**The Development, and Day-to-Day Variation, of a Military-specific
Auditory N-Back Task and Shoot-/Don't-Shoot Task**

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Soldiers are required to successfully complete numerous physical and cognitive tasks during their operational deployments. As such, understanding the typical variance in research tools that may be used to provide insight into the relationship between performance in these two domains is of high importance. This study assessed the inter-day variability of two military-specific cognitive assessments; a Military-Specific Auditory N-Back Task (MSANT) and a Shoot-/Don't-Shoot Task (SDST). Twenty-eight participants completed both tasks seated, across three visits. A sub-sample of twelve participants also completed both tasks whilst walking (10 minutes, 6.5 km·h⁻¹, 1% gradient) over three further visits. Limits of agreement $\pm$ 95% Confidence Intervals, Standard Error of the Mean, and Smallest Detectable Change were calculated to quantify the typical variance in performance. All parameters within the MSANT and SDST demonstrated no mean difference for trial visit in either the seated or walking condition, with equivalence demonstrated for the majority of key variable comparisons. This consistency in performance across experimental trials indicated that the familiarisation employed was sufficient. Collectively, these data provided an indication of the typical variance in MSANT and SDST performance, along with demonstrating that both assessments are capable of completion during seated or walking conditions.

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Introduction

During military operations, personnel are required to maintain high levels of performance in both their role-specific physical military tasks (e.g. load carriage), and in a multitude of corresponding cognitive tasks (e.g. decision making, and communication tasks)(Crawford et al., 2017; Scribner, 2016). Failure to maintain performance in either domain can result in reduced combat readiness and decreased operational performance (Crawford et al., 2017; Vrijkotte et al., 2016). As such, there is a growing interest in the relationship between military-specific physical activity and the cognitive performance of military operators (Armstrong et al., 2022; Bhattacharyya et al., 2017; Eddy et al., 2015; Giles, Hasselquist, et al., 2019; Kobus et al., 2010; Nibbeling et al., 2014; Vine et al., 2021). Despite this amplified interest, the methodologies and approaches used to investigate this relationship have differed considerably, particularly concerning the assessment of cognitive performance.

Applied military researchers have primarily focused on applying visual and auditory assessments of task-specific cognitive performance over well-developed tests of cognitive functioning. For example, a choice reaction task commonly termed a ‘shoot-/don’t-shoot’ task has been used frequently within these investigations. Researchers have however employed this assessment in different ways such as, within a field-based testing scenario opting for human ‘targets’ appearing from behind a walled screen (Nibbeling et al., 2014), to screen-based digital stimuli of people, whilst participants walk on a treadmill (Armstrong et al., 2022; Eddy et al., 2015), to a similar treadmill approach, but instead utilising target symbols of the same spatial frequency (Kobus et al., 2010). Within auditory based tasks, researchers have opted for a variety of tasks such as an auditory go-/no-go task using different acoustic files from ‘friendly’ and ‘enemy’ weapon systems (Eddy et al., 2015; Giles, Hasselquist, et al., 2019), to abbreviated five-paragraph order

relating to a topographical map and patrol instructions (Kobus et al., 2010), to auditory monitoring tasks (Crowell et al., 1999). It, therefore, appears that the consensus of the literature is towards the employment of externally valid measures to assess the cognitive performance of combatants; an approach broadly supporting the concept of representative design (Pinder et al., 2011; Vine et al., 2021).

These cognitive assessment tools have primarily been designed to be used during military-specific physical activity. This has characteristically occurred in the form of five-minute assessment 'blocks', during load carriage tasks, with physiological strain assessed in adjacent periods (Armstrong et al., 2022; Crowell et al., 1999; Eddy et al., 2015; Giles, Hasselquist, et al., 2019; Kobus et al., 2010). This approach is key, given the fact that, despite the well-documented influence of acute aerobic exercise on cognitive function (Giles, Mahoney, et al., 2019), less is known about the influence of military-specific physical activity on cognitive function. In addition, utilising a dual-/multi-tasking approach, is of high importance, given that even at rest, combatants typically wear additional load mass, which has been shown to influence cognitive performance (Son et al., 2019). It has also been suggested that a pre-/post-physical task methodology affords participants sufficient recovery opportunities to manage their cognitive resources, allowing the successful completion of the given cognitive assessment (Mahoney et al., 2007). Therefore, given the limited data regarding the influence of military-specific physical activity on cognitive function, understanding the typical variability in these measurement tools is key for maximising their usability.

