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ORIGINAL RESEARCH

3D Multiple Object Tracking or Adaptive Dual n-back Training Boosts Simple Verbal Working Memory Span but Not Multitasking Performance in Military Participants

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Abstract

There is a growing literature demonstrating that a short regimen of *NeuroTracker*—a task that trains 3D multiple object tracking skills—can improve various aspects of cognition (attention, memory) and performance in regular and elite athletes. Vartanian et al. *Military Psychology* 28:353–360, (2016) extended the application of NeuroTracker to the military domain by demonstrating that it can result in gains in simple working memory (WM) span (verbal, visual, and matrix) in Canadian Special Forces members who trained under the experimenters' supervision. Here, we conducted a follow-up study to determine whether similar gains would accrue if general Canadian Armed Forces (CAF) members were to train unsupervised—a much more likely scenario within military contexts. We randomly assigned CAF members ($n = 66$) to one of the three conditions: (1) NeuroTracker, (2) adaptive dual n-back, or (3) passive control. Participants in the training conditions trained for 20 min per day on ten separate days within a 2-week period. Before and after training, we administered simple WM span measures (verbal and matrix). To examine far transfer to a task drawing on executive functions, we also administered a multitasking paradigm that deploys four visual and auditory tasks in parallel, designed to evaluate operator performance and workload analogous to activities that aircraft crew perform in flight (Multi-Attribute Task Battery: MATB-II). Participants in both training conditions improved on the trained task and exhibited gains in simple verbal WM span. No gains were observed on MATB-II. Our results demonstrate that self-administered training on NeuroTracker or the adaptive dual n-back task can lead to gains in simple verbal WM span but not in simple matrix WM span or multitasking. In other words, in relation to both NeuroTracker and adaptive dual n-back training, we observed near transfer but not far transfer. We discuss the implications for cognitive training interventions in military contexts.

Keywords Cognitive training · Brain training · Working memory · Multitasking · Military

There exists a strong interest in performance optimization and enhancement in the cognitive domain within military contexts (see Blacker et al. 2019; Brunyé et al. 2020). For example, the Center for Enhanced Performance was established at the US Military Academy in West Point in 1989 with a mission to "educate and train the Corps of Cadets on comprehensive performance psychology and academic skills to develop their full potential." This interest stems from the fact that due to operational requirements, soldiers must typically perform under conditions that place large demands on their cognitive capacities, such as those that require performing multiple tasks simultaneously, sustaining attention for long periods of time, and maintaining vigilance under sleep deprivation and stress (Arrabito et al. 2015; Suurd Ralph et al. 2017). Indeed, an analysis of occupations within the Canadian Armed Forces (CAF) indicated that cognitive ability is the most important competency identified for the analyzed occupations, topping a list of 21 competencies that included several personality (e.g., conscientiousness), interpersonal (e.g., communication), and

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organizational (e.g., leadership) factors (Kemp and St-Pierre 2009). This high ranking is likely related to the relevance of domain-general cognitive abilities such as fluid intelligence to performance in many contexts, as well as the contribution of specific capacities to cognitive performance, such as the role of attentional control and inhibition in minimizing distraction when interference is high.

We begin with the assumption that training that can lead to improvements in specific cognitive capacities has the potential to improve performance on militarily-relevant tasks. For example, Biggs et al. (2015) have demonstrated that inhibitory control training involving a novice untrained sample reduced civilian casualties by improving simulated shooting performance. In turn, Hamilton et al. (2019) focused on officers from a law enforcement agency and were able to show that training involving three tasks that focused on processing speed, attention to subtle details, and inhibitory control improved shoot/do not shoot decisions, demonstrating that the benefits of training can extend beyond novice persons to professionals in the domain. Similar training interventions can be envisioned for improving other aspects of executive functions (i.e., working memory (WM) updating, task switching), with potential downstream effects on tasks that typify performance in military environments, such as multitasking.

Recently, we have focused on *NeuroTracker* as a potential tool for improving cognitive performance and capacity among military members. This task trains 3D multiple object tracking skills by requiring that participants track four of eight spherical targets as they move through 3D space (Fig. 1). To do well, participants must pay selective attention to and track multiple objects moving within a three-dimensional space. A critical component of NeuroTracker is that it is adaptive, such that speed thresholds are adjusted dynamically in relation to performance. Substantial evidence from athletic domains suggests that NeuroTracker training results in improved 3D multiple object tracking, as measured by NeuroTracker. For example, the performance of professional athletes, elite amateurs, and non-athlete university students improved across sessions, with professional athletes exhibiting a steeper learning slope than non-professional athletes as a function of training (Faubert 2013; Faubert and Sidebottom 2012). In turn, Mangine et al. (2014) measured visual tracking speed by administering NeuroTracker to twelve professional National Basketball Association (NBA) players in a single session before the start of the season and then assessed basketball-specific measures of performance during the course of the regular basketball season. They found that visual tracking speed was correlated with assists, steals, and assist-to-turnover ratio measured during the NBA season, thereby establishing a link between NeuroTracker scores and athletic performance in actual games.

Of particular interest are more recent studies that have shown that NeuroTracker training is associated with better athletic performance. For example, Junyent et al. (2015) found that the administration of NeuroTracker to a group of polo, taekwondo, and tennis athletes, sandwiched between pre-post assessments, led to improvements in visual acuity, stereopsis, contrast sensitivity, and saccadic movements. In turn, Romeas et al. (2016) examined essential soccer skills before and after a training protocol with three groups: NeuroTracker, active control (watching 3D soccer videos), or passive control (no contact) groups. The results demonstrated that the quality of decision-making for passing (appropriate vs. inappropriate) as rated by an experienced soccer coach was superior for the NeuroTracker group compared to the control groups, indicating that NeuroTracker training can transfer to rated field performance in athletes.

