each obstacle sequentially and assessed them according to the following aims:

1. Identify an overarching scenario that the CBTF represents in relation to current and future operations. The scenario provided must relate to urban environments.

2. Identify the military justification for the inclusion of each feature of the obstacles included in the CBTF.

3. Determine the format of procedures for the CBTF:

    - Markers for the obstacles (start and finish lines)

    - Instructions for negotiating each obstacle[40]

    - Pass/failure criteria - task performance acceptability [41] these relate to the following categories:

        - Catastrophic degradation of task performance

        - Severe degradation of task performance

        - Noticeable degradation of task performance

        - Minor degradation of task performance

        - No degradation of task performance

The information captured was agreed at the time of the meeting and circulated for review.

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[39] Lt Col P McNicholas: STSP, Lt Col R O'Connor: CO ITDU, Maj S Farley: STSP WO1 D Fraser: RSM/Soldier Sys ITDU, WO1 G Simpson: Dstl MA, Mrs E Parish: Dstl HF, Ms Alison Walsh Science Gateway, Mr P Hewkin: STSP, Mr P Flowers: STSP, Mr M Knowles: STSP

[40] Provides details of how to undertake each obstacle

[41] Provides details of events that should be recorded by the Investigator(s) and instructions on how to proceed with the test serial if a participant fails an element of the obstacle.

The following section was determined during the workshop. Please refer to [1] for full details of the obstacles, markers and performance criteria as these have since been modified and updated during the trial.

Overarching Scenario for the CBTF design

Historically, in a conventional context, the UK Armed Forces have usually sought to avoid congested battlespace when trying to achieve freedom to manoeuvre. Over the next twenty years, we will be unable to avoid being drawn into operations in urban regions, thus the future operating environment is likely to be shaped by increasing urbanisation. Cities will be more physically complex, with major cities the key hubs of human activity, where the majority of the World's population live and where political and economic activity is concentrated in 2035.

Physically cities in 2035 will remain characterised by a diverse range of infrastructure, from the glass and concrete of a central business district to the tin shacks and open sewers of slums, perhaps just a short distance away. They will present a complex multi-dimensional challenge containing the street level, roof tops, sewers and tunnels, riverine, surface and subterranean environments . On land, the enemy will develop and exploit underground facilities, neutral spaces such as hospitals, schools and places of worship, and dense urban, populated terrain ranging from small villages through to large cities.

For our Armed Forces, the urban environment will be one of the most challenging areas in which to operate. The obstacles included in the CBTF have all been designed to meet the requirement for the future urban operating environment.

Obstacle 1: Tunnel Crawl

In urban environments, culverts, storm drains and tunnels offer the opportunity to move with cover from view and fire. The tunnel crawl obstacle was designed to replicate this. This rural obstacle fits in with past/present and future operations.

To negotiate the obstacle the soldiers' body armour and equipment are compressed both vertically and horizontally. This should identify if the body armour rides up the body, or is too stiff to bend to the left and right. The length of the obstacle was designed to allow participants to crawl for at least the length of their body. The 90 degree bends force both left and right compression

Obstacle 2: Wire Fence

A simple livestock fence can be a significant obstacle to a heavily laden infantry soldier, urban environments all have fences, hedges and pathways and this obstacle is indicative of these. This obstacle presents three types of wire fence to assess this issue and is representative of other forms of two dimensional obstacles such as railings on road. It was acknowledged at the validation workshop that a fixed wire is inflexible in nature and therefore the realistic “wobble” effect cannot be assessed, an aspiration would be to replace one of the fixed wire strands with a chain to provide that “wobble effect” but it was agreed that the wire fence still provides a representative obstacle for the urban environment.

Obstacle 3: High to Low Crawl

This obstacle assesses transition of movement; soldiers are required to move in certain ways and transition between cover and across open ground by crawling, an activity that focuses physical effort on the shoulders. Soldiers are forced to transition from “leopard crawl” to an upright “monkey run”. The leopard crawl is crawling on the elbows and the inside of the knees. It is useful when moving behind very low cover. The monkey run is crawling on hands and knees and is useful when moving behind low cover.

Wearing helmets exacerbates the perceived effort as the head is held down obscuring vision and making the distance seem much longer than it is. The low to high crawl obstacle replicates this situation. The crawl was designed to allow the participants to crawl for a greater distance than their body length.

Obstacle 4: Balance Beam

A fundamental skill required of DCC soldiers is the ability to be carefully agile in constrained environments such as crossing a ditch or moving from one specific area to another. Planks, tree trunks, sand-channels, ladders and pallets are all employed to get over short gaps during operations and training. This obstacle is designed to replicate this. Hatched areas are included to ensure that the participants did not cut the corners. This obstacle is designed to test balance, changes in direction, elevation and the effect of distribution of weight.

Obstacle 5: Stairs and Ladders Climb

Front view

Rear View

Operations in built up, urbanised areas often require entry to buildings from steps and ladders into the upper floors. When stairways and floors have been destroyed access to upper or lower levels will have to be by ladders. This obstacle simulates such circumstances and requires the soldiers to enter and exit the upper level via ladders. The angles of the ladders are based on the heights of adobe walls in different continents. The obstacle has been designed to assess both ascent and descent.

Obstacle 6: Ditch Climb[42]

This obstacle examines the impact of weight and bulk on the soldier's ability to operate in and from a ditch, to mount and dismount a slope and to use the slope as a fire position. The depth of the ditch is varied and should be matched to the soldier completing the task; e.g. a 95th percentile soldier would be expected to negotiate the deepest part of the trench while a 5th percentile would use the shallow end. The ditch has an open side so the observers can see the effect of the soldier's equipment on the task and adopting a fire position.

NB whilst this obstacle forms part of the CBTF, due to a fault with the obstacle during the current trial it was deemed unsafe and was withdrawn from the CBTF sequence. It is intended that this obstacle will be up and running for future trials.

Obstacle 7: Window and Mouse - Holed wall

This obstacle replicated features of urban environments which soldiers are required to negotiate. The dimensions of the obstacle were based on military observations, lessons learned and operational experiences. The obstacle has three elements:

[42] The ditch climb obstacle broke on day two of the trial so all data was removed from the analysis for this obstacle to allow for comparisons to be made.

Mouse hole: The mouse hole was designed to replicate a hole generated by explosive entry techniques. While no two holes are the same they are frequently below waist height. Wall: Conventional UK military assault courses usually have two walls at approximately 3.7m (12ft) and 1.5m (5ft). As a 3.7m (12ft) wall requires two or more people to successfully negotiate it, 1.5m (5ft) was selected for this course as it is a height most soldiers would be expected to overcome. Window: The height of this window was based on military observations and the requirement to ask a participant to raise their leg to a point where it was at least parallel to the ground. To move through any environment soldiers need to get over, under or through a variety of obstacles.

Obstacle 8: High Windowed Wall

The mouse hole in the wall was identified during previous method development as a significant indicator of soldier burden. The thickness of the wall is the differentiating what can be tested from the low mouse hole on the previous task. The soldier should negotiate the hole in an alert, heads up manner leading with their weapon. When over burdened by weight or bulk getting through the hole becomes a priority rather than being aware of what is beyond the hole.

Obstacle 9: Courtyard Wall

This obstacle replicated features of urban environments which soldiers are required to negotiate. To move through any environment soldiers need to get over a variety of obstacles.