With broadly similar research approaches being utilised, it demonstrates an appetite for an applied understanding of this research area. However, despite these similarities, and the large focus on external validity, the mixed methodologies employed in combination with some external validity caveats, limit both consensus conclusions across

investigations and assessment usability in future investigations. In particular, the typical variation in performance of these assessment tools is not known. This is critical, given that military operations typically comprise of numerous sequential tasks that are often protracted in nature, and may last multiple days. Without this understanding, it is plausible that interpretations of data could be misplaced. This notion is supported by seminal work in this area by Knapik et al. (1997), whereby the authors acknowledge that some cognitive assessment interaction effects were difficult to interpret due to a lack of stability in baseline scores. Furthermore, this information forms the basis of an assessment's translational ability to the 'real world'; in combination with construct validity (Close et al., 2019). To further support the application of these assessment tools within military-specific research, it is important to also understand an assessment tool's typical learning duration, and provide guidance on familiarisation protocols; something many of these investigations have not provided. Therefore, obtaining a grasp of both typical performance variation and required familiarisation durations is integral to understanding the applied implications of this research area.

Based on these limitations, as well as the mixed methodologies of previous investigations, this study aimed to devise and detail the methodology of two cognitive assessment tools, which were designed and developed based on those previously utilised within the literature. To strengthen the assessment tools, by way of establishing strong content validity, a group of subject matter experts were consulted on aspects of the cognitive assessment's design. Their collective experience included active and former military service and military research both within academia and industry. Given the large variation in the load carriage tasks (external loads carried, movement speeds, distances covered, terrain crossed etc.) and general tasks conducted by combatants, as well as the manner in which these assessment tools have been used, and might be used in the future, it was

decided that assessment tool performance variation would principally be assessed under seated conditions. However, given the dual-/multi-tasking approach employed by many investigations, a sub-sample of participants was also utilised to assess the typical variation under an unloaded walking transfer test. Based on the use of both visual and auditory stimuli in the literature to date, a Military Specific Auditory N-Back Task (MSANT) using phonetically described pairs of letters, representing aspects of military radio communications, and a Shoot-/Don't-Shoot (SDST) representing aspects of any military scenario where visual search and inhibition are required (e.g. assaulting an enemy position) were selected. The current study, therefore, aimed to 1) devise and detail the methodology of the MSANT and SDST; 2) quantify the day-to-day variability of both of these assessment tools under seated conditions; 3) quantify the day-to-day variability of both of these assessment tools under walking conditions in a sub-sample of the study population.

Methods

Study Overview

The study comprised of two distinct elements. First, the reliability of the MSANT and SDST was assessed in a seated condition on three separate occasions. As noted previously this was chosen due to the large variability in the way in which the assessment tools may be utilised in future projects. Second, within a sub-sample of the study population, the reliability of the MSANT and SDST was assessed during a 10-minute military-specific walking activity ($6.5 \text{ km} \cdot \text{h}^{-1}$; 1% gradient), on three separate occasions. Whilst a matched study population, for this part of the study would have been optimal, given the time required for this portion of the study (a result of the necessity to reach a physiological

steady-state before conducting the test, and the recovery period required between each walking bout to prevent the onset of fatigue), a sub-sample approach was instead chosen. For the subsample of the study population that completed part 2, the familiarisation in part 1 acted as the familiarisation for this part as well. For all study visits, participants were required to arrive in a fed and hydrated state having avoided caffeine for a minimum of three hours before their laboratory visit. Study visits were completed at approximately the same time of day (± 2 hours) to control for the potential effect of circadian rhythm on test performance.

Participants

Twenty-eight participants volunteered for part 1 of the study (14 male, 14 female, age [mean $\pm$ SD] 27.3 ± 4.3 y) and 12 participants for part 2 (6 male, 6 female, age 28.4 ± 3.5 y). The study sample size for part 1 was calculated using an A Priori power calculation (G Power; version 3.1.9.4) as detailed by Prajapati, Dunne, & Armstrong (2010). A sample size, of 28 was identified, for the seated portion of the investigation, as the number required to identify a moderate effect size ($d = 0.5$), with a statistical power of 80%, and an alpha level of 0.05, based upon a correlation coefficient between repeated test performances of $r = 0.5$ (identified from initial pilot testing). This effect size was chosen as the smallest effect size of interest to military policymakers, based on data from both pilot testing and previous investigations utilising similar cognitive assessment tools (Eddy et al., 2015). The sub-sample population size was designed to represent the typical size (and therefore likely variation) of study populations within this research area (e.g. Bhattacharyya et al., 2017; Crowell et al., 1999; Eddy et al., 2015). On the participants' first visit to the laboratory written consent was provided following a written and verbal brief of the study requirements and methodologies. Ethical approval was provided by the Institution's Research Ethics Committee. All procedures were conducted in accordance

with the declaration of Helsinki.