NeuroTracker training has also been shown to benefit specific aspects of WM. For example, Parsons et al. (2016) have shown that ten NeuroTracker sessions can enhance scores on the letter-number sequence and spatial span subscales of the Wechsler Adult Intelligence Scale (WAIS, Wechsler 1997). This is perhaps not surprising, given that maintaining and updating visuospatial information about the position and dynamics of targets in the face of distraction trains core components of WM (Conway et al. 2005). In turn, Vartanian et al. (2016) have demonstrated that compared to a condition training on the adaptive dual n-back task (a task designed to train

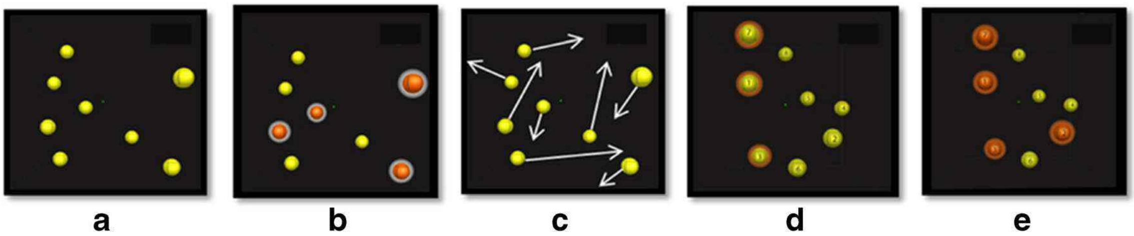

Fig. 1 Five steps of each trial in the NeuroTracker task. **a** Presentation phase where 8 spheres are shown in a 3D volume space, **b** indexing phase where 4 spheres (targets) change color (red) and are highlighted (halo) for 1 s, **c** movement phase where the targets indexed in stage b return to their original form and color and all spheres move for 8 s crisscrossing and bouncing off of each other and the virtual 3D volume cube walls that are not otherwise visible, **d** identification phase where the spheres come to a halt and the observer has to identify the 4 spheres originally indexed in phase (b). The spheres are individually tagged with a number so the observer can give the number corresponding to the original targets, and **e** feedback phase where the participant is given information on the correct targets. Figure and caption reproduced by kind permission from Faubert (2013)

the maintenance and updating aspects of WM) or a passive control condition, NeuroTracker training resulted in gains in simple WM verbal ($d = .96$), visual ($d = .60$), and matrix ($d = .79$) span. With the exception of simple visual WM span ($d = .58$), the adaptive dual n-back condition resulted in gains of smaller magnitude in simple verbal WM span ($d = .56$) and simple matrix (i.e., spatial) WM span ($d = .39$). In conjunction with recent evidence based on transfer to *n*-back performance (Harris et al. 2020a), these results suggest that multiple object tracking can be effective in increasing specific aspects of WM capacity, as measured by simple WM span tasks as well as the letter-number sequence and spatial span subscales of the WAIS.

To provide a more holistic overview of the efficacy of NeuroTracker as a training tool, we have used Barnett and Ceci's (2002) framework to categorize the NeuroTracker literature to date in terms of nine relevant dimensions that are important in judging success of transfer. Having reviewed the transfer literature dating back to the early twentieth century, Barnett and Ceci (2002) argued that an important reason why agreement regarding the success (or failure) of transfer has been difficult to achieve is that researchers have meant different things when they have used the term *transfer*—and by extension what is meant by far vs. near transfer. They argued that what the field needs is an agreed upon set of dimensions based on which researchers can specify the precise conditions that characterize each transfer scenario, thereby enabling informed discussion and inferences. Toward that end, we conducted a literature review and unearthed thirteen experiments in which NeuroTracker had been used for training purposes and assessed transfer to various outcome measures of interest (Table 1). We unearthed the relevant papers by conducting a search for "NeuroTracker" on MEDLINE, as well as by consulting the list of scientific studies posted on the manufacturer's website (https://www.neurotrackerx.com).[1] Barnett and Ceci (2002) broke down their nine dimensions into two broad categories: Content and context. Three relevant *content* dimensions were used to specify *what was transferred*: (1) learned skill (what is the specificity/generality of the learned skill: procedure, representation, or general principle/heuristic), (2) performance change (the measure against which performance is measured: speed, accuracy, or approach to the task), and (3) memory demands (does the transfer task requires the execution of a learned activity only, or are there additional memory demands: execute only, recognize, and execute or recall, recognize, and execute). In turn, six relevant *context* dimensions were used to specify *the contextual conditions under which transfer was assessed*: (4) knowledge domain (are the training and transfer domains similar or different?), (5) physical context (did training and transfer testing occur in the same physical location?), (6) temporal context (what was the time lag between the end of training and transfer testing?), (7) functional context (which mindsets do the training and transfer skills evoke in the person?), (8) social context (are training and transfer testing administered individually or in groups?), and finally (9) modality (what are the modalities of the training and transfer tasks?).