Obstacle 10: Fire and Manoeuvre

Fire and movement is a battlefield skill upon which all dismounted combat is based. The fire and movement obstacle was designed to combine movements that a soldier would encounter while under fire with a figure 11 target for aim, and identify any issues that interfere with this requirement. The obstacle involves movements to the left and right and prone to test the participant's agility. The prone firing position was selected to assess equipment integration. LOORST reports have identified that soldiers are unable to adopt the prone firing position due to the weight of their equipment, thus the kneeling firing position was also included to allow mobility comparisons between the prone and kneeling positions.

This obstacle is broken down into individual elements: cover stance, kneel to prone and prone to finish. Split times for these individual elements are recorded.

APPENDIX B Configuration List of Individual Equipment [43]

Configuration	Equipment	Target Total (kg)
A Unencumbered	Virtus Helmet	
	Kneepads- (one size)	
	Low Impact Eyewear Spectacles - (Regular)	
	General Purpose Gloves	
	Boots	
	Under Body Armour Clothing System (UBACS)	
	Personal Clothing System Trousers (PCS)	
	Deactivated Weapon (SA80 A2)	
	Total weight	**10kg**
B Assault Order	Weight carried over from Configuration A	
	VIRTUS Sourced Tactical Vest with neck protection	
	Soft Armour Filler (SAF)	
	Placebo plates (front and rear)	18.493
Webbing	VIRTUS Chassis (Yoke and belt) (Medium)	
	2 x mag pouch	
	5 x Mag	
	Water bottle pouch	
	Filled water bottle	
	ETH pouch	
	ETH	
	1 x grenade pouch	
	1 x smoke grenade pouch	
	2 x Prac Grenade	
	utility pouch	
	2 x meals from 24-hr ration pack	
	1 x bayonet	
	1 x bayonet pouch	
	Total weight	**30kg**
C Patrol Order	In addition to Configuration B -	
	VIRTUS General user Daysack	
	Dynamic Weight Distribution system	
	Pack Side 3L Hydration Zip Pouch	
	22L immersion bag	
	Issue smock	
	1 x 24hr ration box	
	Water proof jacket	
	Total weight	**40kg**

[43] Equipment list produced by DE&S (STSP)

APPENDIX C TCO Quality of Task Performance Questionnaire

Quality of Task Rating Scale
(1) Catastrophic degradation of task performance- (2) Severe degradation of task performance [3} Noticeable degradation of task performance. (4) Minor degradation of task performance, (5) No degradation of task performance

Failure Criteria (tick and provide further details)	Quality of Task (circle using the rating scale)
Tunnel Crawl □ Assistance required - state reason □ Note if the body armour rides up the body, or is too stiff to bend to the left and right. □ Alternative procedures to instructions are adopted, if so state how and why Unable to complete tunnel crawl: Number of attempts: 1 / 2 / 3	1 / 2 / 3 / 4 / 5
Wire Fence □ Unable to fit under single strand. Number of attempts: 1 / 2 / 3 □ Assistance required - state reason □ Unable to get over fence. Number of attempts: 1 / 2 / 3 □ Alternative procedures to instructions are adopted, if so state how and why	1 / 2 / 3 / 4 / 5
Low to High Crawl □ Assistance required - state reason □ Alternative procedures to instructions are adopted, if so state how and why Number of attempts: 1 / 2 / 3 Comments: ➢ Did the participant maintain conduct for the leopard crawl and monkey run as described above or did the participant have to adopt an alternative position to get under the obstacle ➢ Did the participant's equipment snag on the obstacle, could they get down low enough	1 / 2 / 3 / 4 / 5

Balance Beam □ Failure to make contact with cross hatched areas. Number of falls 1 / 2 / 3 / 4 □ Fall after check point 1. Number of falls 1 / 2 / 3 □ Fall after check point 2. Number of falls 1 / 2 / 3 □ Fall after check point 3. Number of falls 1 / 2 / 3 □ Alternative procedures to instructions are adopted, if so state how and why Was the participant able to move tactically with two hands on the weapon at all times?	1 / 2 / 3 / 4 / 5
Stairs and Ladders Climb □ unable ascend the low rise stair Number of attempts: 1 / 2 / 3 □ unable to descend the high rise stair case Number of attempts: 1 / 2 / 3 □ unable to ascend the angled ladder case Number of attempts: 1 / 2 / 3 □ unable to descend the vertical ladder case Number of attempts: 1 / 2 / 3 □ unable to ascend the high rise stair case Number of attempts: 1 / 2 / 3 □ unable to descend the low rise stair case Number of attempts: 1 / 2 / 3 □ Alternative procedures to instructions are adopted, if so state how and why **Comments** ➢ Did the participants make contact with all the steps and rungs of ladders? ➢ Did the participants maintain TTP's or did they have to adopt alternative styles? ➢ Did they have to use the hand rail for safety purposes?	1 / 2 / 3 / 4 / 5
Ditch Climb □ Unable to exit. Number of attempts: 1 / 2 / 3 □ Unable to adopt a workable fire position □ Alternative procedures to instructions are adopted, if so state how and why ➢ Notes: The approach to landing will depend on the equipment being worn so comment should be made on how the subject entered the ditch.	1 / 2 / 3 / 4 / 5

Window and Mouse – Holed Wall □ Unable to get over right wall. Number of attempts: 1 / 2 / 3 □ Unable to get over left wall. Number of attempts: 1 / 2 / 3 □ Assistance required □ Alternative procedures to instructions are adopted, if so state how and why ➢ Did the participant's equipment get caught? ➢ Did the participant maintain balance when climbing through the window or did the participants fall through the window?	1 / 2 / 3 / 4 / 5
High Windowed Wall □ Unable to move through the mouse hole. Number of attempts: 1 / 2 / 3 □ Assistance required - state reason □ Alternative procedures to instructions are adopted, if so state how and why	1 / 2 / 3 / 4 / 5
Court Yard Wall □ Unable to get over the wall. Number of attempts: 1 / 2 / 3 □ Assistance required - state reason □ Alternative procedures to instructions are adopted, if so state how and why	1 / 2 / 3 / 4 / 5
Fire and Manoeuvre Walls □ Unable to adopt/maintain a workable fire position. Number of attempts: 1 / 2 / 3 □ Alternative procedures to instructions are adopted, if so state how and why Comments:	1 / 2 / 3 / 4 / 5

APPENDIX D Time to Complete Data for Individual Obstacles

Tunnel Crawl

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

Overall repeat 3 gave a significantly quicker time to complete than repeat 1 at the (p= <0.01).