Cognitive Assessments

Design decisions were always made in favour of military relevance over ‘typical’ cognitive research norms. For example, stimuli in the SDST were not of equal spatial frequency, as employed in previous research (Kobus et al., 2010), but instead, were of individuals adopting realistic stances that would require specific responses, as used previously within the literature (Armstrong et al., 2022; Eddy et al., 2015; Nibbeling et al., 2014).

MSANT

The MSANT was developed to mimic aspects of coded military radio traffic, with stimuli comprising of letter pairs, described phonetically, using the International Radiotelephony Spelling Alphabet (International Civil Aviation Organization, 2019). Each letter within a pair was separated by 0.4 s, and each pair was separated by 2 s. After a random number of letter pairs (3-7 pairs), an auditory tone (0.25 s, 1000 Hz) was sounded and the participant was required to identify the pair of letters described two previous to the auditory tone (i.e. 2-back). The auditory tone occurred 1 s after the last pairing of that stimuli string. In line with previously employed n-back assessments, each test lasted approximately 5 minutes; depending on letter combinations. Each MSANT contained 100 letter stimuli (Kazemi et al., 2018) and required 10 responses.

Letter stimuli were generated using online speech generation software (www.fromtexttospeech.com) and compiled into a single audio track using an open-source digital audio editing software (Audacity® v2.3, Audacity®, USA). Speech generation variables were set to ‘British English’, male voice, and medium for the speech speed. All letter stimuli were randomly selected using an online random number generator

(Research Randomiser; <https://www.randomizer.org/>). The letter 'F' was excluded due to the lack of clarity in generated audio stimuli. For both seated and walking conditions participants received the auditory information via headphones at a standardised volume. During the seated condition, participants recorded their answers, whilst during walking trials, participants were required to relay their answers verbally to be recorded on their behalf. Whilst this approach may have been less than optimal for action fidelity, due to a difference in response modes, as the study was not designed to compare walking and seated conditions, the practicalities of this approach made this approach preferential.

SDST

The SDST was designed to be a visual search and inhibition task similar to those tasks previously employed within the literature (Armstrong et al., 2022; Eddy et al., 2015; Kobus et al., 2010). The urban scene depicted a derelict warehouse (Figure 1), with 12 possible target locations (windows); comprising of 6 on the ground floor and 6 on the first floor. There were no stimuli on the gantry level. Using a calibration stick, the warehouse within the scene was measured to be 9.18 m high and 18.42 m in width. Windows containing the target stimuli were standardised, to a size of 1.60 m x 0.87m (555 x 300 pixels) and coloured using a dark grey (RGB 58,50,48) in order that they provided a uniform background for the target stimuli. At random time intervals (0.5 - 3 s), either a target (persons adopting a shooting stance) or non-target (persons with hands up above their head) would appear at a random window. For a target stimulus, a mouse click was required as quickly as possible (no locational movement required), whereas no response was required for a non-target. The two stimuli were not of the same spatial frequency due to this not being representative of real-world scenarios, however stimuli size was standardised. Participants were instructed to place equal importance on both response time and accuracy. For the SDST there was a 2:1 ratio between targets and non-

targets, with two targets and one non-target appearing in each location during each SDST. The SDST was created and recorded using SuperLab 5 software (version 5.05; Cedrus®, San Pedro, USA), with response times recorded to the nearest millisecond for all target stimuli.

For both conditions, a gaming mouse (Logitech G203, Logitech, Lausanne, Switzerland) with 1 ms latency was employed. In the walking condition, the mouse was attached to the side of a replica SA80 rifle, of correct mass, with a mouse button adjacent to the trigger location. During the seated condition, the tests were displayed on a laptop screen (30.9 x 17.4 cm; Toshiba, Tokyo, Japan), whilst for the walking condition, the task was projected ~2.6 m in front of the individual walking on the treadmill (0.97 x 0.79 m). A marker was placed on the side of the treadmill, and participants were instructed to stay in line with it, so that the stimuli size was consistent for all participants. Again, whilst this approach may have been less than optimal, with respect to action fidelity, due to different response modes, as the study was not designed to compare walking and seated conditions, this approach was chosen principally due to the impracticalities of utilising physiological laboratories to collect seated data.