An examination of Table 1 is useful because it can reveal features of studies in which the use of NeuroTracker as a training intervention led to successful transfer. Here we will not focus on studies for which we considered transfer to have been only partially successful (e.g., only successful when certain factors were controlled for, etc., see Table 1 for details). Instead, we will focus on those studies for which successful transfer was obtained. It appears that those studies can be grouped into three categories. One group focused on specific cognitive capacities such as inhibition (Spaner et al. 2019) or WM capacity (Parsons et al. 2016; Vartanian et al. 2016). Another set focused on various aspects of visual competence, including dynamic visual acuity, visual contrast sensitivity, saccadic fixation, and stereopsis (Junyent et al. 2015), as well as resistance to the effects of physical fatigue on 3D multiple object tracking (Faubert and Barthes 2018). Finally, Romeas et al. (2016) focused on the quality of decision-making for passing as rated by an experienced soccer coach. Aside from Romeas et al. (2016) for which this information was unavailable, in all other cases of successful transfer, the gap between training and testing was not longer than 1 week. Thus, NeuroTracker training has shown promise in cases where one seeks transfer to outcome measures shortly after training, involving a host of target tasks such as cognitive capacities targeted by multiple object tracking (i.e., WM capacity, inhibition), visual competencies, resistance to the effects of physical fatigue, and rated decision-making in the athletic domain (i.e., passing in soccer).

Present Experiment

Vartanian et al. (2016) had left three questions unanswered. First, the sample in that study was comprised exclusively of Special Forces members. In Canada, members of the Special Forces undergo rigorous physical and psychological selection for inclusion in that elite group. Therefore, it is unknown whether training-related simple WM span gains observed in that group would be observed in general CAF members. Indeed, Blacker et al. (2019) have noted that there are two possible scenarios for seeing improvement following cognitive training: magnification vs. compensation. According to *magnification* models, those with the most cognitive resources at baseline will gain more from training because they can learn

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[1] Please note that we focused on published peer-reviewed and archived articles only. A far more extensive list of NeuroTracker transfer studies involving conference presentations, proceedings, etc. can be found at: https://drive.google.com/file/d/11opgnL6lRmnlkW-pNmhqdB_6BZpLp52O/view.

Table 1 A taxonomy of NeuroTracker training studies

Experiment	Transfer task	Learned skill	Performance change	Memory demands	Knowledge domain	Physical context	Temporal context	Functional context	Social context	Modality	Transfer
Assed et al. (2016)	1) M&M Scale	Principle	Self-report questionnaire score	N/A	Visuospatial memory & sustained attention to self-perceived attention,	Unknown	Unknown	Game-like training to self-report	Both individual	Computer to paper-and-pencil	N/A - Case study of single individual
	2) Quality of Life Scale	Principle	Self-report questionnaire score	N/A	Visuospatial memory & sustained attention to self-perceived quality of life	Unknown	Unknown	Game-like training to self-report	Both individual	Computer to paper-and-pencil	N/A - Case study of single individual
	3) Lipp Inventory of Stress Symptoms for Adults (ISSL)	Principle	Self-report questionnaire score	N/A	Visuospatial memory & sustained attention to self-perceived stress	Unknown	Unknown	Game-like training to self-report	Both individual	Computer to paper-and-pencil	N/A - Case study of single individual
	4) PH9	Principle	Test score	Unknown	Visuospatial memory & sustained attention to intellectual performance	Unknown	Unknown	Game-like training to academic testing	Both individual	Computer to paper-and-pencil	N/A - Case study of single individual
	5) Colored Trails Test	Principle	Time to complete	Execute only	Visuospatial memory & sustained attention to concentrated, sustained and alternating attention & cognitive flexibility	Unknown	Unknown	Game-like training to academic testing	Both individual	Computer to paper-and-pencil	N/A - Case study of single individual
	6) Memo Checkup	Principle	Accuracy & processing speed	Execute only	Visuospatial memory & sustained attention to episodic & working memory	Unknown	Unknown	Game-like training to academic testing	Both individual	Computer to computer	N/A - Case study of single individual
Faubert and Barthes (2018)	1) Fatigued Neurotracker	Principle	Speed threshold	N/A	Visuospatial memory & sustained attention to fatigued visuospatial memory & sustained attention	Same Location	Unknown	Game-like training to fatigued game-like testing	Both individual	Screen while sitting on exercise bike to screen while peddling on exercise bike	Successful
Fleddermann et al. (2019)	1) Processing speed (ZVT)	Principle	Time to complete	N/A	Visuospatial memory & sustained attention to processing speed	Same Location	Unknown	Game-like training to academic testing	Both individual	Computer with large 3D compatible TV screen to paper-and-pencil	Partially successful (A)
	2) Memory span (KAI-N)	Principle	Number of correct repetitions	Execute only	Visuospatial memory & sustained attention to verbal memory	Same Location	Unknown	Game-like training to academic testing	Both individual	Computer with large 3D compatible TV screen to verbal	Unsuccessful
	3) Working speed (KAI-N)	Principle	Time to complete	N/A	Visuospatial memory & sustained attention to working speed	Same Location	Unknown	Game-like training to academic testing	Both individual	Computer with large 3D compatible TV screen to verbal	Unsuccessful
	4) Sustained attention (d2-R)	Principle		N/A	Visuospatial memory & sustained attention to		Unknown			Computer with large 3D compatible	

(continued)

