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A job task analysis of the physical demands of manually preparing a 4-person battle trench as a military defensive position

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ABSTRACT

Aim: Conduct a Job Task Analysis (JTA) to quantify the physical demands of preparing a defensive position by British Army Ground Close Combat (GCC) roles.
Method: Subjective data to describe the demands of preparing a defensive position were gathered from focus groups (n = 90) and questionnaires (n = 1495). Eight GCC personnel were observed preparing a defensive position which involved digging, lifting, and carrying materials. The oxygen cost of digging was measured using staged reconstructions at *slow* (12 shovels min^{-1}, n = 16) and *fast* (22 shovels min^{-1}, n = 13) rates.
Results: The JTA identified digging trenches, filling sandbags, and shovelling debris as principal tasks of preparing a defensive position. Oxygen cost during the *fast*-digging rate (27.45 ± 4.93 ml kg^{-1} min^{-1}) was 26 % greater than the *slow*er rate (21.75 ± 2.83 ml kg^{-1} min^{-1}; $p < 0.001$, $d = -1.461$).
Conclusion: Digging a defensive position was identified by military experts as a critical job-task, with variability in metabolic cost dependent on work rate. Data may inform selection, training, and technology interventions to improve task performance.

1. Introduction

Typically, a job task analysis (JTA) involves the collection of subjective and objective data to determine the physical demands of criterion tasks. The criterion tasks are considered (by the experts in the occupation) to be *critical* components of the job-role and as such all personnel who are employed to the specific job-role are expected to be capable to perform them to a defined standard (Tipton et al., 2013; Lee-Bates et al., 2017). These data can be used to document the functional movements performed and the components of fitness (i.e., physical constructs) that underpin the successful completion of job-tasks (Brown and Fallowfield, 2019; Beck et al., 2016). As such, a JTA can inform methods to select, and train employees for the type of work as well as informing the development of technology which may improve the safe and efficient performance of the job-task. A fundamental process to inform the selection and training of personnel is the development of Physical Employment Standards (PES), where subjective and objective data are used to inform role-related physical fitness standards for the selection and retention of personnel within job-roles (Tipton et al., 2013; Beck et al., 2016; Payne and Harvey, 2010; Stevenson et al., 2016; Blacker et al., 2016). PES can be used to inform selection, training and injury intervention strategies (applying technology) and/or employment policy to ensure that personnel have the level of physical capability needed to safely perform the most physically demanding job-tasks in their role. Thus, the introduction of PES can increase the physical capability of a workforce and reduce the likelihood of injury or adverse events, thereby improving operational effectiveness (Payne and Harvey, 2010).

Manually preparing military defensive positions (e.g., 4-person bat-

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tle trenches, shell scrapes, constructing observation posts) are tasks performed by military personnel to provide force protection against potential threats (e.g. small arms fire and blast hazards) and/or to act as a base from which to conduct other job-tasks. Sub-tasks (i.e., components) involved in preparing military defensive positions include digging, filling sandbags, and shovelling debris, which have been identified as common military tasks during land-based, military operations in various Armed forces groups (Sharp et al., 1998; Rayson, 1988; Jaenen, 2005; Singh et al., 1991; Deakin et al., 2000). During a project to develop a bona fide Minimum Physical Fitness Standard for the Canadian Forces personnel, an entrenchment dig task was identified as one of the five most common tasks applicable to military duty (Deakin et al., 2000). Digging tasks are considered to incur a ‘very heavy physical demand’ and 2 % of all ‘moderately heavy’ tasks (Nevola et al., 2003; Nevola. et al., 2003). Digging has previously been identified as a common military task (Sharp et al., 1998; Rayson, 1988; Jaenen, 2005; Singh et al., 1991; Deakin et al., 2000), but there are limited publications within the scientific literature describing the physical demands of military digging (Gledhill et al., 2001; Nevola, 2009). The compendium of physical activities assigned Metabolic Equivalent of Task (MET) ratings of 7.0–9.0 METs for digging tasks such as shovelling [light (<10 lbs/min or 0.07 kg/s), moderate (10–15 lbs/min or 0.07–0.11 kg/s), and heavy rates (>15 lbs/min or >0.11 kg/s)] and digging ditches (Ainsworth et al., 2000); whilst two investigations have reported the cardiorespiratory responses to manually preparing defensive positions (Richmond et al., 2008; Pihlainen et al., 2014). Pihlainen et al. reported an absolute $\dot{V}O_2$ of 1.8 ± 0.4 L min^{-1}, and relative $\dot{V}O_2$ of 24.3 mL kg^{-1}•min^{-1} (51 ± 9 % $\dot{V}O_{2max}$) during a self-paced digging task. During this task, heart rate (HR) values corresponded to 132 ± 10 beats•min^{-1} (68 ± 4 % age predicted maximal heart rate [HR_{max}]) (Pihlainen et al., 2014). Furthermore, during a study by Richmond et al. (2008) participants reached 90 % HR_{max} while shovelling 0.25 m^3 of gravel as fast as possible. This latter investigation formed part of a task-related fitness test validation study for the Royal Air Force (Richmond et al., 2008).

The aim of the present study was to comprehensively assess the physical demands of manually preparing a 4-person battle trench as a military defensive position that could be used to inform the development of PES, with the following specific objectives.

(1) conduct a JTA using focus groups and questionnaires to identify and assess the critical tasks involved in the role.
(2) quantify the physical demand and metabolic cost of the task through observations and staged reconstructions.