*** Insert Figure 1 near here ***

Seated Reliability of Military Specific Cognitive Assessments

Part 1 comprised of three laboratory visits. During the first visit, participants were familiarised (two full trial completions of each assessment) with the MSANT and SDST, in a randomised counterbalanced order. The number of familiarisation trials was based on initial pilot testing, and time expediency. For the second, and third visits, participants completed the MSANT and SDST in the same randomised counterbalanced order as they had during visit one. Trials were separated by a minimum of 24 hours.

Walking Reliability of Military Specific Cognitive Assessments

For part 2, a subsample of 12 participants completed three additional laboratory visits and completed the SDST and MSANT whilst walking on a treadmill. The MSANT and SDST were again completed in a randomised counterbalanced order. All tests were completed with 10 minutes of seated rest between trials to negate the influence of physical fatigue. To enable a physiological steady-state to occur, participants completed five minutes of walking before the commencement of the cognitive assessments. For all walking trials, participants walked on a motorised treadmill ($6.5 \text{ km} \cdot \text{h}^{-1}$, 1% gradient) based on the fastest load carriage walking speed within the literature (Blacker et al., 2013) and represents a typical 'enemy contact' speed (Armstrong, Ward, Lomax, Tipton, & House, 2019).

Analysis of Cognitive Assessment Parameters

MSANT

The number of correct responses and partially correct responses was collected and compared for each trial. A correct response was when both letters were correctly identified and in the correct order. A partial response was when an individual letter in a pair was identified, in the correct location (i.e. first or second letter), but the other letter given was incorrect. To give an additional level of fidelity and sensitivity between individuals, the parameter of total combined correct responses was calculated (Equation 1). Within this equation, a weighting was added to total correct responses to differentiate from partial correct responses and also highlight the importance of correct responses compared with partial correct responses within the context of military operations.

Total combined correct responses =

$$(3 \times \text{Total correct responses}) + \text{Partial correct responses} \quad (1)$$

SDST

The number of shoot correct, don't-shoot correct, total correct (Equation 2), and response times was compared across trials. A response time greater than 1 second, was classified as a non-response. To determine whether changes in the aforementioned SDST parameters were operationally relevant the accuracy-speed trade-off ASTO) variable was calculated (Equation 3).

$$\text{Total correct responses} = (\sum \text{shoot correct} + \sum \text{don't-shoot correct}) \quad (2)$$

$$\text{ASTO} = (\text{Average response time}) \div (\text{Total correct responses}) \quad (3)$$

Statistical Analysis

Data were principally analysed using JASP (JASP, 2020; Version 0.14.1) and are presented as mean $\pm$ standard deviation unless otherwise stated. For comparative purposes, scores were converted to percentages. Data were assessed for normality using skewness and kurtosis ratios (Fallowfield et al., 2005), and sphericity; with the Greenhouse-Geisser correction applied if sphericity assumptions were violated. For normally distributed data, a one-way ANOVA was employed to identify whether a likely main effect of assessment time point (including familiarisation trials) was apparent. Effect sizes are presented as Omega squared (Ω^2) (Levine & Hullett, 2002), with 0.01, 0.06, and 0.14 classed as small, medium and large, respectively (Field, 2013). Where F-statistics, *p*-values, and effect sizes, likely indicate an incompatibility with the null model, Holm-Bonferroni adjusted pairwise comparisons were made *post-hoc*. Whilst this approach was utilised to investigate incompatibility with the null model across assessment periods, a lack of incompatibility does not imply equity between time points; thus two one-sided tests were employed between trials 1, 2, and 3, to assess whether differences in scores between trials were at least as extreme as the smallest effect size of

interest (Lakens et al., 2018). For non-parametric data a Wilcoxon Two One Sided Tests was conducted in R Studio (version 2021.09.1), and the TOSTR package (version 0.4.1). Based upon the A Priori sample size calculation, $d = 0.5$ was employed as the smallest effect size of interest. To describe the typical variation in assessment parameters between trials, Limits of Agreement (LoA) $\pm$ 95% Confidence Intervals (CI), Standard Error of the Mean (SEM), and Smallest Detectable Change (SDC) values were calculated. The SEM was calculated by dividing the standard deviation of the difference between trials by $\sqrt{2}$ (Hopkins, 2000; Ludbrook, 2010). Using SEM the SDC was also calculated; SEM $\times 1.96 \times \sqrt{2}$ (van Kampen et al., 2013). For non-parametric data a Friedman's test was employed with effect sizes presented using Kendall's W. Where the combination of χ^2 -statistics, p -values, and effect sizes, indicate a likely incompatibility with the null model, *post hoc* pairwise comparisons were made using Conover's test.