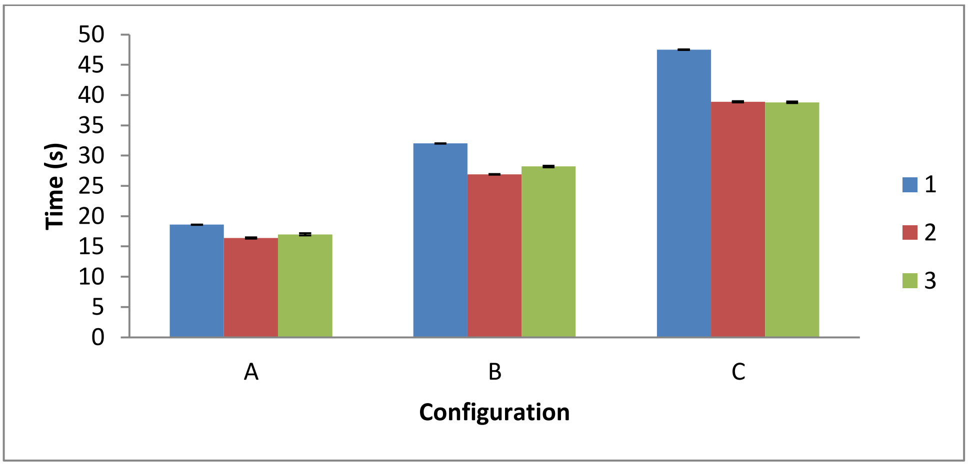

Figure 8 Time to complete Tunnel Crawl for all configurations and all repeats.

Wire fence

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01. Configuration B gave significantly quicker time than C at the same confidence level. As expected as the lighter options produced quicker times.

There was no difference in time for repeat 1 for all three configurations however repeat 2 and 3 for all three configurations were significantly quicker than repeat 1.

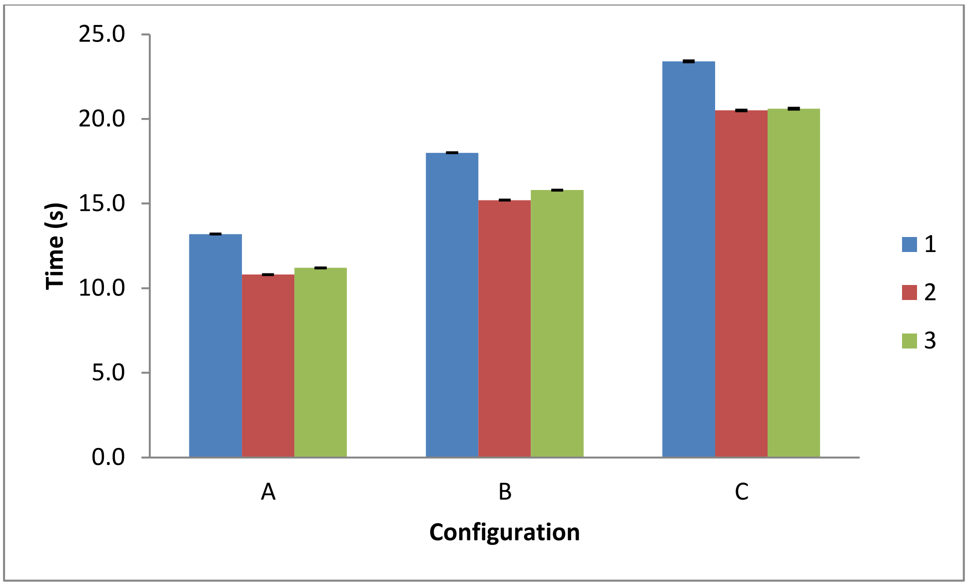

Figure 9 Time to complete Wire Fence for all configurations and all repeats.

High Crawl to Low Crawl

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

There was no difference in time for repeat 1 for all three configurations however repeat 2 and 3 for all three configurations were significantly quicker than repeat 1

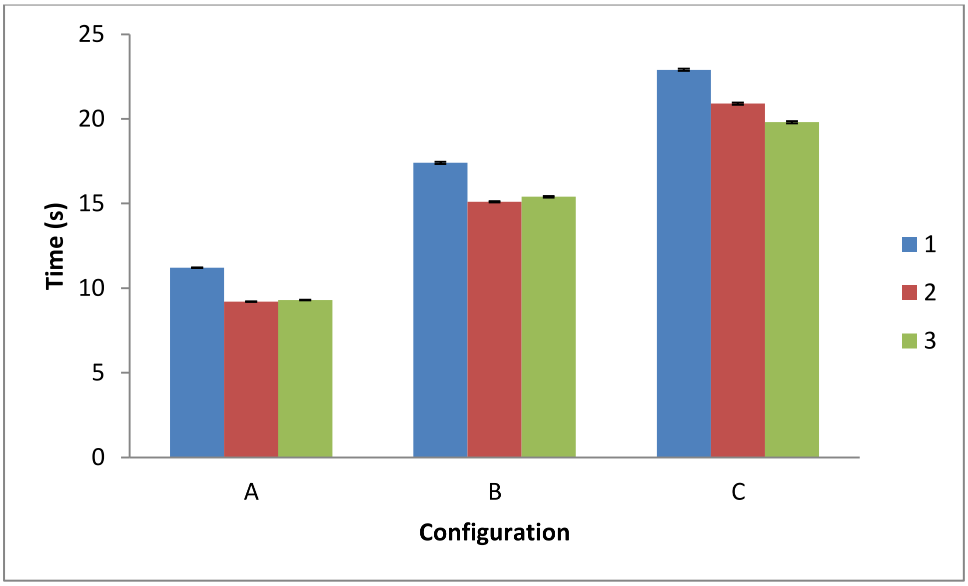

Figure 10 Time to complete High Crawl to Low Crawl for all configurations and all repeats.

Balance Beam

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

There was no difference in time for repeat 1 for all three configurations however repeat 2 and 3 for all three configurations were significantly quicker than repeat 1.

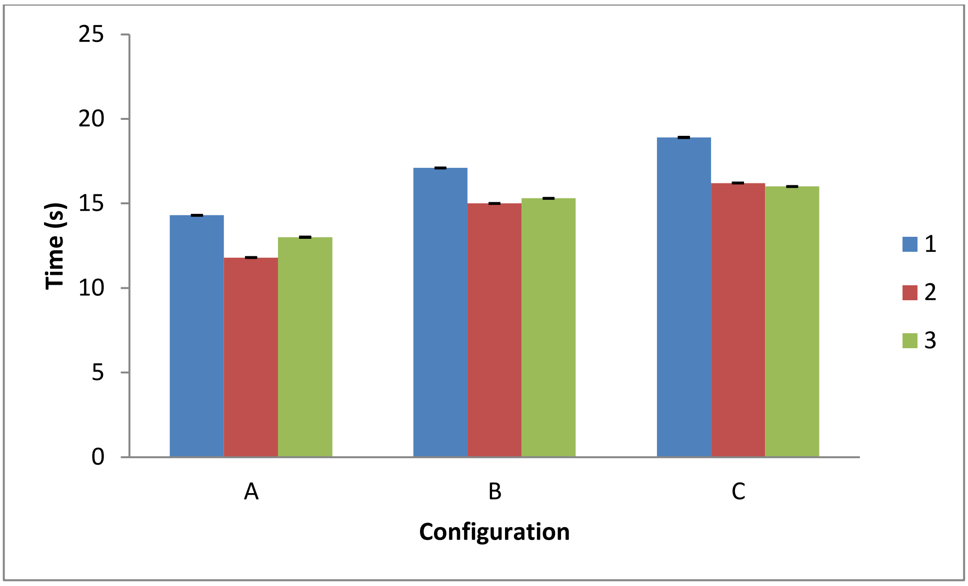

Figure 11 Time to complete Balance Beam for all configurations and all repeats.

Stairs and Ladders Climb

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

There was no difference in time for repeat 1 for all three configurations however repeat 3 for all three configurations was significantly quicker than repeat 1 and 2.