2. Method

2.1. General approach

Where required, participants provided their informed consent to participate in this MOD Research Ethics Committee (MODREC) approved study (protocol number 804MODREC17). The MODREC was designed in full compliance with best practice for conducting a JTA as described by the scientific experts in the development of PES (Tipton et al., 2013; Payne and Harvey, 2010). All participants were active, task-experienced, military personnel serving in GCC roles within the UK Armed Forces. All participants were men as, at the time of this study, only men were permitted to be employed in GCC roles within the UK Armed Forces. Prior to the start of the research, a group of stakeholders and military Subject Matter Experts (SMEs) defined the requirement and then provided oversight and assurance throughout the research. These SMEs were able to make key decisions at the Military Judgement Panels (MJPs), that were conducted to define the details associated with successfully conducting the job-task and provided task-related assurance (including compliance with military policy and doctrine).

The general approach to the research involved conducting a JTA to identify and define the physically demanding sub-tasks of preparing a 4-person battle trench as a military defensive position using focus groups, questionnaires, task observation and sub-task reconstructions (each phase subsequently informing the next; see Fig. 1). Use of these techniques in the study design complied with best practice methodology for developing PES (Brown and Fallowfield, 2019; Beck et al., 2016). Ten workshops were conducted, one with each of the Ground Close Combat (GCC) role-groups in the UK Armed Forces, these included Air Assault Infantry, Armoured Cavalry, Armoured Infantry, Armoured Regiment, Light Cavalry, Light Infantry, Light Mechanised Infantry, Mechanised Infantry, RAF Regiment, and Royal Marines. These workshops were used to identify and describe the job-tasks undertaken in these GCC roles including those encapsulated by manually preparing a defensive position (e.g., manually preparing a 4-person battle trench, manually preparing a shell scrape, constructing an observation post). The job-task descriptions were then used to produce an online questionnaire which was completed by a sample size equivalent to a minimum of 5 % of incumbent workforce for each role-group. The questionnaire was used to validate and further quantify the importance, duration, physical demands, and frequency of the manual preparation of the type of defensive position which was identified in the focus groups as a critical job-task (i.e., dig a 4-person battle trench using shovels and picks over ~72 h with short breaks throughout). Subsequently, an observation was completed during a training course to clarify and verify the descriptions of selected tasks from the focus groups. The information gathered from the JTA was used to design a controlled staged reconstruction of three sub-tasks related to manually preparing a defensive position (picket drive, digging, sandbag carry).

2.1.1. JTA - focus groups

Ten, two-day facilitated focus groups (n = 90 military male participants, nine per GCC role-group) were conducted to identify and describe all physically demanding job-tasks conducted within their role. All focus group participants met at least four of the inclusion criteria identified by Blacklock et al. (2015) and were rank stratified to ensure that they represented a range of experience and included personnel (Blacklock et al., 2015).

The focus groups were performed according to the Technique for Research of Information by Animation of a Group of Experts (TRIAGE) process (Gervais and Pépin, 2002; Spivock et al., 2011). Prior to each focus group, participants were asked to list 5 to 10 of the most physically

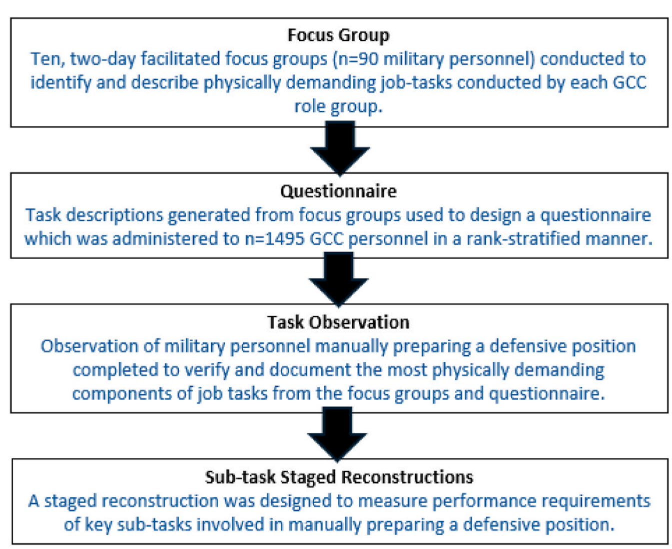

Fig. 1. The Job Task Analysis (JTA) process to identify and define the physically demanding sub-tasks of preparing a 4-person battle trench as a military defensive position comprising of focus groups, questionnaires, task observation and sub-task reconstructions with each phase subsequently informing the next.

demanding tasks conducted in their job-role. After removing duplications from the combined list of all participants and adding any tasks that had been identified by a review of the literature, the facilitators printed the selected tasks on cards and placed these on a board to guide discussion. Focus groups participants reviewed the tasks and associated descriptions and then confirmed or amended the responses in order to establish a working-consensus. Participants were presented with summaries of tasks on a PowerPoint slide and were asked to vote using 1 to 6 Likert scales independently and anonymously using electronic keypads (Votech Audience Response, Guildford, Surrey, UK), on; [a] the **importance** (1 = not applicable, 2 = not important, 3 = somewhat important, 4 = important, 5 = very important, 6 = critical); [b] **duration** (1 = <5 s, 2 = 5–60 s, 3 = 1–10 min, 4 = 11–30 min, 5 = 30 min to 2 h, 6 = > 2 h), [c] **physical demands** (1 = very light, 2 = light, 3 = moderate, 4 = hard, 5 = very hard, 6 = maximum) and; [d] **frequency** that the job-task may be expected to be conducted in a typical career in this role (1 = never, 2 = very infrequent, 3 = infrequent, 4 = quite frequent, 5 = frequent, 6 = very frequent). A task descriptor for manually preparing a defensive position was generated for each of the 10 GCC role-groups for inclusion in the questionnaire.