Results

The mean, standard deviation, and range for each of the cognitive assessment's key performance parameters are presented in Table 1. To support these data, Table 2 reports the day-to-day variation observed in these key performance outcomes by way of LoA and 95% CI, SEM and SDC. One participant was removed from the analysis, due to being more than two SDs outside the remainder of the data set.

Seated Performance of Military Specific Cognitive Assessments

MSANT

There was no likely main effect for time on either total correct response ($\chi^2_{(4)} = 4.531$, $p = 0.361$, Kendall's W = 0.492), or combined correct responses ($\chi^2_{(4)} = 3.856$, $p = 0.426$,

Kendall's $W = 0.488$), however, a likely main effect for time was evident for partial correct responses ($\chi^2_{(4)} = 11.846, p = 0.19$, Kendall's $W = 0.426$). For the key variable of combined correct responses, the comparison between trial 1 vs trial 2 was both statistically equivalent ($W_{(25)} = 64, p = 0.002$) and not statistically different ($W_{(25)} = 70, p = 0.938$). Similarly, trial 2 vs trial 3 were both statistically equivalent ($W_{(25)} = 20, p = 5.82e^{-03}$) and not statistically different ($W_{(25)} = 10, p = 1.51e^{-01}$). Likewise trial 1 vs trial 3, were also both statistically equivalent ($W_{(25)} = 50, p = 3.24e^{-02}$) and not statistically different ($W_{(25)} = 39, p = 2.42e^{-01}$).

SDST

There was no likely main effect for time on either shoot correct ($\chi^2_{(4)} = 4.00, p = 0.406$, Kendall's $W = 0.175$), don't-shoot correct ($\chi^2_{(4)} = 3.069, p = 0.546$, Kendall's $W = 0.482$) total correct ($\chi^2_{(4)} = 3.375, p = 0.497$, Kendall's $W = 0.471$), and average response time ($F_{(2.981, 77.515)} = 1.035, p = 0.382, \eta^2 = 0.001$). There was however, a main effect for time in the ASTO parameter ($F_{(4, 104)} = 7.037, p < 0.001, S > 9.97, \eta^2 = 0.089$). Importantly, the sole noteworthy difference, occurred between familiarisation 1 and trial 3 ($t_{(26)} = 4.855, p < 0.001, d = 0.756$) suggesting no discernible difference were likely between performances in the three experimental trials, following two familiarisation trials. For the key variable of total correct responses trial 1 vs trial 2, trial 1 vs trial 3, and trial 2 vs trial 3, were both statistically equivalent (1 vs 2: $W_{(26)} = 93, p = 0.011$; 1 vs 3: $W_{(26)} = 61, p = 0.047$; 2 vs 3: $W_{(26)} = 41, p = 0.04$) and not statistically different (data reported previously). For the other key variable of ASTO all comparisons all comparisons were likely neither statistically equivalent (1 vs 2: $t_{(26)} = -1.701, p = 0.05$; 2 vs 3: $t_{(26)} = -0.127, p = 0.45$; 1 vs 3: $t_{(26)} = 0.287, p = 0.612$), nor statistically different (data reported previously).

Walking Performance of Military Specific Cognitive Assessments

MSANT

As with data pertaining to seated MSANT performance, there was no likely effect of time on total correct responses ($\chi^2_{(2)} = 1.000, p = 0.607$, Kendall's $W = 0.568$), partial correct responses ($\chi^2_{(2)} = 1.280, p = 0.527$, Kendall's $W = 0.541$) and combined correct responses ($\chi^2_{(2)} = 1.000, p = 0.607$, Kendall's $W = 0.582$). For the key variable of combined correct responses trials 1 vs 2, and trials 2 vs 3 were statistically equivalent (1 vs 2: $W_{(11)} = 12, p = 0.017$; 2 vs 3: $W_{(11)} = 13, p = 0.020$) and not statistically different (data reported previously). Conversely, trial 1 vs 3 was neither statistically equivalent, nor statistically different ($W_{(11)} = 29, p = 0.215$).