Experiment	Transfer task	Learned skill	Performance change	Memory demands	Knowledge domain	Physical context	Temporal context	Functional context	Social context	Modality	Transfer
			Processed target objects and errors		attention & concentration ability under time pressure	Same Location		Game-like training to academic testing	Both individual	TV screen to paper-and-pencil	Partially successful (A)
	5) Volleyball-specific block decision task	Principle	Jumping height, volleyball--specific errors & decision accuracy	N/A	Visuospatial memory & sustained attention to athletic performance	Different locations	Unknown	Game-like training to athletic testing	Both individual	Computer with large 3D compatible TV screen to physical	Not successful
Harris et al. (2020a)	1) Multiple Object Tracking (MOT)	Principle	Performance score (from MOT program output)	Execute only	Visuospatial memory & sustained attention to working memory capacity	Same Location	Unknown	Game-like training to game-like testing	Both individual	Large screen using a 3D projector to computer	Partially successful (A)
	2) Eye gaze tracking while completing MOT	Principle	Gaze duration and switches between targets (eye tracker)	N/A	Visuospatial memory & sustained attention to gaze strategy	Same Location	Unknown	Game-like training to game-like testing	Both individual	Large screen using a 3D projector to computer	Unsuccessful
	2) N-Back	Principle	Percentage correct	Execute only	Visuospatial memory & sustained attention to working memory capacity	Same Location	Unknown	Game-like training to game-like testing	Both individual	Large screen using a 3D projector to computer	Partially successful (A)
Harris et al. (2020b)	1) Multiple Object Tracking (MOT)	Principle	Percentage correct	Execute only	Visuospatial memory & sustained attention to multiple object tracking	Same Location	12–13 days	Game-like training to game-like testing	Both individual	large screen using a 3D projector to computer	Unsuccessful
	2) N-back	Principle	Percentage correct	Execute only	Visuospatial memory & sustained attention to working memory capacity	Same Location	12–13 days	Game-like training to game-like testing	Both individual	large screen using a 3D projector to computer	Partially successful (A)
	3) Concurrent route recall and auditory monitoring task	Principle	Overall score from the three aspects of the recall task	Execute only	Visuospatial memory & sustained attention to auditory working memory, visual working memory & multitasking	Same Location	12–13 days	Game-like training to task representative of real-world military activities	Both individual	large screen using a 3D projector to large projector screen	Unsuccessful
Junyent et al. (2015)	1) Static visual acuity	Principle	Accuracy	N/A	Visuospatial memory & sustained attention to visual	Different location	<1 week	Game-like training to academic testing	Both individual	Computer to paper-and-pencil	Successful
	2) Dynamic visual acuity	Principle	Accuracy and RT	N/A	Visuospatial memory & sustained attention to visual	Different location	<1 week	Game-like training to academic testing	Both individual	Computer to computer	Successful
	3) Visual contrast sensitivity	Principle	Accuracy	N/A	Visuospatial memory & sustained attention to visual	Different location	<1 week	Game-like training to academic testing	Both individual	Computer to computer	Successful
	4) Saccadic fixations (near, far)	Principle	Accuracy and RT	N/A	Visuospatial memory & sustained attention to visual	Different location	<1 week	Game-like training to academic testing	Both individual	Computer to paper-and-pencil	Successful
	5) Response to peripheral stimulus	Principle	Accuracy and RT	N/A	Visuospatial memory & sustained attention to visual		<1 week			Computer to computer	Unsuccessful

(continued)

Experiment	Transfer task	Learned skill	Performance change	Memory demands	Knowledge domain	Physical context	Temporal context	Functional context	Social context	Modality	Transfer
						Different location		Game-like training to academic testing	Both individual		
	6) Stereopsis	Principle	Accuracy	N/A	Visuospatial memory & sustained attention to visual	Different location	<1 week	Game-like training to academic testing	Both individual	Computer to computer	Successful
	7) Selective focused attention	Principle	Accuracy and RT	N/A	Visuospatial memory & sustained attention to visual	Different location	<1 week	Game-like training to academic testing	Both individual	Computer to paper-and-pencil	Unsuccessful
Legault and Faubert (2012)	1) Biological motion task	Principle	Tolerable noise quantity	N/A	Visuospatial memory & sustained attention to visuospatial to complex perceptual-cognitive processing	Same Location	Same week	Game-like training to visual testing	Both individual	Cave Automatic Virtual Environment (CAVE) system to CAVE	Partially Sucessful (B)
	2) Contrast task	Principle	Contrast Thresholds	N/A	Visuospatial memory & sustained attention to visuospatial to complex perceptual-cognitive processing	Same Location	Same week	Game-like training to visual testing	Both individual	Cave Automatic Virtual Environment (CAVE) system to CAVE	Partially Sucessful (B)
Moen et al. (2018)	1) Athlete Satisfaction Questionnaire (ASQ; 32)	Principle	Self-report questionnaire score	N/A	Visuospatial memory & sustained attention to self-report performance satisfaction	Same Location	Uknown	Game-like training to self-report	Both individual	Computer to Computer	Partially Sucessful (C)
Musteata et al. (2019)	1) California Verbal Learning Test, Second Edition	Principle	Test score (further information about scoring not provided)	Execute only	Visuospatial memory & sustained attention to episodic memory & auditory learning ability	Same Location	<1 week	Game-like training to academic testing	Both individual	Computer to Verbal	Partially Sucessful (B)
	2) D-KEFS Trail Making Test	Principle	Test score (further information about scoring not provided)	N/A	Visuospatial memory & sustained attention to processing speed, motor speed & cognitive flexibility	Same Location	<1 week	Game-like training to academic testing	Both individual	Computer to Paper-and-pencil	Partially Sucessful (B)
	3) D-KEFS Verbal Fluency Test	Principle	Test score (further information about scoring not provided)	N/A	Visuospatial memory & sustained attention to processing speed and cognitive flexibility	Same Location	<1 week	Game-like training to academic testing	Both individual	Computer to Verbal	Partially Sucessful (B)
	4) Digit Span	Principle	Number of digits successfully repeated	Execute only	Visuospatial memory & sustained attention to working memory	Same Location	<1 week	Game-like training to academic testing	Both individual	Computer to Verbal	Unsuccessful
	5) Stroop Test	Principle	Test score (further information about scoring not provided)	N/A	Visuospatial memory & sustained attention to selective attention, psychomotor speed & cognitive flexibility	Same Location	<1 week	Game-like training to academic testing	Both individual	Computer to App	Unsuccessful
		Principle		N/A			Unknown				Successful