2.1.2. JTA - questionnaire

The task descriptions generated from the focus groups were used to design a questionnaire which was administered electronically in person to 1495 GCC personnel in a rank-stratified manner (from private soldier to Lieutenant Colonel [or equivalent within each service]). The purpose of the questionnaire was to validate the tasks defined in the focus groups across a wider population of each of the GCC roles and further rate their importance, physical demand, and frequency of completion. Initially details of age, highest formal qualification, rank, years served, and operational experience were obtained. Participants were then provided with summary task descriptions including details of task duration, distances covered, equipment used, mass carried, dress order, and team size (generated in the focus group for their role), before being asked whether they had ever completed the task. Using electronic keypads (Votech Audience Response, Guildford, Surrey, UK), those voting 'yes' were prompted to rate the frequency, importance, and physical demands of the tasks using the same 1–6 ratings scales used in the focus groups. All responses were anonymised. The results from the questionnaire conducted with 5 % of each of the 10 GCC roles were used to generate a summative summary score of the Likert ratings (with a maximum possible score of 18) for each of the most physically demanding tasks, including manually preparing a defensive position.

2.1.3. JTA - military doctrine

UK Armed Forces' doctrine was used to verify the tasks, and such information permitted the scientific study team to consider the likely components of fitness that would be required by personnel to meet the future physical requirements of GCC roles. Additionally, the doctrine was used to assess if there was an intention to continue undertaking these tasks (in their present form) in the future.

2.1.4. JTA - task observation

A task observation was completed to verify the components (and their order) of the task and to document the most physically demanding components of each physically demanding task identified within the focus groups and subsequent questionnaire. Participants were those who were already performing routine training during the observation and were not convened specifically for research purposes, therefore informed consent was not required.

Eight trainee GCC personnel (Mean ± 1SD; age 22 ± 3 years; stature 1.79 ± 0.05 m; body mass [without fatigues] 87.9 ± 11.6 kg) were observed conducting the manually preparing a defensive position task. The task involved a team of 4 to dig a 4-person trench, using shovels and pickaxes over a 52-h time period (see Tables 2 and 3 for more details). All GCC personnel wore weather appropriate combat uniform including boots and helmet throughout the observation. During the observation, the actions performed, timings of events, and equipment used were documented through notational analysis. This involved recording the event name, description, clothing worn, equipment mass (if applicable; Table 3), distance (using Catapult Optimeye S5 GPS devices (Catapult, UK)), duration, number of participants, and physical actions for each task (e.g., walking, lifting, running etc.).

2.1.5. JTA – sub-task staged reconstructions (job-task simulation)

The subjective data from the focus groups and questionnaires, and the objective data from the observations, were collectively used to inform the design of a controlled task reconstruction of manually preparing a 4-person battle trench as a defensive position. The purpose of this staged reconstruction was to describe the physical actions and techniques, and to measure the physical requirements of key sub-tasks involved in manually preparing a defensive position within a controlled and prescribed situation. Three sub-tasks related to manually preparing a defensive position were identified from the earlier stages of the JTA: picket drive, digging, sandbag carry and building a 3x3 (width x height) sandbag position. Thirty-one trained GCC personnel [Mean ± 1SD; age 24 ± 4 years; stature 1.78 ± 0.05 m; body mass (without fatigues) 80.4 ± 8.7 kg] completed the manually preparing a defensive position staged reconstruction. All participants wore fatigues, boots, body armour (without plates), and helmet throughout. The agreed manually preparing a defensive position staged reconstruction design was approved at MJP.

Prior to the staged reconstruction, all participants completed a Multi-Staged Fitness Test (MSFT). The MSFT required participants to complete repeated 20 m shuttle runs at an increasing pace determined by bleeps from a digital audio track (Ramsbottom et al., 1988). No verbal 'level' indicators were provided by this audio track. Starting speed was set at 2.5 m s^{-1} (8.9 km h^{-1}) and the frequency of the audio signal increased every minute corresponding to an increase in running speed of approximately 0.5 km h^{-1}. The test was terminated when the participant could no longer keep pace with the audio signal (i.e., fail to meet the 20 m line on two consecutive occasions) or retired voluntarily. The MSFT data were used to randomly assign each digging rate using a matched paired design according to their MSFT performance (Table 4):

The sub-task staged reconstruction comprised of three sequential phases, which were completed by all participating trained GCC personnel.