SDST

Again there were no likely effects of time, during SDST trials on shoot correct responses ($\chi^2_{(2)} = 4.800, p = 0.091$, Kendall's $W = 0.449$), don't-shoot correct responses ($\chi^2_{(2)} = 2.480, p = 0.289$, Kendall's $W = 0.672$), total correct responses ($\chi^2_{(2)} = 3.161, p = 0.206$, Kendall's $W = 0.741$), response times ($F_{(2,22)} = 2.880, p = 0.077, \eta^2 = 0.018$), and ASTO ($F_{(2,22)} = 2.713, p = 0.088, \eta^2 = 0.042$). For the key variable of total correct responses all comparisons were neither statistically equivalent (1 vs 2: $W_{(11)} = 6, p = 0.096$; 1 vs 3: $W_{(11)} = 0, p = 0.093$; 2 vs 3: $W_{(11)} = 14, p = 0.084$), nor statistically different (data reported previously). Similarly, For the other key variable of ASTO all comparisons all comparisons were likely neither statistically equivalent, nor statistically different (1 vs 2: $t_{(11)} = 0.127, p = 0.549$; 2 vs 3: $t_{(11)} = -1.205, p = 0.127$; 1 vs 3: $t_{(11)} = 0.787, p = 0.776$).

*** Insert Table 1 near here ***

*** Insert Table 2 near here ***

Discussion

This study has resulted in the development of two military-specific cognitive assessment tools (MSANT and SDST) and quantified the typical day-to-day variability in their performance. The data provides the typical magnitudes of variation for the key parameters of each assessment. Whilst no likely performance differences were observed across the three experimental measurement points, not all walking comparisons were statistically equivalent; suggesting additional data are required before this assertion is made for the given equivalency bounds. The current investigation has also demonstrated that these assessments are both time expedient, and have the potential to be utilised during military-specific physical activity within a laboratory setting.

Before this investigation, the day-to-day performance variation in any military-specific cognitive assessments had not been quantified. This is an issue for several reasons, including the translational ability of research findings to the 'real world' (Close et al., 2019), and also for methodological decision making (e.g. sample size calculations). Moreover, with military operations rarely conducted in isolation, information on inter-test performance is highly relevant to research investigating sequential or repeated bout performance.

The data reported herein, demonstrate largely consistent day-to-day variation, as described by SEM, SDC, and LoA. For the SDST, the SDC for percentage total correct is ~7.5%, which represents a score change of approximately three. With a reduced number of response opportunities during the MSANT, the average SDC for percentage total correct also represents a change of approximately three. These percentage data are broadly in line with data provided by other authors utilising similar assessment tools. For example, Kobus et al. (2010), reported a change of ~4%, in correct response rate, compared to baseline, (during a similar SDST) which was not considered meaningful

(carrying 44.45 kg). However, in the same investigation a mean change of ~9% was a likely difference (carrying 61.23 kg) following 85 minutes of walking with the load. Meaningful comparisons beyond this example, are difficult, primarily due to the large differences in assessment tasks employed and data available between studies. The comparison between seated and walking performance was not a research question of interest in the current study; particularly given that in the military specific literature differences in cognitive performance are typically observed after extended periods of time (upwards of 30 minutes; Eddy et al., 2015), especially when comparing loads carried (Giles, Hasselquist, et al., 2019). This is why acute exercise studies are not overly applicable to military scenarios. However, observationally, the typical variation in performance between trials appears similar between seated and walking conditions.

Adequately familiarising participants with assessment tools is critical for research, particularly when time limitations may inhibit access to study participants (e.g. military populations). Collectively, the current study's data demonstrates that beyond two full seated trials, a continued improvement in performance was not likely apparent, suggesting this familiarisation length is sufficient to minimise possible learning effects. To date, limited information on the required number of familiarisation trials exists, with studies either not appearing to explicitly include a familiarisation trial(s) or not detailing the familiarisation protocols used (e.g. Bhattacharyya et al., 2017; Eddy et al., 2015; Giles, Hasselquist, et al., 2019). Notably, the study by Kobus et al. (2010), employed an abridged version of their assessments lasting two minutes, with practising continuing until a 90% score was achieved. Within the current study, using the current equivalence bounds, not all walking comparisons of performance data were deemed to be statistically equivalent. Plausibly this lack of equivalency could be a result of the reasonably low number of response opportunities in both assessments, which resulted in high variability

due to a relatively large score change potential of each error made. Moreover, in the current investigation, the smallest effect size of interest of $d = 0.5$ was used. A standardised effect size was chosen, as opposed to a raw effect size, due to the likely variability between populations, and to maximise the usability of the data collected herein. In addition, this smallest effect size of interest matched the effect size which the study was powered to identify. However, future investigations may wish to use raw effect sizes defined by the specific research context; for example, using equivalence bounds of 100 ms for response time data. In these instances, adjusted bounds, and or large sample sizes may mean trial comparisons become statistically equivalent.