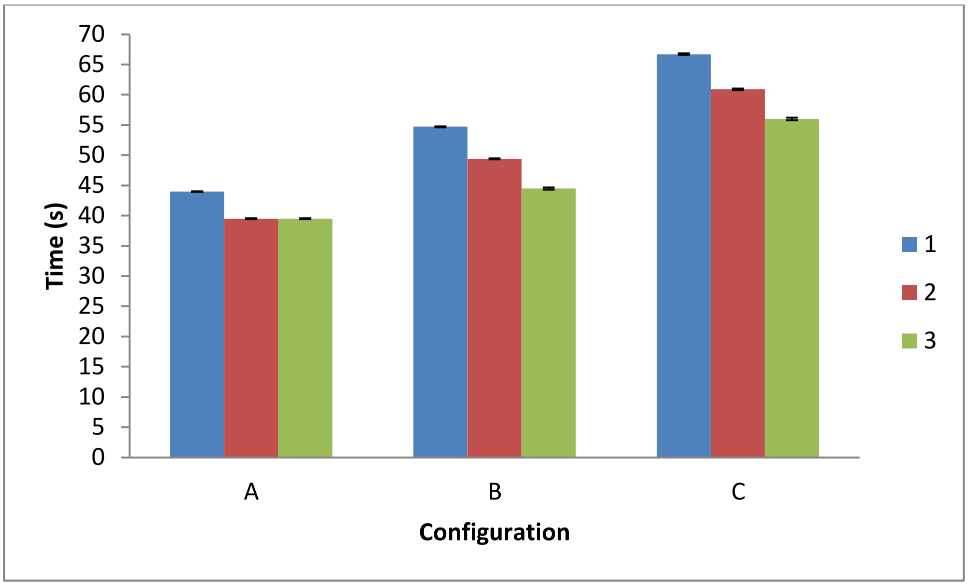

Figure 12 Time to complete Stairs and Ladders Climb for all configurations and all repeats.

Window and Mouse-holed Wall (in main body of report)

High Windowed Wall

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

Repeat 3 was significantly quicker than repeat 1 and 2, which indicates that there was still a learning effect. Repeat 2 gave significantly quicker time than 1.

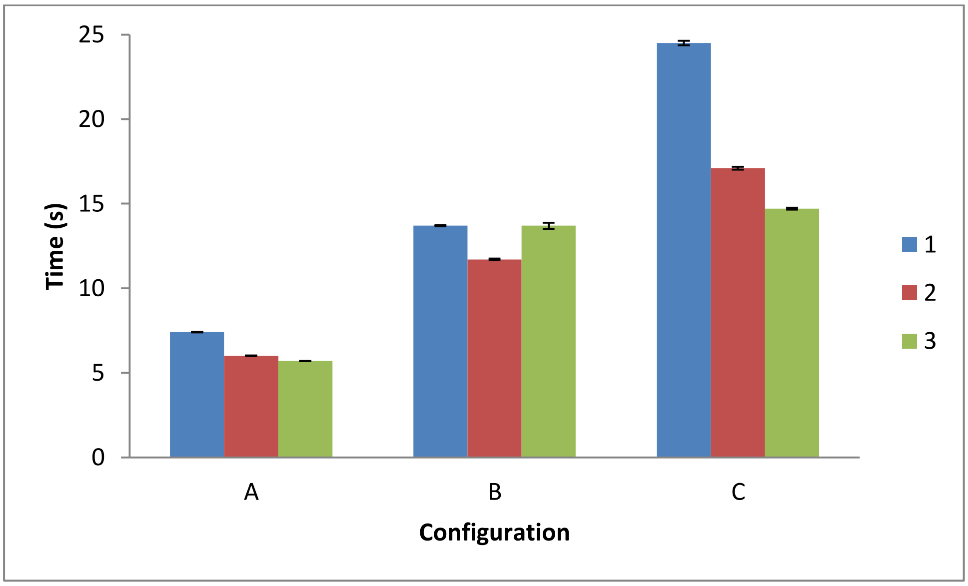

Figure 13 Time to complete High Windowed Wall for all configurations and all repeats.

Courtyard Wall

Configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

Repeat 3 was significantly quicker than repeat 1 and 2, which indicates that there was still a learning effect. Repeat 2 gave significantly quicker time than 1.

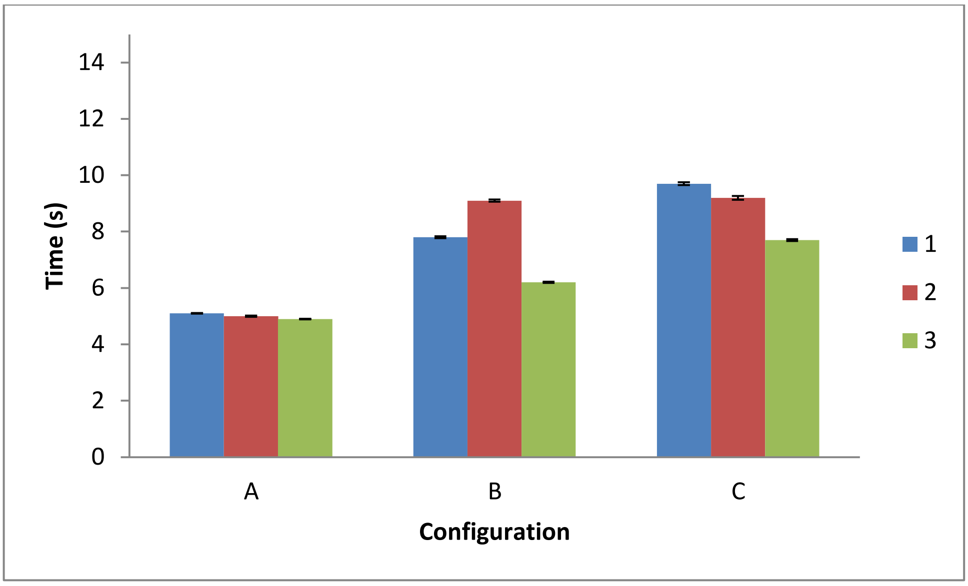

Figure 14 Time to complete Courtyard Wall for all configurations and all repeats.

Fire and Manoeuvre (F & M)

For all three elements of the fire and manoeuvre obstacle, configuration A gave a significantly quicker time than both configuration B and C at the (p= <0.01). Configuration B gave significantly quicker time than C at the same confidence level.