(1) Hammering of Pickets: Complete three powerful, controlled hammering actions using a picket post driver at a rate of 6 strikes•min^{-1} on four 6 ft. pickets. The rationale for this picket height was determined using observation data and doctrine.
(2) Digging: Complete a digging task for 12 min using a standard issue short T-handled general service shovel to move pea shingle (10 mm grade) between two wooden digging boxes (1.1 x 0.9 × 0.25 m) at a rate of 12 or 22 shovels•min^{-1} (set by a metronome). The shovel scoop size was self-selected by each participant. Digging rates were calculated by computing the volume of the trench/shell scrape and dividing by the number of people digging and then the defined duration of the tasks described in the Phase 1 workshops, observed in Phase 2, and reported in the literature. The shovelling rate was calculated based upon 100 shovel scoops being required to move 0.125 m^3 of pea shingle using a general service shovel as reported by Nevola et al. (2003).
(3) 20 kg Sandbag Carry and Build (3 x 3 sandbag position) – Lift and carry 9 × 20 kg sandbags a set distance of 5 m to build a 3 x 3 sandbag position at a pace they would usually adopt when building a defensive position. There were no restrictions on how many sandbags could be carried at any one time. Rationale for the mass and number of sandbags used were determined using observational data (i.e., a 4-person trench is 36 sandbags, divided between four personnel equals nine sandbags per soldier).

Table 1
The median (interquartile range; IQR) of ratings from the questions in the focus group and questionnaire for all 10 GCC roles.

		Focus Group						Questionnaire					
TASK ID	JOB TASK TITLE	n	IMPORTANCE[a]	DURATION[b]	PHYSICAL DEMAND[c]	FREQUENCY (FORCE PREP)[d]	FREQUENCY (OPERATIONS)[d]	n	COMPLETED THE TASK? (YES/NO)	IMPORTANCE[a]	PHYSICAL DEMAND[b]	FREQUENCY OVER LAST 5 YEARS[c]	SUMMARY SCORE
1–1	Manually Prepare Defensive Position in the Open	9	4 (3)	6 (1)	6 (1)	2 (1)	2 (2)	228	186/40	4 (5)	5 (5)	2 (5)	11
1–2	Manually prepare Defensive Position - Urban	9	4 (3)	6 (0)	4 (2)	3 (3)	2 (3)	228	160/66	4 (5)	4 (5)	2 (5)	10
2–1	Establish a Harbour Area	9	6 (1)	6 (1)	4 (2)	3 (3)	3 (2)	110	108/1	5 (5)	3 (5)	2 (5)	10
2–2	Manually Establish an Urban Defensive Position	9	5.5 (3)	6 (0)	5 (2)	3 (2)	3 (1)	110	103/6	5 (5)	5 (4)	2 (4)	12
3–1	Manually Prepare a 4-man Shell Scrape	9	n/a	n/a	n/a	n/a	n/a	81	40/28	3 (5)	5 (4)	1 (2)	9
3–2	Establish a Harbour Area	9	3 (3)	6 (2)	5 (2)	2 (1)	2 (4)	81	80/1	4 (5)	4 (4)	2 (4)	10
4–1	Construction of a Sub-surface Observation Post (OP) and Rear OP	9	5 (2)	6 (0)	5 (4)	3 (1)	2.5 (1)	106	81/25	5 (5)	5 (5)	2 (5)	12
5–1	Manually Prepare Defensive Position in the Open	9	4.5 (2)	6 (0)	5 (2)	2 (1)	2 (2)	101	94/6	6 (5)	5 (5)	2 (5)	13
5–2	Manually Establish an Urban Defensive Position	9	5 (2)	6 (0)	4.5 (2)	2.5 (2)	3 (2)	101	96/4	6 (3)	5 (5)	2 (5)	13
6–1	Establish a Harbour Area	9	6 (1)	6 (0)	4 (2)	3 (2)	4 (2)	339	336/3	6 (5)	4 (5)	3 (5)	13
6–2	Establish a Defensive Position	9	6 (2)	6 (0)	5 (1)	2 (0)	2.5 (2)	339	320/19	6 (5)	5 (4)	2 (5)	13
6–3	Establish an OP and Rear Admin Area	9	5 (2)	6 (3)	5 (1)	2 (2)	3 (2)	339	299/40	5 (5)	4 (5)	2 (5)	11
7–1	Construct a Rural OP	9	6 (1)	6 (0)	5 (1)	2 (1)	3 (2)	77	64/12	6 (5)	6 (3)	2 (4)	14
8–1	Manually Prepare Defensive Position	9	5 (3)	6 (0)	5 (2)	2 (1)	2 (2)	160	145/12	4 (5)	6 (4)	2 (4)	12
8–2	Manually Prepare a Shell Scrape	9	6 (2)	5 (2)	4 (2)	3 (2)	5 (3)	160	149/8	4 (5)	4 (4)	2 (4)	10
8–3	Establish an OP	9	5 (2)	6 (0)	5 (2)	3 (1)	3 (3)	160	138/19	4 (5)	5 (4)	2 (4)	11
9–1	Establish a Company Defensive Position	9	5 (2)	6 (0)	5 (2)	2 (2)	3 (2)	149	133/16	5 (5)	5 (5)	2 (5)	12
9–2	Establish an OP Screen	9	6 (1)	6 (0)	4 (1)	3 (4)	4 (1)	149	121/28	6 (5)	5 (4)	2 (5)	13
10–1	Construct a Defensive Position	9	4 (2)	6 (0)	4 (1)	2 (2)	2 (2)	144	117/27	4 (5)	4 (4)	2 (3)	10
10–2	Manually Prepare Field Defences	9	5 (1)	6 (0)	5 (2)	2 (1)	1 (1)	144	125/19	4 (5)	5 (5)	2 (4)	11

Notes: (1) The summary score for each task was generated by summing the importance, physical demands, and frequency ratings from the questionnaire. For example, for task 1-1, the sum of importance (4), physical demand (5), and frequency (2) is equal to a summary score of 11. (2) The variability in the response rate (n) for the questionnaire reflects the different tasks identified by each role group. For example, those tasks denoted by 1-1 and 1–2 both have 228 responses.