(continued)

Experiment	Transfer task	Learned skill	Performance change	Memory demands	Knowledge domain	Physical context	Temporal context	Functional context	Social context	Modality	Transfer
Parsons et al. (2016)	1) Quantitative electroencephalogram (qEEG)		EEG activity analyzed using the NeuroGuide qEEG normative database		Visuospatial memory & sustained attention to EEG activity	Same Location		Game-like training to EEG measurement	Both individual	Large projector screen to Mitsar 202 system	
	2) Integrated Visual and Auditory Continuous Performance Test	Principle	Test score (further information not provided)	N/A	Visuospatial memory & sustained attention to attention	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to computer	Partially successful (B)
	3) WAIS-III - symbol search	Principle	Test score (further information not provided)	N/A	Visuospatial memory & sustained attention to visual information processing speed	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to paper-and-pencil	Successful
	4) WAIS-III - code	Principle	Test score (further information not provided)	N/A	Visuospatial memory & sustained attention to visual information processing speed	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to paper-and-pencil	Successful
	5) WAIS-III - block design	Principle	Test score (further information not provided)	N/A	Visuospatial memory & sustained attention to visuospatial abilities	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to blocks	Successful
	6) WAIS-III - number sequence	Principle	Test score (further information not provided)	Execute only	Visuospatial memory & sustained attention to auditory short-term memory & working memory	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to verbal	Unsuccessful
	7) WAIS-III - letter-number sequence	Principle	Test score (further information not provided)	Execute only	Visuospatial memory & sustained attention to auditory working memory	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to verbal	Successful
	8) WAIS-III - spatial span	Principle	Test score (further information not provided)	Execute only	Visuospatial memory & sustained attention to visual short-term memory & working memory task	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to blocks	Successful
	9) d2 Attention Test	Principle	Test score (further information not provided)	N/A	Visuospatial memory & sustained attention to attention	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to paper-and-pencil	Successful
	10) Delis-Kaplan Executive Functions System Color-Word Interference Test (D-KEFS).	Principle	Time and the number of uncorrected and corrected errors	N/A	Visuospatial memory & sustained attention to visual inhibition	Same Location	Unknown	Game-like training to academic testing	Both individual	Large projector screen to verbal	Partially successful (B)
Romeas et al. (2016)	1) Field test (soccer matches) - On-field decision making assessment	Principle	Percentage accuracy values	N/A	Visuospatial memory & sustained attention to control, decision & execution	Different location	Unknown	Game-like training to athletic training	Individual to team	Immersive virtual environment to soccer field	Partially successful (B)
	2) Sport Performance Scale	Principle	Visual analog scale	N/A	Visuospatial memory & sustained attention to players'		Unknown	Game-like training to self-report			Successful

(continued)

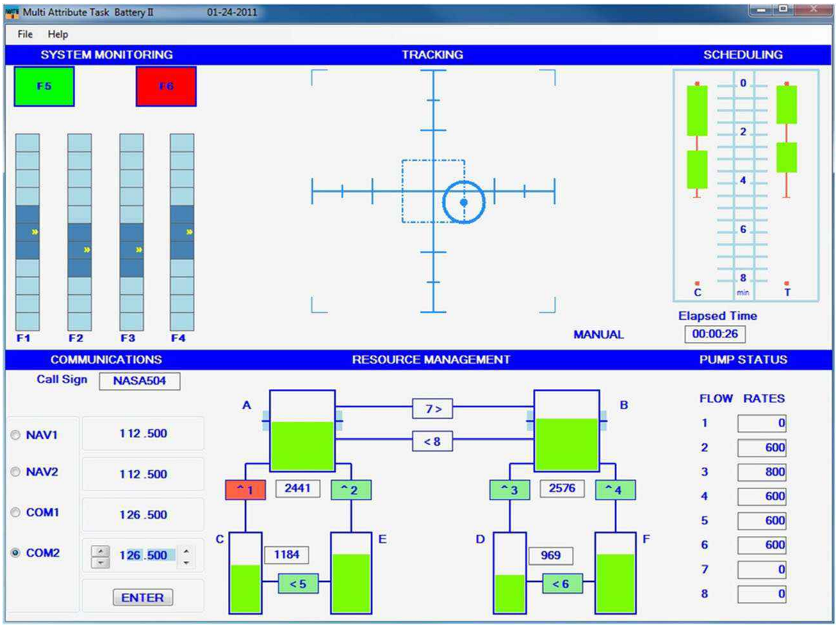
Experiment	Transfer task	Learned skill	Performance change	Memory demands	Knowledge domain	Physical context	Temporal context	Functional context	Social context	Modality	Transfer
					confidence levels in decision-making accuracy	Different location			Both individual	Immersive virtual environment to tablet	
Spaner et al. (2019)	1) Stroop	Principle	Time to complete without making any errors	N/A	Visuospatial memory & sustained attention to selective attention, cognitive flexibility & psychomotor speed	Same location	1 week	Game-like training to academic testing	Both individual	Screen to smartphone	Successful
Vartanian et al. (2016)	1) Word (verbal) span	Principle	Accuracy	Execute only	Visuospatial memory & sustained attention to verbal working memory	Same location	<1 week	Game-like training to academic testing	Both individual	3D projection screen to paper-and-pencil	Successful
	2) Visual span	Principle	Accuracy	Execute only	Visuospatial memory & sustained attention to visual working memory	Same location	<1 week	Game-like training to academic testing	Both individual	3D projection screen to paper-and-pencil	Successful
	3) Matrix span	Principle	Accuracy	Execute only	Visuospatial memory & sustained attention to spatial working memory	Same location	<1 week	Game-like training to academic testing	Both individual	3D projection screen to paper-and-pencil	Successful