Cover stance 1 to 2

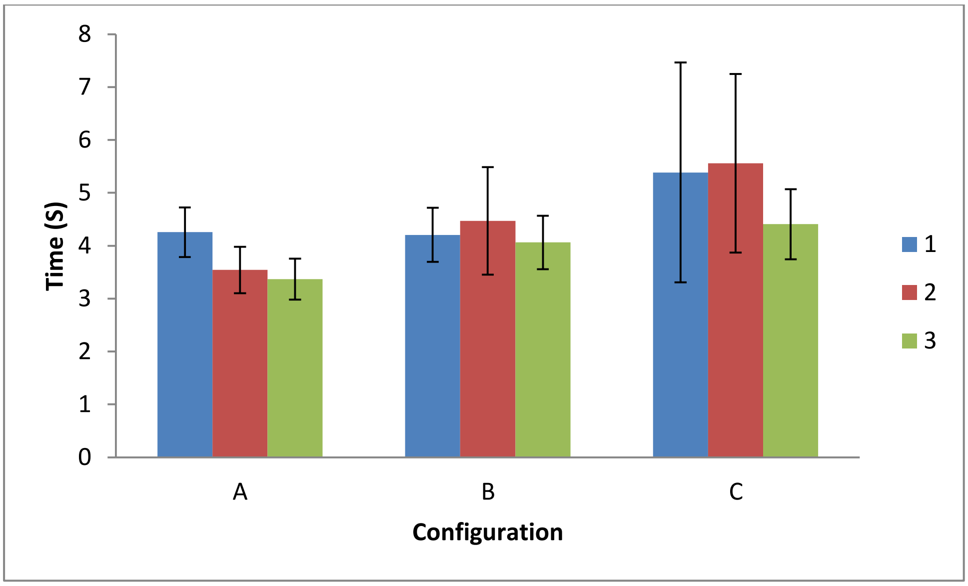

Figure 15 Time to complete Cover stance 1 to 2 for all configurations and all repeats.

Kneel to prone

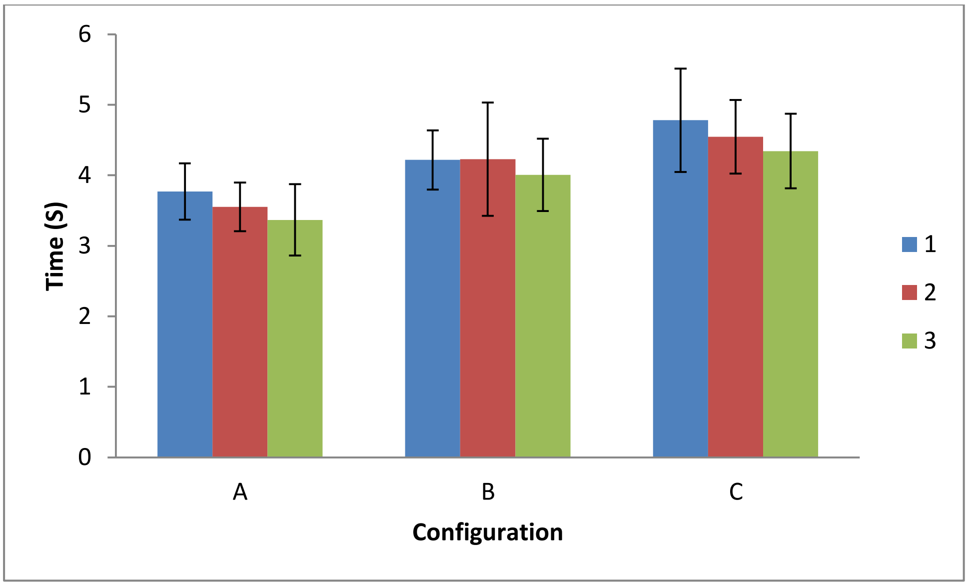

Figure 16 Time to complete Kneel to prone for all configurations and all repeats

Prone to finish (in main body of text)

Total time of F & M

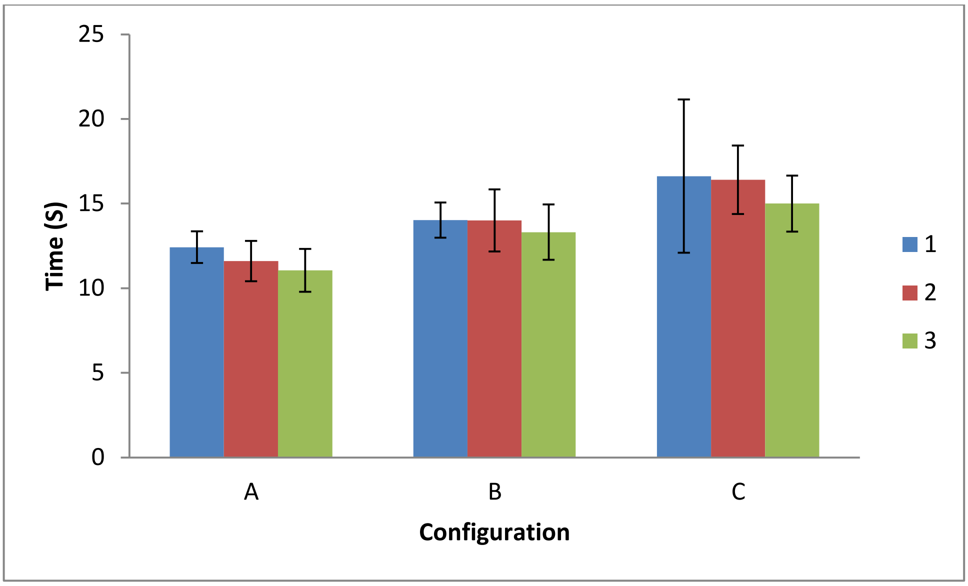

Figure 17 Time to complete Total time of F & M for all configurations and all repeats

APPENDIX E Bespoke Participant Subjective Questionnaire Results

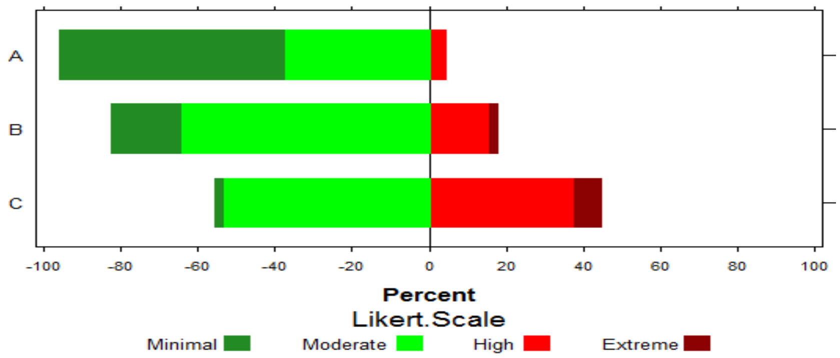

Figure 18 physical effort ratings for all configurations for the Tunnel Crawl

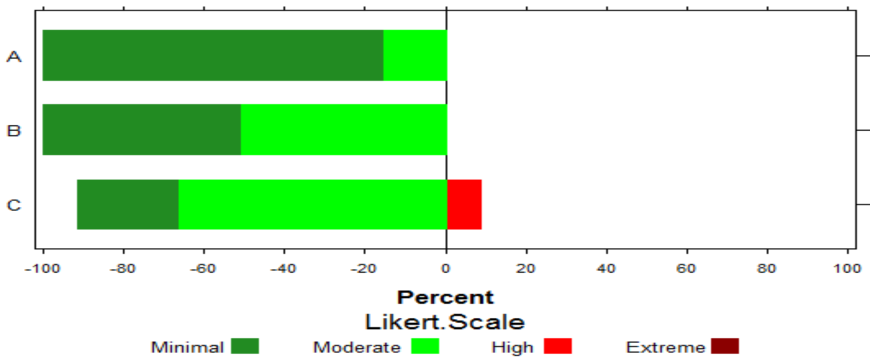

Figure 19 physical effort ratings for all configurations for the Wire Fence

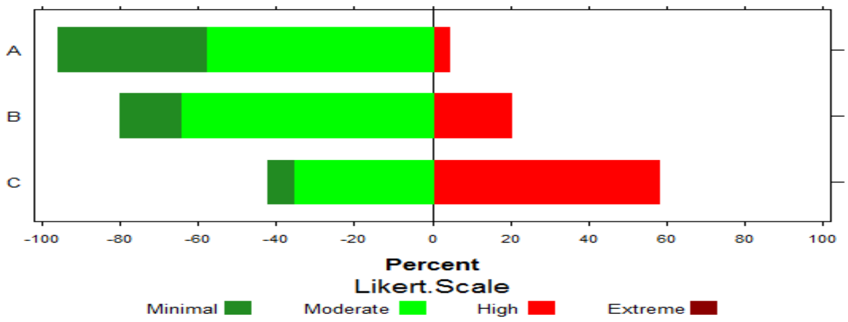

Figure 20 physical effort ratings for all configurations for the High to Low crawl