[a] 1 = not applicable, 2 = not important, 3 = somewhat important, 4 = important, 5 = very important, 6 = critical.

[b] 1 = <5 s, 2 = 5–60 s, 3 = 1–10 min, 4 = 11–30 min, 5 = 30 min to 2 h, 6 = > 2 h.

[c] 1 = very light, 2 = light, 3 = moderate, 4 = hard, 5 = very hard, 6 = maximum.

[d] 1 = never, 2 = very infrequent, 3 = infrequent, 4 = quite frequent, 5 = frequent, 6 = very frequent).

Table 2
Summary description of the manually preparing a defensive position task observed.

Task Summary	Observation Task Description	Focus Group/QuestionnaireTask Description
Manually prepare field defences	In a team of 4, wearing fatigues and helmet, the soldiers dug a stage 4 trench using shovels and pickaxes over 52-h, with short breaks for administration and lessons from the instructors at each stage of the dig. The stages of the dig were as follows:-**Stage 1:** Mark out 4-person trench and de-turf. -**Stage 2:** Trench Excavation -**Stage 3:** Sandbag filling and metalwork. -**Stage 4:** Re-turf.	Wearing fatigues and helmet, dig a stage 4 trench using shovels and picks over ~72-h with short breaks (~15 min every hour). De-turf (3 m radius), then dig discontinuously (day and night). Picket, river (corrugated iron sheets), sandbag, and backfill the trench and fill sandbags.
Sub-Task	**Observation Task Description**	**Doctrine Description**
Stage 1: Mark out 4-person trench and de-turf	Soldiers marked out the area (spitlock) and de-turfed (~3 m radius) with a shovel and carry turfs to an area beyond the trench area (~5.5 h)	Spitlock and de-turf an area 3.45 m long and 0.75 m wide. Place the turfs to one side for subsequent use as camouflage.
Stage 2: Trench excavation	Soldiers excavated the area to a depth of 1.5 m. Two soldiers used a pickaxe to dig down into the ground, working at either end of the trench, working into the centre. The other two soldiers used shovels to dig out the loose soil.	Excavate the area to a depth of 1.5 m (unless otherwise ordered), placing the soil, preferably on ground sheets, in front of where the shelter will be. The two ends may be curved during excavation if digging by hand. Excavate elbow rests 0.45 m wide and 0.30 m deep around both fire bays. Dig three anchor wire channels 0.3 m deep and 3.0 m long at each end of the positions.
Stage 3: Sandbag filling and metalwork	Soldiers placed 4 revetment pickets (1.8 m) in position in the trench and drove them about 0.20 m into the ground. They also placed 4 anchor pickets (0.6 m) in position outside the trench and drove them fully into the ground. They connected two pairs of split hairpin shelter sheets for revetment and used one pair to rivet the end of each bay. They wrapped wire around the revetment picket and the anchor picket which was positioned directly opposite five times to create a tourniquet effect and secure the split hairpin shelter and corrugated iron sheets in position. They built a wall on either side of the fire bays using sandbags. Sandbags were filled approximately three quarters full and tapped into position with a shovel or by hand.	Place the 6 revetment pickets in position and drive them about 0.2 m into the ground. Place the 6 anchor pickets in position and drive them fully into the ground. Connect two pairs of split hairpin shelter sheets for revetment and use one pair to rivet the end of each fire bay. Lay two 1.8 m pickets as bearer, along the bottom of the shelter bay to one side, leaving a gap of about 0.3 m between them. Lay two more pickets on the other side of the trench and secure them all in position with 0.6 m pickets. Next connect two pairs of split hairpin shelter sheets, connected to support overhead protection and place one pair at each end of the shelter bay so that the fire bays are each 1.5 m long.
Stage 4: Re-turf	Participants back-filled the trench with soil and replaces the turfs over the shelter bay to camouflage the whole position.	Place 0.45 m of earth over the shelter bay and compact it thoroughly. Remove the remaining soil to another place. Replace the turfs over the shelter bay and camouflage the whole position.

Throughout the sub-task staged reconstruction, HR was measured using Polar Team 2 HR monitors (Polar Electro UK, Ltd, Warwick, UK), with zones classified using the method described by Howley (2001). Expired gas was collected using the Douglas bag technique (Douglas, 1911; Hopker et al., 2012), during the final 2 min of the digging phase. A nose clip was worn by personnel to ensure exclusive mouth breathing during the gas collection. Single 200 L Douglas bags (Cranlea Human Performance Limited, UK) were held by the researchers and connected to a mouthpiece by low resistance tubing (Hans Rudolph, inc., USA) and Salford type valve (Cranlea Human Performance Limited, UK). Prior to use, Douglas bags were flushed with ambient air and evacuated fully. Respiratory gas fractions were analysed (Servomex 5200, Servomex, UK), and then volume (Harvard dry gas meter, Harvard Apparatus, USA) and temperature were recorded (digital thermometer; Fisher Scientific, UK). The gas analyser underwent a two-point calibration, following the manufacturer's instructions. Expired gas data were subsequently used to determine metabolic rate using the following equation (Nishi et al., 1981):

$$\text{Metabolic rate (W/m}^2) = (352((0.23 \ast \text{Respiratory Exchange Ratio} + 0.77) \ast (VO_2))/\text{Dubois body surface area.}$$

2.2. Statistical analysis

Statistical analyses were undertaken using JASP (Version 0.16, JASP Team, 2021) and Microsoft Excel software (2016, Microsoft, USA). Normative performance data are reported as mean ± one standard deviation and as a number (n). Data normality was assessed using Shapiro-Wilk to determine whether a parametric or non-parametric test should be used for analysis. To examine group differences in staged reconstruction performance, independent samples Student's t-tests and Welch t-tests were applied to normally and non-normally distributed data, respectively with effect sizes reported as Cohen's *D* alongside 95 % confidence intervals (CI) of the effect sizes.