more or learn more quickly (see Wiemers et al. 2019). In contrast, according to *compensation* models, those with lower initial cognitive resources can gain more from training because they have more room to improve. We can test these two competing models by administering NeuroTracker to a general CAF sample and comparing training-related changes in simple WM span to the levels observed in Vartanian et al. (2016). Second, in Vartanian et al. (2016), training occurred under the experimenters' supervision, a setup which likely maximized performance motivation. However, for cognitive training to become mainstream in military contexts, it is necessary to demonstrate that gains can occur when members train individually at their convenience. This possibility can be tested by determining whether training-related gains occur when participants train individually rather than under the experimenters' supervision. Third, although NeuroTracker can improve certain aspects of WM (Parsons et al. 2016; Vartanian et al. 2016), it has yet to be demonstrated that it can result in far transfer to a militarily-relevant task that draws more broadly on executive functions. To take a step in that direction, an intermediate aim would be to test its impact on a cognitive task purposefully built to mimic what some military operators do. To address these three questions, we randomly assigned CAF members to one of three conditions: NeuroTracker, adaptive dual n-back, or passive control. Participants in the training conditions trained for 20 min per day on ten separate days within a 2-week period using handheld devices (tablets and/or laptops). Before and after training, we administered not only measures of simple WM span but also a multitasking paradigm developed by NASA (National Aeronautics and Space Administration) to evaluate operator performance and workload, analogous to activities that aircraft crew perform in flight. This task deploys four visual and auditory tasks in parallel and requires WM updating, task switching, and inhibition for optimal performance (Fig. 2). We hypothesized that NeuroTracker training would lead to gains in simple WM span and multitasking performance—thereby replicating and generalizing the reliability of our earlier findings, as well as testing far transfer to multitasking. We focused on multitasking because NeuroTracker is understood to train attention and WM—two related constructs that likely contribute to multitasking performance (Boehm-Davis et al. 2015; Gladwin et al. 2012).

Method

Participants

Our protocol was approved by the Human Research Ethics Committee of Defence Research and Development Canada. Because the effect sizes for WM span obtained in our previi-



Elapsed Time 00:00:26

Call Sign NASA504

○ NAV1 112.500
○ NAV2 112.500
○ COM1 126.500
● COM2 126.500

FLOW	RATES
1	0
2	600
3	800
4	600
5	600
6	600
7	0
8	0

A/B: 2441, 2576; C: 1184; D: 969

Fig. 2 A screenshot of the interface of MATB-II. MATB-II necessitates parallel engagement in four concurrent tasks. For *Tracking* (top right quadrant), the participant must ensure that they hover as close to the central point as possible using a joystick. For *System Monitoring* (top left quadrant), the participant must (a) click on F6 if it is red (to turn it blank), (b) click on F5 if it is blank (to turn it green), and (c) click on the columns F1–F4 if the yellow dot deviates from the center of the column. For *Resource Management* (bottom right quadrant), the participant must regulate the flow of liquid across the eight pumps to keep the level within the reservoirs A and B as close to 2400 as possible. For *Communications* (bottom left quadrant), the participant must respond only to their own call signal (NASA504) while ignoring all other call signals coming through the auditory channel (i.e., headphones), and set the appropriate channel to the correct frequency. The program provides separate accuracy and reaction time data for each of the tasks. (For further details see Santiago-Espada et al. (2011).

ous NeuroTracker study were based on pre-post *t* tests (Vartanian et al. 2016), they were not suitable for estimating the sample size for a study involving the test of an interaction effect, as was the case here. Therefore, we based our sample size requirement on previous training studies involving NeuroTracker and recruited as many military participants as was feasible to meet similar numbers. The demographics of the CAF members ($n = 66$) who volunteered to participate in our study appear in Table 2.

Materials and Procedures

The design of the study replicated Vartanian et al. (2016). Baseline testing occurred in a single session and lasted approximately 90–120 min. The sessions were scheduled in the morning or in the afternoon, depending on the availability of the participants. The sessions began with the assessment of a brief measure of crystallized and fluid intelligence using Shipley-2 (Shipley et al. 2009). We administered the Shipley-2 because WM capacity accounts for approximately half of the variance in fluid intelligence scores (Kane et al. 2005; Oberauer et al. 2005), sometimes exhibiting a nearly perfect correlation with it (Chuderski 2013). As such, it is necessary to have a measure of every participant's fluid intelligence score at the outset of the experiment. This was followed by the administration of *Theories of Intelligence Scale* (TIS; see Dweck 1999) which measures the degree to which one believes whether intelligence is malleable or fixed. This is important because those who believe in the malleability of cognitive ability can benefit more from training interventions than those who do not (see Jaeggi et al. 2014). Finally, the participants completed the Big Five Aspect Scales (BFAS, DeYoung et al. 2007). Although we administered the BFAS in its entirety, from a theoretical perspective we were only interested in the two aspect scales used to compute conscientiousness (i.e., industriousness and orderliness). Specifically, we reasoned that participants who score higher on conscientiousness and are therefore more organized, diligent, and industrious would be more likely to benefit from training by scheduling their sessions during optimal times during the day, and by greater task engagement. We had no predictions regarding the other four factors. These measures were administered to ensure that the three conditions were equated in terms of relevant dimensions that might impact the extent to which one might benefit from cognitive training. The matching of the three groups on these measures occurred at the analysis stage rather than at the assignment stage.