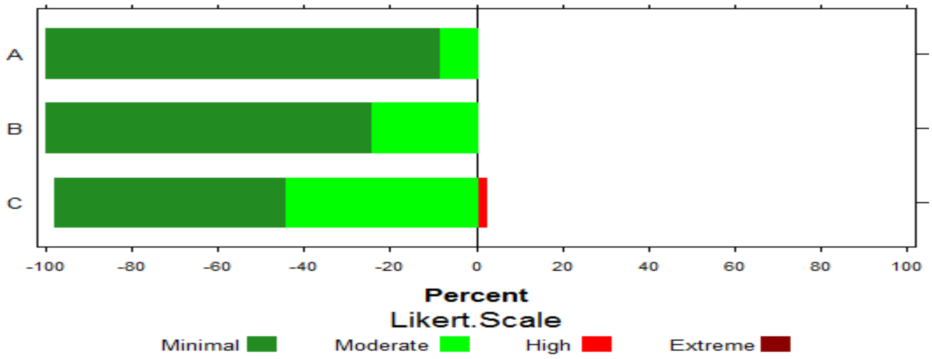

Figure 21 physical effort ratings for all configurations for the Balance Beam

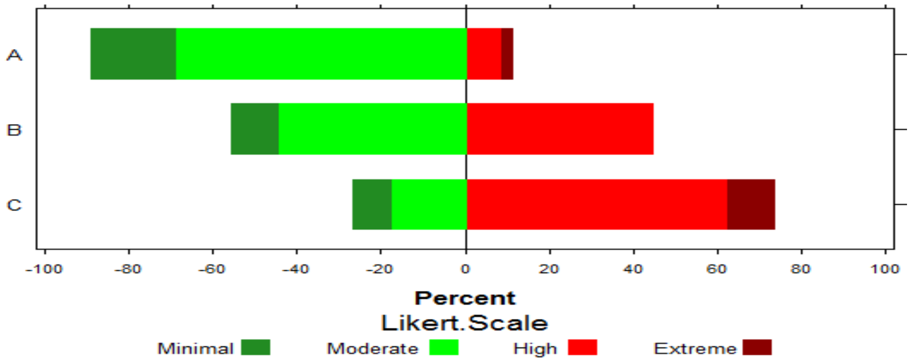

Figure 22 physical effort ratings for all configurations for the Stairs and Ladders Climb

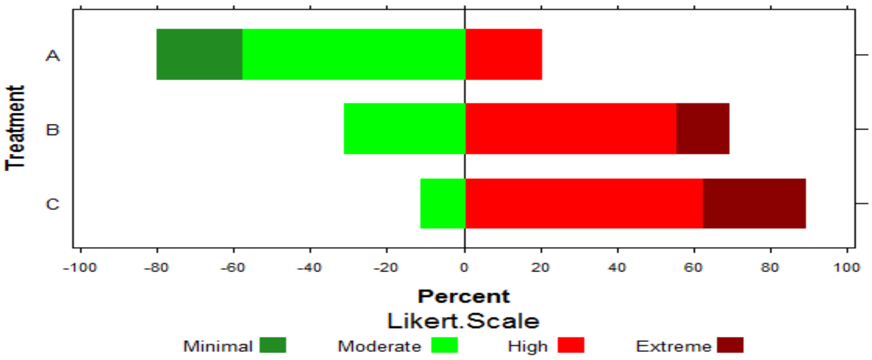

Figure 23 physical effort ratings for all configurations for the Window and Mouse-Holed Wall

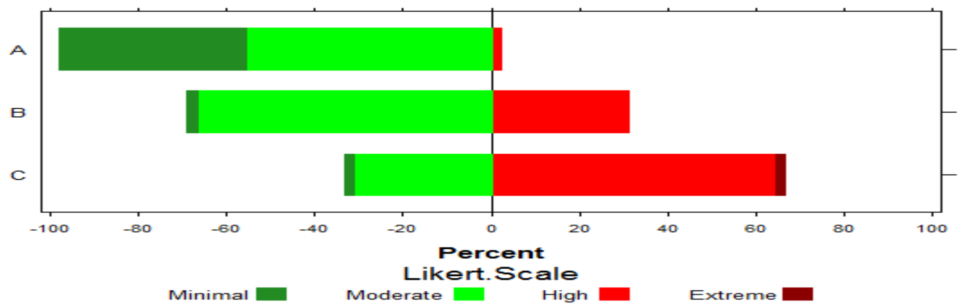

Figure 24 physical effort ratings for all configurations for the High Windowed Wall

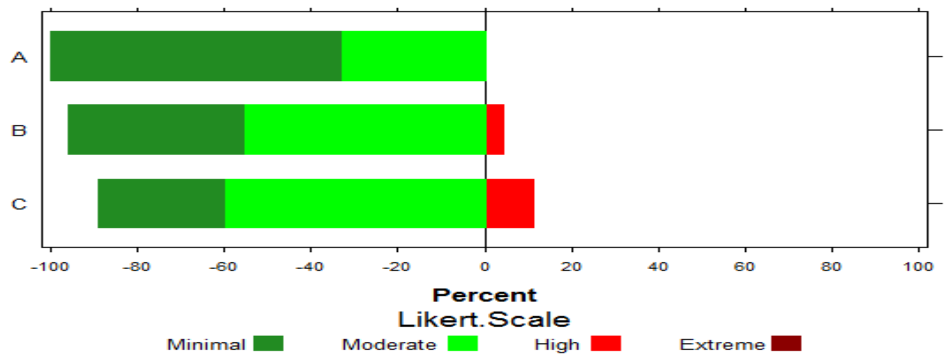

Figure 25 physical effort ratings for all configurations for the Courtyard Wall

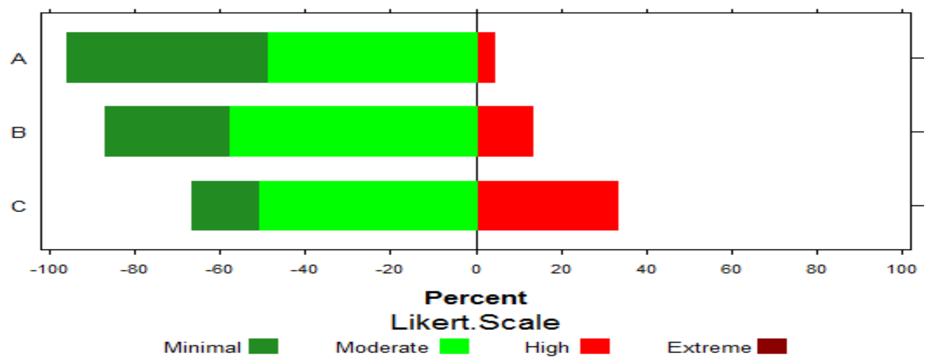

Figure 26 physical effort ratings for all configurations for the Fire and Manoeuvre