3. Results

3.1. Job task analysis: focus groups/questionnaires

Manually preparing a defensive position was identified in the focus groups as a physically demanding job-task for all 10 GCC roles. A total of 20 individual examples of tasks to manually prepare a defensive position were described (e.g., trenches, shell scrapes, constructing an observation post); each of which were given a summary score using data obtained from the questionnaire (Table 1). These summary scores ranged from 9 to 14 out of a possible 18. The summative summary scores were similar across all roles, demonstrating the requirement for manually preparing a defensive position to be classified as a common military task.

3.2. Job task analysis: observations

The observations confirmed that the tasks discussed in the focus groups (and rated in the questionnaire) were being carried out by personnel and provided further insight into how they were completed. Observing personnel manually preparing a 4-person battle trench as a military defensive position provided the researchers with the opportunity to gain a deeper understanding of the requirements relating to the task and those necessary to perform the job-tasks. As such, the elements that were considered to be most physically demanding included 'hammering of pickets', 'digging discontinuously', and 'lifting and carrying sandbags'. Detailed descriptions of each individual sub-task observed during the manually preparing a 4-person battle trench as a defensive position are presented in Table 2. The primary actions carried out by soldiers during these tasks comprise of digging, walking, kneeling, squatting, crawling, lifting, carrying, and climbing (Table 3).

Table 3
A summary of the sub-tasks observed during a 52-h manually preparing a defensive position task. *Data are presented as mean.

Sub-task	Summary of Actions	Components of Fitness	Duration (mins)	Total Distance (km)	Equipment Used [n per trench]	Equipment Mass (kg)
Mark out 4-person trench	Walking, Kneeling, Squatting	Aerobic Endurance	6	0.10		
De-turf	Carrying, Walking, Kneeling, Crawling, Digging	Aerobic Endurance, Muscular Endurance, Muscular Strength, Mobility	332	6.8	Shovel [4]	2.1
Trench Excavation	Lifting, Carrying, Walking, Climbing, Kneeling, Digging	Aerobic Endurance, Muscular Endurance, Muscular Strength, Mobility	1057	10.7	Pickaxe [2] Shovel (4)	3.3 2.1
Filling sandbags	Lifting, Carrying, Walking, Digging	Aerobic Endurance, Muscular Endurance, Muscular Strength	123	1.1	Sandbags [24–36]	20.0
Metal work (install split hairpin shelter sheets/pickets)	Lifting, Carrying, Walking, Digging, Hammering, Lowering, Crawling	Aerobic Endurance, Anaerobic Endurance, Muscular Endurance, Muscular Strength, Muscular Power	1369	16.2	Sandbags [24–36] Long Picket [4] Short Picket [4] Split Harpin Shelter [4] Picket Hammer/ Thumper [1] Corrugated Iron Sheets [2–4]	20.0 6.9 1.6 8.0 10.0 –
Filling sandbags	Lifting, Carrying, Walking, Digging	Aerobic Endurance, Muscular Endurance, Muscular Strength, Mobility	128	1.1		
Re-turf	Lifting, Walking, Kneeling, Crawling, Digging	Aerobic Endurance, Muscular Endurance, Muscular Strength	65	1.4		
Whole Task Summary	Walking, Kneeling, Squatting, Carrying, Crawling, Digging, Lifting, Climbing, Lowering, Hammering		3080	37.4		

Table 4
Summary of the rate of oxygen utilisation, heart rate and metabolic data for manually preparing a defensive position staged reconstruction for both digging rates. Data are presented as mean ± 1 SD.