Next, we administered simple WM span tasks that were modifications of the tasks reported in Harrison et al. (2013). For *verbal span*, four-letter monosyllabic words were presented one at a time on a monitor. After each block of words, participants were prompted by the software to recall the words

Table 2 Demographics by condition

	NeuroTracker	Adaptive dual n-back	Passive control
Frequencies			
Gender			
Male	15	12	19
Female	8	9	3
Status			
Regular force	12	9	11
Reserve force	11	12	11
Rank			
NCM (Pte, Cpl/MCpl, Sgt)	14	14	11
Senior NCM (WO, MWO, CWO)	0	2	4
Junior officer	8	5	6
Senior officer	1	0	1
Years of service			
0–5	11	7	4
6–10	3	3	5
11–15	5	6	9
16–20	2	3	1
21–25	2	2	1
26–30	0	0	1
31–35	0	0	0
35+	0	0	1
Education			
High school diploma	5	5	4
College diploma	6	7	9
Univ undergraduate degree	8	7	8
Univ graduate degree	4	2	1
Means (standard deviations)			
Age	31.95 (9.68)	31.33 (8.82)	35.14 (10.17)
Cognitive Measures			
Shipley verbal	31.48 (5.43)	30.81 (4.53)	32.23 (4.35)
Shipley shapes	17.52 (5.47)	19.57 (4.26)	18.86 (4.74)
Intelligence beliefs	2.71 (1.00)	2.52 (0.81)	2.80 (1.09)
Personality measure			
Conscientiousness	3.70 (0.46)	3.8 (0.48)	3.62 (0.37)

There were no statistically significant differences between the three groups on any demographic, cognitive ability, or personality measure (*ps* > .05). *Pte* Private, *Cpl* Corporal, *MCpl* Master Corporal, *NCM* Non-commissioned Member, *Sgt* Sergeant, *MWO* Master Warrant Officer, *WO* Warrant Officer. *Univ* University; among big five factors, we focused only on conscientiousness (see text).

they saw in the order they were presented in. Blocks ranged from 3 to 9 words. For *matrix span*, participants were presented with a 4 × 4 matrix where one square (out of 16) appeared in red and the rest in white. At the end of each block of matrices, participants were instructed to recall the locations of the red squares in the order in which they were presented. Blocks ranged from 3 to 9 matrices. The computer task provided a detailed description of each task prior to the start, and the experimenter reviewed the instructions and provided an example in each case to the participants. The order of the simple WM span tasks was randomized across participants.

Finally, we administered the Multi-Attribute Task Battery (MATB-II) which is a computer-based task designed to evaluate operator performance and workload (https://matb.larc.nasa.gov/). As noted earlier, the platform is meant to mimic a number of tasks that aircraft aircrew would be expected to perform in flight. A central feature of MATB-II is that it necessitates the simultaneous performance of four tasks: System Monitoring, Communications, Tracking, and Resource Management (Fig. 2, Santiago-Espada et al. 2011). The participant uses a joystick to maneuver the location of the aircraft for Tracking, and the mouse as well as prespecified keys on the keyboard to enter input for the System Monitoring, Communications, and Resource Management tasks. A headset is used to receive auditory input for Communications. MATB-II represents an operationally relevant platform for assessing executive functions because it draws on inhibition, updating, and switching. After explanation and a 5-min practice session, participants completed two 10-min blocks of the task.

Immediately following the completion of baseline testing, participants were randomly assigned to either the experimental ($N = 23$), active control ($N = 21$), or passive control ($N = 22$) condition. For participants in the passive control condition, this marked the end of the baseline session. In turn, participants in the experimental (NeuroTracker) condition were provided with a handheld tablet (CogniSens Inc.) and instructed to complete ten 20-min training sessions within a 2-

week period in isolation and in a quiet location. We also asked them to find times in the course of the 2 weeks during which they were not fatigued or otherwise engaged in concurrent, distracting tasks in order to stay alert and focused on the training task. No other specific instructions were provided. They were then equipped with 3D glasses to enable depth perception on the screen. NeuroTracker is designed to offer different types of training, each meant to exercise different abilities. We focused on *core* training, where each session unfolds in the form of twenty 8-s repetitions—repeated twice. The difficulty (i.e., speed of target motion) is adjusted using the staircase method between repetitions. The following were the instructions to the participant:

> Four targets will light up red, then return to yellow. Pay attention to these four targets as they move for 8 seconds. At the end of each 8 second repetition, identify the four targets. If you identify all four correctly, the speed will increase. If you make a mistake, the speed will decrease. At the end of 20 reps, you will get a final score for the whole session.

The final score generated at the end of each session (i.e., accuracy as a function of speed) represents a composite measure of performance.