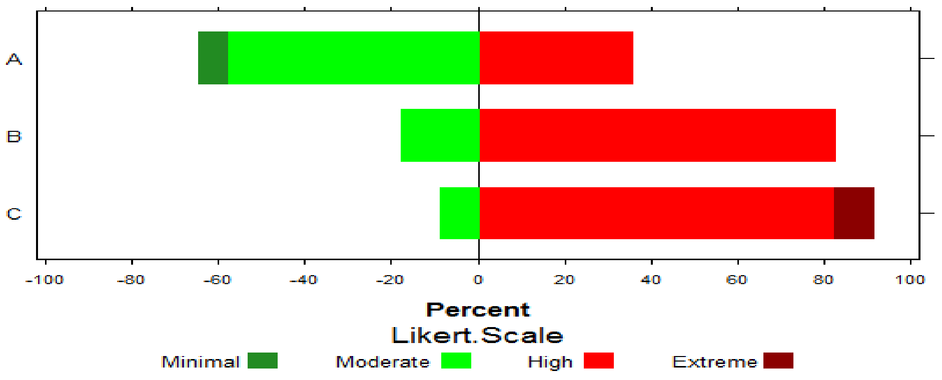

Figure 27 physical effort ratings for all configurations for the whole obstacle course

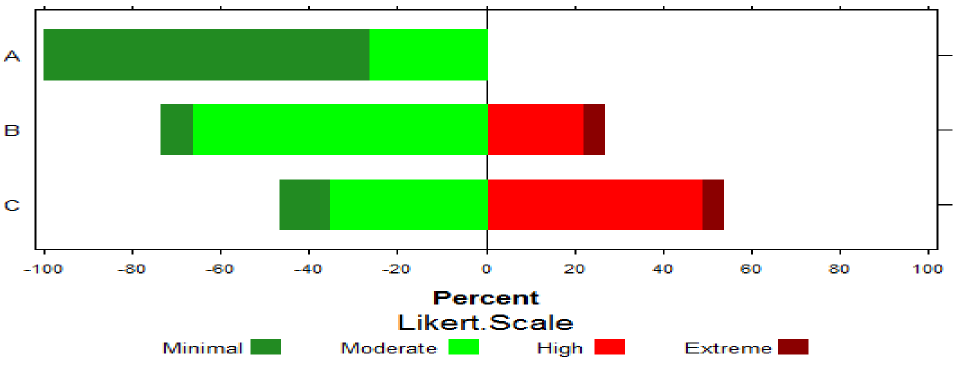

Figure 28 Rigidity ratings for all configurations for the whole obstacle course in all three configurations.

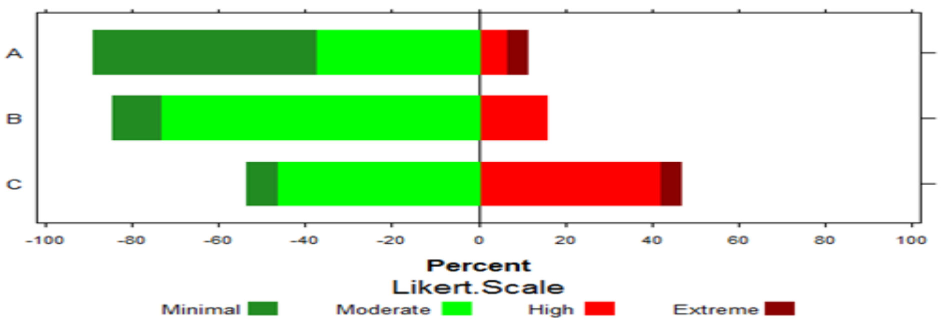

Figure 29 Mobility ratings for all configurations for the whole obstacle course in all three configurations.

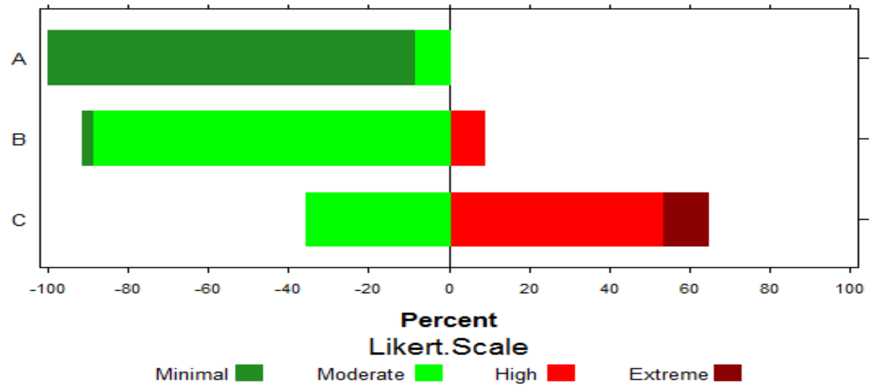

Figure 30 Weight ratings for all configurations for the whole obstacle course in all three configurations

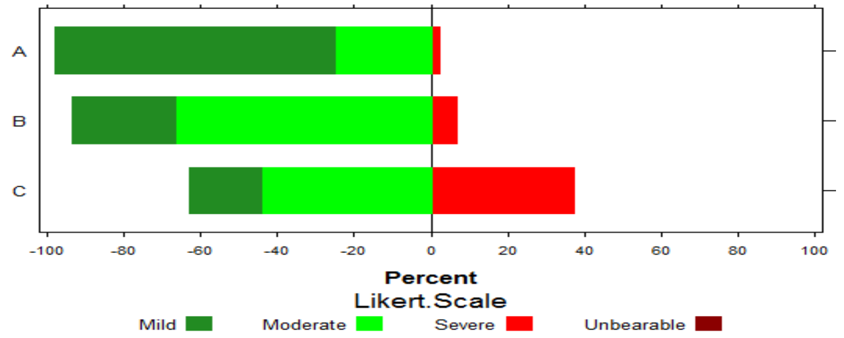

Figure 31 discomfort ratings for all configurations for the whole obstacle course in all three configurations

APPENDIX F Quality of Task Results

Tunnel Crawl Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	0	0	0	0	0
	Severe	0	2	4	0	0	1
	Noticeable	6	7	18	0	3	22
	Minor	6	22	14	1	34	22
	None	33	14	9	44	8	0

Table 10: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Tunnel Crawl

Wire Fence Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	1	2	0	0	0
	Severe	1	2	1	0	0	0
	Noticeable	2	2	7	0	0	2
	Minor	0	15	16	0	7	24
	None	42	25	18	45	38	19

Table 11: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Wire Fence

High to Low Crawl Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	0	3	0	0	0
	Severe	0	2	2	0	0	0
	Noticeable	5	13	18	0	0	2
	Minor	10	16	15	0	9	21
	None	30	14	7	45	36	22