Variable	12 shovels•min^{-1}	22 shovels•min^{-1}	p	d	95 % CI for Cohen's d
N	16	13	–	–	–
Stature (m)	1.77 ± 0.06	1.79 ± 0.05	0.347	−0.345	[-1.055, 0.371]
Body Mass (kg)	82.4 ± 9.7	78.8 ± 7.4	0.360	0.336	[-0.380, 1.045]
Predicted VO_{2max} (ml•kg^{-1}•min$_{-1}$)	49.53 ± 5.99	51.21 ± 5.53	0.428	−0.290	[-0.999, 0.423]
VE_{STPD} (L•min^{-1})	35.39 ± 6.89	46.54 ± 12.28	0.009	−1.117	[-1.921, −0.289]
VE_{BTPS} (L•min^{-1})	42.70 ± 8.31	56.25 ± 14.65	0.008	−1.138	[-1.944, −0.306]
$\dot{V}O_2$ (L•min^{-1})	1.77 ± 0.26	2.14 ± 0.38	0.005	−1.149	[-1.933, −0.347]
$\dot{V}O_2$ (ml•kg^{-1}•min^{-1})	21.75 ± 2.83	27.45 ± 4.93	<0.001	−1.461	[-2.279, −0.622]
$\dot{V}CO_2$ (L•min^{-1})	1.50 ± 0.24	1.92 ± 0.38	0.001	−1.347	[-2.151, −0.522]
VE/ $\dot{V}O_2$	24.01 ± 2.37	26.06 ± 3.17	0.056	−0.746	[-1.497, −0.019]
VE/ $\dot{V}CO_2$	28.34 ± 2.10	28.99 ± 2.06	0.412	−0.311	[-1.045, 0.428]
RER	0.85 ± 0.04	0.90 ± 0.06	0.011	−1.025	[-1.797, −0.236]
Metabolic Rate (W•m^2)	327 ± 41	394 ± 67	0.009	−1.055	[-1.830, −0.263]
Energy Expenditure (kJ•min^{-1})	38 ± 4	46 ± 8	0.006	−1.123	[-1.904, −0.324]
Mean HR (b•min^{-1})	121 ± 16	143 ± 16	<0.001	−1.369	[-2.161, −0.556]
%HR_{max}[a]	62 ± 8	72 ± 8	0.002	−1.241	[-2.019, −0.443]

[a] Age-predicted HR_{max}.

The average distance covered over 52-h was 37.4 km.

3.3. Job task analysis: summary

Data from the job-task observation reinforced the subjective (qualitative) findings from the survey (focus groups and questionnaire). This evidence informed the JTA for the 10 GCC roles, provided task descriptions, techniques adopted, and equipment used to perform tasks related to manually preparing a defensive position. In addition, the data quantified the most physically demanding elements of the tasks, which were scrutinised and agreed by MJPs.

The MJP endorsed the task of manually preparing a defensive position as a common military task. It was agreed by a MJP that this job-task should be further investigated during a controlled reconstruction to quantify the physiological strain and physical demands of the most physically demanding elements of the criterion task.

3.4. Staged reconstruction

Whole-task duration for the staged reconstruction was 14:24 ± 00:33 mm:ss, which comprised 12 min of digging and the remainder of the time allocated to hammering pickets and the sandbag carry and build elements of the task.

Absolute and relative $\dot{V}O_2$ of digging were 1.77 ± 0.26 L min^{-1} and 21.75 ± 2.83 ml kg^{-1}•min^{-1} for 12 shovels•min^{-1} (45 ± 10 % predicted $\dot{V}O_2$max), and 2.14 ± 0.38 L min^{-1} and 27.45 ± 4.93 ml kg^{-1}•min^{-1} (54 ± 13 % predicted $\dot{V}O_2$max) for 22 shovels•min^{-1} (Table 4). Corresponding HR were 121 ± 16 b min^{-1} (62 ± 8 % age predicted HR_{max}) and 143 ± 16 b min^{-1} (72 ± 8 % age predicted HR_{max})

for 12 and 22 shovels•min^{-1}, respectively. In addition, relative HR values for digging at 12 shovels•min^{-1} matched to equal percentage of time between light (47 %) and moderate (46 %) HR zones. For digging at the higher rate of 22 shovels•min^{-1}, less time was spent in the light zone (14 %), with more time spent in the moderate (67 %) and hard zones (19 %). Metabolic rate, as calculated by the formula in equation 1 (Nishi et al., 1981), was 327 ± 41 W m^{-2} for 12 shovels•min^{-1} and 394 ± 67 W m^{-2} for 22 shovels•min^{-1}, which equates to 38 ± 4 kJ min^{-1} (2284 ± 326 kJ h^{-1}) and 46 ± 8 kJ min^{-1} (2724 ± 481 kJ h^{-1}).

4. Discussion

This study conducted a comprehensive JTA of manually preparing a 4-person battle trench as a military defensive position that has informed the subsequent development of an representative military task. The most physically demanding discrete sub-tasks were identified as the intermittent hammering of pickets, digging, and the lifting and carrying of sandbags, which required a range of primary physical actions (e.g., walking, kneeling, carrying, digging) and were underpinned by contribution from all components of fitness (aerobic endurance, anaerobic endurance, muscle endurance, muscle strength, and mobility). While muscle strength is essential for lifting and carrying heavy objects, and mobility crucial for manoeuvring in confined spaces (e.g., trenches), we suggest that muscle endurance and aerobic endurance are the most vital components of fitness when preparing a defensive position as evidenced by our digging $\dot{V}O_2$ and HR data and the work of others demonstrating the aerobic demand of digging (Richmond et al., 2008; Pihlainen et al., 2014). Furthermore, the existing literature emphasises the importance of material manual handling in excavation tasks supporting the premise that muscular endurance is a critical determinant in the manual preparation of defensive positions (Carstairs et al., 2018; Sharp and Rosenberger, 2009). Collectively these findings are important for informing the development of PES.Increasing the digging rate from 12 to 22 shovels•min^{-1}elicited a 18 % increase in HR and a 26 % increase in $\dot{V}O_2$. These results are consistent with previous findings from digging tasks (Richmond et al., 2008; Pihlainen et al., 2014; Patton et al., 1995). In male soldiers, digging individual defensive positions resulted in mean absolute and relative VO_2 of 1.3L•min^{-1} and 17 ml kg^{-1}•min^{-1}, respectively (Patton et al., 1995). Similarly, during a self-paced digging task, others have reported a relative $\dot{V}O_2$ of 24.3 mL kg^{-1}•min^{-1} equating to 51 ± 9 % $\dot{V}O_{2max}$ (Pihlainen et al., 2014). In conjunction with measures of VO_2, Pihlainen and colleagues observed HR values corresponding to 132 ± 10 beats•min^{-1} (68 ± 4 % age predicted HR_{max}) (Pihlainen et al., 2014). In contrast, HR responses of digging in a task-related fitness validation study were notably higher, with participants reaching 90 % of their age-predicted HR_{max} while shovelling 0.25 m^3 of gravel as fast as possible (Richmond et al., 2008). The findings of the present study were similar to those of Pihlainen et al. (2014) suggesting that exercise intensities may have been similar between studies providing a realistic representation of the work rates involved during military digging tasks offering credibility to the science underpinning the development of PES and ensuring a legally defensible link between the job task and associated representative military task.