The cognitive performance assessments in the current study were principally designed for use during military-specific physical activity tasks. Given both the hypotheses of this thesis, and data available to date, these assessments were designed with sufficient scope for likely performance decrements. Consequently, task difficulty was set to position typical assessment scores towards the upper end of possible scores. In the current investigation total correct response rates were in the region of 95% for the SDST and 90% MSANT; which is broadly in line with previous investigations during their control conditions. For example, Kobus et al., (2010), investigated the effects of varying load masses carried on cognitive function, the baseline detection rate (no mass carried) was ~92% in a task similar to the SDST. Moreover, Giles et al. (2019), again investigating carried load masses on cognitive performance, the correct response rate in an auditory go/no-go task, in the low load condition at the beginning of the first trial was 97%. The two aforementioned publications were conducted using military populations as opposed to the current study's civilian population. Differences between these populations warrant further investigation in order to support the translational ability of research findings between civilian and military cohorts.

In the current study, we have reported response time data. However, it is important to note, that without combining this parameter with a response accuracy outcome (e.g. total correct or shoot correct) it's application and operational relevance is limited. Devoid of this association, a faster response time may purely be a result of a reduction in choice reaction capabilities. Concerning mission relevance, equal importance is required for expediency and accuracy; the rationale for this instruction to participants during trials and the notion supporting the ASTO parameter. This trade-off has previously been highlighted as important to assess during military-specific physical activity (Mahoney et al., 2007). Future research should attempt to pair reliable and applied cognitive tasks (such as those described herein) with operationally relevant and appropriate physical activity. This in turn will support enhanced applied research as well as enabling a greater focus to be placed on developing mitigation strategies where the greatest mission impact can be obtained.

Following two full familiarisation trials, both the military-specific cognitive assessments developed herein, appear to be consistent in terms of variability when compared across experimental trials. Future investigations should endeavour to incorporate these measures into applied military research to maximise outcome relevance to operational scenarios. Thereby supporting the research into the interaction between military physical and cognitive performance; an area that has received limited applied research to date.

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545 **Figures and Tables**

546 Figure 1. Warehouse Scene used in the Shoot-/Don't-Shoot Task.

547 Grey boxes, of standardised size, denote the 12 possible target locations. An example of a 'Do-
548 Not Shoot' stimuli is presented in the furthest left window on bottom level with an example of a
549 'Shoot' stimuli presented adjacent to this in the window on the right hand side.

Table 1. Descriptive statistics for cognitive assessments (mean $\pm$ SD [range]) during seated (S) and walking (W) conditions.