Table 12: Quality of task ratings for participant (self-assessed) and TCO (MA) for the High to Low Crawl

Balance Beam Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	0	3	0	0	0
	Severe	1	1	2	0	0	0
	Noticeable	1	1	2	0	0	1
	Minor	6	8	10	0	2	5
	None	37	35	28	45	43	39

Table 13: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Balance Beam

Stairs and Ladders Climb Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	0	3	0	0	0
	Severe	0	1	4	0	1	0
	Noticeable	3	8	14	0	0	4
	Minor	9	16	16	2	30	39
	None	33	19	8	43	14	2

Table 14: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Stairs and ladders Climb

Window and Mouse-Holed Wall Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	1	2	0	2	15
	Severe	1	3	13	0	1	2
	Noticeable	3	15	8	0	3	18
	Minor	10	16	13	5	36	10
	None	31	10	8	40	3	0

Table 15: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Window and Mouse-Holed Wall

High Windowed Wall Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	0	1	0	0	0
	Severe	0	0	1	0	0	0
	Noticeable	2	9	16	0	0	7
	Minor	10	16	18	2	10	17
	None	33	20	9	43	35	21

Table 16: Quality of task ratings for participant (self-assessed) and TCO (MA) for the High Windowed Wall

Courtyard Wall Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	0	3	0	0	0
	Severe	0	3	1	0	0	0
	Noticeable	1	1	6	0	2	4
	Minor	5	9	12	0	2	1
	None	39	32	23	45	41	40

Table 17: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Courtyard Wall

Fire and Manoeuvre Obstacle		Self-Assessment			MA Assessment		
		A	B	C	A	B	C
Degradation	Catastrophic	0	1	3	0	0	0
	Severe	0	1	3	0	1	0
	Noticeable	1	2	10	0	0	1
	Minor	1	14	11	0	0	9
	None	43	27	18	44	44	35

Table 18: Quality of task ratings for participant (self-assessed) and TCO (MA) for the Courtyard Wall

APPENDIX G Subjective Ratings Results

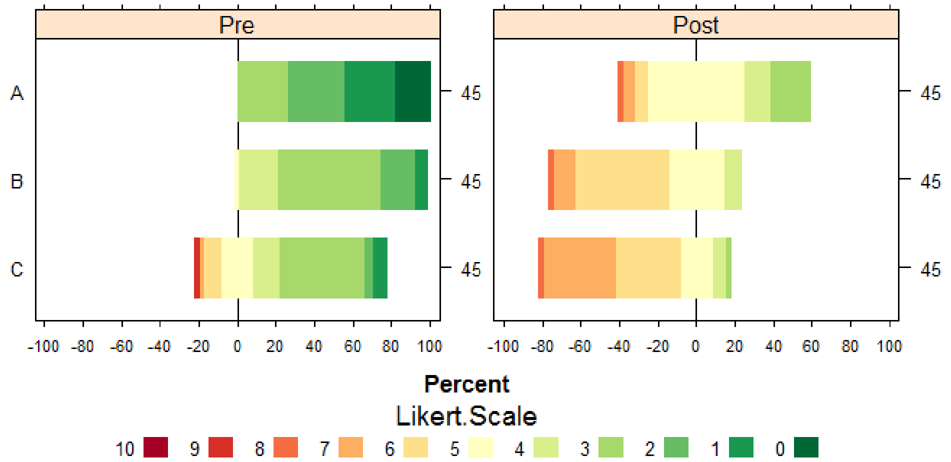

Figure 32: pre and post subjective ratings for perceived exertion for all configurations.

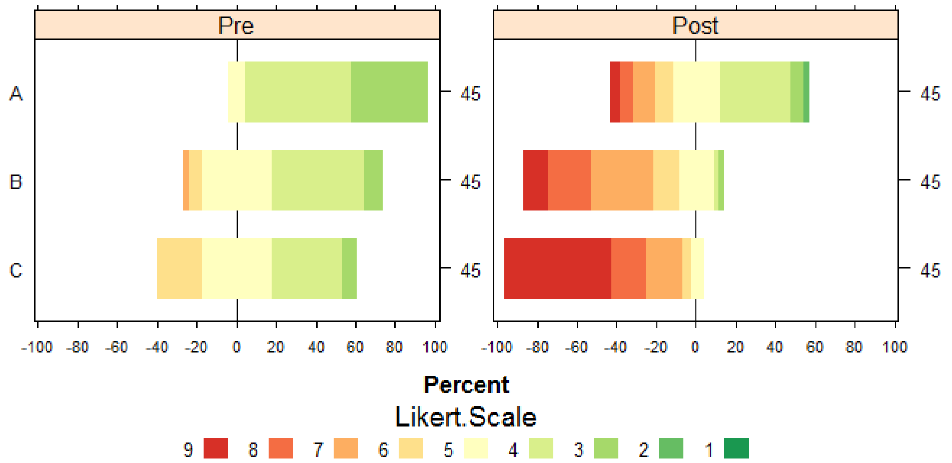

Figure 33: pre and post subjective ratings for thermal sensation for all configurations

Initial distribution

1.	KIS	Dstl	electronic
2.	Lt. Col. Paul McNicholas	DE&S STSP	electronic
3.	Lt Col Nick Serle	ITDU	electronic
4.	Richard Leigh	Dstl Prog Man	electronic

Report documentation page — v5.0

* Denotes a mandatory field

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2	Date of publication: *	SEPTEMBER 2016	3.	Number of pages:	i + 724
4a.	Report UK protective marking: *	UK OFFCIAL			
4b.	Report national caveats: *	NONE			
4c.	Report descriptor: *	NONE			
5a.	Title: *	Verification and Reliability assesment of the Common Battlefield Test facility (CBTF): A Scientific tool to assess agility and mobility during individual soldier performance			
5b.	Title UK protective marking: *	OFFCIAL			
5c.	Title national caveats: *	NONE			
5d.	Title descriptor: *	NONE			
6.	Authors: *	Emily Parish			
7a.	Abstract: *	This report summarises the Common Battlefield Test Facility (CBTF) verification and reliability trial in support of the Dismounted Soldier System Integration development objectives of Defence Equipment and Support, Solider Training and Special Programmes (DE&S STSP). That is to understand the effect of military clothing and equipment on the effectiveness of the soldier through robust, sensitive and repeatable test and evaluation methods. When used in combination with the Dstl Human Factors Analysis Framework (HFAF) assessment and its standardised set of procedures the CBTF has been successfully proven to provide scientifically robust and reliable data to support Military personal clothing and equipment procurement decision making. The CBTF has been verified as reliable when conducted under the standardised HFAF conditions as followed in this trial for the following performance metrics: bespoke subjective questionnaires, quality of task performance, and individual times to complete for all obstacles except the Window and Mouse-holed Wall and F&M. Overall the configuration effect had a larger impact than the repeated run effect, showing that although there was some variation across the repeated runs, there was much more variation across the three configurations, which is useful for discriminating between testing options in equipment trials.			
7b.	Abstract UK protective marking: *	OFFCIAL			
7c.	Abstract national caveats: *	NONE			
7d.	Abstract descriptor: *	NONE			
8.	Keywords: CBTF, RELAIBILITY, EQUIPMENT TRIALS,				

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17a. Patents:	NO		
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