The metabolic rate from digging at the slow and fast rates were 38 ± 4 kJ min^{-1} (546 ± 78 kcal h^{-1}) and 46 ± 8 kJ min^{-1} (651 ± 115 kcal h^{-1}), respectively. Thus, the digging element of a manually preparing a defensive position over several hours would result in significant energy expenditure. Similarly, in coal miners, shovelling yielded an energy expenditure of 30–32 kJ min^{-1} (Passmore and Durnin, 1955). In a summary of studies assessing energy expended by coal miners whilst shovelling (working with a pick and shovel), Åstrand and Rodahl (1986) reported a typical range from 25 to 29 kJ min^{-1} (Åstrand and Rodahl, 1986). Ayoub et al. (1981) also reported an average energy expenditure of 38.9 kJ min^{-1}, but they showed that when participants self-selected their shovelling rate, they only maintained the higher shovelling rate (25 shovels·min^{-1}) for 4 min before reducing to a more sustainable 16 shovels·min^{-1}) (Ayoub et al., 1981). In summary, these data provide further evidence to substantiate the view that digging tasks are inherently physically demanding.

Manual material handling tasks such as hammering, lifting and carrying, and digging have been identified as common military tasks performed by various Armed forces groups (Sharp et al., 1998; Rayson, 1988; Jaenen, 2005; Singh et al., 1991; Deakin et al., 2000). By their very nature, these tasks can be classified as discrete, continuous, or repetitive (Savage et al., 2014). As such, digging tasks are a typical example of a predominantly aerobic-based military-specific activity that should ideally be performed at sub-maximal level to limit fatigue and reduce the risk of injury (Savage et al., 2012). Consequently, the oxygen uptake data herein, in combination with sustainability curves (Drain et al., 2016) could be used to estimate the duration for which prolonged digging tasks could be maintained, during the construction of a defensive position. This would enable personnel to optimise digging rates to ensure they are working in the most efficient manner and may help to inform work:rest ratios. Moreover, these oxygen uptake data could also prove useful during PES decision-making. Specifically, during the down selection of the most physically demanding tasks, this predominantly aerobic task could be compared with other aerobic tasks such as load carriage to identify the most physically demanding tasks.

The research underpinning the design of the staged reconstruction is subject to limitations, influenced by having to balance the fidelity of making detailed measurements and the feasibility of time, resources and physical demands experienced by participants. The development of, and subsequent data derived from, the staged reconstruction were based on the down-selection of only two digging rates, limiting the scope of available data. While the rates served a specific purpose suited to the current research specification, it is acknowledged that future research would benefit from encompassing a wider range of digging rates. Secondly, the JTA utilised in the study exclusively reflects digging in temperate environmental conditions and observations made on soil/clay ground suitable for digging. Moreover, the use of shingle in the staged reconstruction compounds the appropriateness to other ground surfaces (e.g., sand, silt, chalk, hardpan, etc.). This implies that the findings may be constrained in diverse operational environments, such as urban settings, where the construction of a defensive position differs significantly (e.g., soil composition, digging conditions, obstacles). If required, future investigations should consider incorporating a more varied range of environmental scenarios, ensuring the staged reconstruction is both adaptable and applicable across a broader spectrum of military scenarios. Finally, whilst the capture of expired gas data using the Douglas bag methods are valid, reliable and cost-effective, these measurements could be further optimised in future research using modern technology such as a wearable metabolic system (e.g., Cosmed K5, VO_2 Master Pro).

5. Conclusion

This study has produced a comprehensive JTA to quantify the physical demands of manually preparing a 4-person battle trench as a military defensive position. The most physically demanding sub-tasks were hammering of pickets, digging, and the lifting and carrying of sandbags, which require a combination of aerobic endurance, anaerobic endurance, muscle endurance, muscle strength, and mobility. These data findings can help support the development of PES, and inform interventions for selection and training of personnel, and technology to improve task performance.

CRediT authorship contribution statement

C.A. Rue: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **S.D. Myers:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **C.A.J. Vine:** Writing – original draft, Methodology, Investigation, Data curation. **V.R. Nevola:** Writing – review & editing, Investigation, Conceptualization. **B.J. Lee:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **E.F. Walker:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **S.L. Coakley:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **T.R. Flood:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **J. Doherty:** Methodology, Investigation, Formal analysis, Data curation. **S. Jackson:** Resources, Project administration, Conceptualization. **J.P. Greeves:** Writing – review & editing, Funding acquisition, Conceptualization. **S.D. Blacker:** Writing – original draft, Project administration, Funding acquisition, Conceptualization.

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Declaration of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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