Task (condition)	Parameter	Experimental Trial				
		FAM 1	FAM 2	Trial 1	Trial 2	Trial 3
SDST (S)	Total Correct (%)	96.4 $\pm$ 3.3 [86.1-100.0]	97.3 $\pm$ 2.7 [91.7-100.0]	96.5 $\pm$ 3.0 [88.9-100.0]	96.3 $\pm$ 3.2 [88.9-100.0]	97.1 $\pm$ 3.2 [83.3-100.0]
	RT (ms)	579 $\pm$ 58 [490-684]	574 $\pm$ 57 [478-683]	562 $\pm$ 57 [472-704]	550 $\pm$ 51 [450-639]	528 $\pm$ 43 [433-655]
	ASTO (ms $\cdot$ cr ⁻¹)	16.7 $\pm$ 1.6 [14.1-20.4]	16.4 $\pm$ 1.7 [13.7-19.2]	16.2 $\pm$ 1.8 [13.7-19.9]	15.9 $\pm$ 1.4 [13.2-18.3]	15.1 $\pm$ 1.4 [12-18.7]
SDST (W)	Total Correct (%)			94.9 $\pm$ 5.3 [80.6-100]	96.1 $\pm$ 3.8 [88.9-100]	96.5 $\pm$ 5.4 [80.6-100]
	RT (ms)			594 $\pm$ 70 [496-678]	575 $\pm$ 69 [457-661]	566 $\pm$ 69 [451-666]
	ASTO (ms $\cdot$ CR ⁻¹)			17.4 $\pm$ 1.4 [15-19.4]	16.6 $\pm$ 1.6 [13.9-18.4]	16.3 $\pm$ 1.9 [13.3-19]
MSANT (S)	Total Correct (%)	87.7 $\pm$ 15 [50-100]	88.5 $\pm$ 16.7 [30-100]	90.4 $\pm$ 14.6 [40-100]	90.8 $\pm$ 16 [30-100]	94.2 $\pm$ 9.5 [60-100]
	Combined Score (%)	91 $\pm$ 11.3 [60-100]	91.4 $\pm$ 12.8 [46.7-100]	92.9 $\pm$ 10.8 [56.7-100]	92.7 $\pm$ 12.3 [46.7-100]	95.1 $\pm$ 7.7 [70-100]
MSANT (W)	Total Correct (%)			93.3 $\pm$ 8.9 [70-100]	95 $\pm$ 10 [70-100]	94.2 $\pm$ 9 [80-100]
	Combined Score (%)			95.3 $\pm$ 6.7 [76.7-100]	96.1 $\pm$ 7.9 [76.7-100]	95.8 $\pm$ 6.5 [83.3-100]

Where: S, seated; W, walking; FAM, familiarisation; RT, response time; ASTO, accuracy-speed trade-off; CR, correct response; SDST, shoot/don't-shoot task; MSANT, military-specific auditory n-back task. Greyed areas denote data that wasn't collected due to the seated condition acting as the familiarisation for the walking condition.

Table 2. Descriptive statistics for cognitive assessments (mean $\pm$ SD) during seated (S) and walking (W) conditions.

Task (condition)	Parameter	Trial 1 vs 2			Trial 2 vs 3			Trial 1 vs 3		
		Mean Bias $\pm$ 95% CI	SEM	SDC	Mean Bias $\pm$ 95% CI	SEM	SDC	Mean Bias $\pm$ 95% CI	SEM	SDC
SDST (S)	Total Correct (%)	0.2 $\pm$ 5.1	2.4	6.7	-0.8 $\pm$ 4.8	2.3	6.4	-0.6 $\pm$ 6.1	2.9	8.0
	RT (ms)	12 $\pm$ 88	42	116	22 $\pm$ 65	31	87	34 $\pm$ 84	40	111
	ASTO (ms $\cdot$ CR ⁻¹)	0.3 $\pm$ 2.8	1.3	3.7	0.7 $\pm$ 2.3	1.1	3.1	1.1 $\pm$ 2.9	1.4	3.8
SDST (W)	Total Correct (%)	-1.2 $\pm$ 6.2	2.7	7.5	-0.5 $\pm$ 8.3	3.6	10.1	-1.6 $\pm$ 4.1	1.8	4.9
	RT (ms)	19 $\pm$ 60	26	73	9 $\pm$ 66	29	80	28 $\pm$ 75	33	91
	ASTO (ms $\cdot$ CR ⁻¹)	0.8 $\pm$ 2.3	1.0	2.8	0.3 $\pm$ 3.1	1.4	3.8	1.0 $\pm$ 2.3	1.0	2.8
MSANT (S)	Total Correct (%)	-0.4 $\pm$ 18.5	8.8	24.5	-3.5 $\pm$ 13.2	6.3	17.5	-3.8 $\pm$ 15.2	7.2	20.0
	Combined Score (%)	0.3 $\pm$ 14.5	6.9	19.1	-2.4 $\pm$ 11.2	5.4	14.8	-2.2 $\pm$ 11.9	5.7	15.7
MSANT (W)	Total Correct (%)	-1.7 $\pm$ 13.5	5.9	16.4	0.8 $\pm$ 16.1	7.0	19.5	-0.8 $\pm$ 21.2	9.3	25.7
	Combined Score (%)	-0.8 $\pm$ 10.3	4.5	12.5	0.3 $\pm$ 11.8	5.2	14.3	-0.6 $\pm$ 15.8	6.9	19.1

Where: S, seated; W, walking; RT, response time; ASTO, accuracy-speed trade-off; CR, correct response; SDST, shoot/don't-shoot task; MSANT, military-specific auditory n-back task; SEM, standard error of the mean; SDC, smallest detectable change; CI, confidence intervals.