Each participant in the active control condition (i.e., adaptive dual n-back task) was provided with a laptop and instructed to complete ten 20-min training sessions within the same 2-week period in isolation and in a quiet location. The design of the adaptive dual n-back task was based on the version used in Jaeggi et al. (2008). Specifically, on each trial of this task, the participants were presented with a letter through the auditory channel and saw one of the eight possible target locations light up around a central fixation point (500 ms). Participants were instructed to indicate whether the presented letter matched a letter presented a specific number of positions (i.e., *n*) earlier by pressing a button on the keyboard. Similarly, they were instructed to indicate whether the lit location matched a location lit a specific number of positions (i.e., *n*) earlier by pressing another button on the keyboard. The inter-stimulus interval was fixed at 2500 ms. So, for example, on 1-back there is a match if the present item (letter and/or location) matches the one presented one position earlier, on 2-back there is a match if it matches the one presented two positions earlier, and so on. Importantly, we administered an adaptive version of the dual n-back, meaning that following initiation with 1-back, the level of *n* was adjusted in relation to performance. This mimics the adaptive nature of NeuroTracker training. Each session of the adaptive dual n-back task consisted of 20 blocks of trials. Within each block, the level of *n* stayed the same. Each block consisted of 20 trials plus *n* (i.e., for the 1-back block the number of trials was 21, for the 2-back block the number of trials was 22, etc.). If necessary, adjustments to higher or lower levels of *n* occurred after the completion of each block. Specifically, if the participant made fewer than three mistakes in each modality (verbal and spatial), then the level of *n* increased by one. Alternatively, if the participant made more than five mistakes in any modality, then the level of *n* is dropped by one. Else, *n* remained unchanged (see Jaeggi et al. 2008). Our version of the adaptive dual n-back task did not have a maximum limit of *n* per session. Average *n* per session was calculated by averaging the levels of *n* associated with the 20 blocks completed in that session. As described above, the adaptive dual n-back task targets the maintenance and updating functions of WM because participants must maintain and update a dynamic rehearsal set for optimal performance. We opted to implement this feature for our active control condition in order to assess NeuroTracker's relative effectiveness in boosting simple WM span and multitasking performance compared to a training task that targets WM functioning directly. Participants in the passive control condition did not engage in any systematic training in the 2-week period.

Participants in both training conditions completed practice trials in our lab to ensure familiarity with the task at baseline. For participants in the training conditions, the baseline sessions ended following practice on their assigned task (i.e., NeuroTracker or adaptive dual n-back). The practice session lasted approximately 15 min, depending on the ease with which the instructions were learned and the questions that followed. All practice sessions were part of the initial baseline session. Because the only reason for administering the practice sessions was familiarization with the task, we did not record performance scores associated with them. Following the completion of the 2-week training regimen, all participants returned to the original testing location to complete the span tasks again in random order. We analyzed data only from those participants who had completed the training sessions as instructed. We ensured that basic data quality assumptions for the core outcome measures (e.g., WM span tasks) had been met before conducting the analyses, such as checking the skewness and kurtosis of the distributions for deviations from normality in SPSS.

Results

Although initially 66 participants were recruited into the study, only 54 participants (i.e., 82%) completed all measures (i.e., two WM span measures, four MATB-II measures) both pre- and post-training (NeuroTracker, 20; adaptive dual n-back, 17; passive control, 17). In addition, the number of participants who completed various measures varied by group: In the NeuroTracker Group the number of participants who completed each measure fell in the 21–23 range, whereas that range was 18–21 for the adaptive dual n-back group and 20–22 for the passive control condition.

As shown in Table 2, no significant differences were found on any demographic, cognitive, or personality variable across the three conditions. The training profiles for the NeuroTracker and the adaptive dual n-back conditions are depicted in Fig. 3. In the present study our manipulation check consisted of *average* level of performance per session (i.e., average n for the adaptive dual n-back task and average accuracy as a function of speed for NeuroTracker per session). Note that for each session, average and maximum level of performance exhibited a strong positive correlation for both NeuroTracker (r = .91, ranging from .76 to .98 across sessions) and the adaptive dual n-back (r = .91, ranging from .77 to .97 across sessions) conditions. As such, an alternative approach could have been to focus on maximum level of performance per session instead. We opted to focus on average level of performance because that is more consistent with the published literature. Two separate repeated-measures analyses of variance (ANOVAs) demonstrated that performance improved across the 10 training sessions for both the NeuroTracker (F[9, 126] = 11.45, $p < .001$, partial η^2 = .45) and the adaptive dual n-back (F[9, 126] = 6.20, $p < .001$, partial η^2 = .31).

Performance on the WM span tasks (see Fig. 4) was assessed using a 2 (Time) × 3 (Group) ANOVA. For simple matrix span, there was a main effect of Time (F[1, 61] = 7.12, p = .01, partial η^2 = .11), indicating a significant increase in performance from baseline to post-training, but no main effect of Group (F[2, 61) = 0.06, p = .94, partial η^2 = .01) or Time × Group interaction (F[2, 61] = 0.57, p = .57, partial η^2 = .02).[2] For simple verbal span, there was a main effect of Time (F[1, 62] = 35.83, $p < .001$, partial η^2 = .37), no effect of Group (F[2, 62] = 0.15, p = .86, partial η^2 = .01), and a significant Time × Group interaction (F[2, 61] = 5.77, p = .005, partial η^2 = .16). Post hoc tests revealed that a significant increase in performance across sessions was found for the NeuroTracker (t[22] = − 3.61, p = .002, d = .38) and the adaptive dual n-back (t[19] = − 4.58, $p < .001$, d = .82) groups, but not for the passive control group (t(21) = − 1.56, p = .13, d = .31).[3]

Performance on each of the four components of the MATB-II was assessed using a 2 (Time) × 3 (Group) ANOVA, with accuracy as the dependent variable in each case. None of the main effects involving Group or the Time × Group interactions reached statistical significance (Fig. 5). For *System Monitoring*, there was a main effect for Time (F[1, 54] = 18.21, $p < .001$, partial η^2 = .25), no effect for Group (F[2, 54] = 1.10, p = .34, partial η^2 = .04), and no Time × Group interaction (F[2, 54] = .95, p = .39, partial η^2 = .03). For *Communications*, there was a main effect for Time (F[1, 55] = 10.24, p = .002, partial η^2 = .16), no effect for Group (F[2, 55] = .71, p = .50, partial η^2 = .03), and no Time × Group interaction (F[2, 55] = 2.02, p = .14, partial η^2 = .07). For *Tracking*, there was a main effect for Time (F[1, 54] = 9.45, p = .003, partial η^2 = .15), no effect for Group (F[2, 54] = .17, p = .85, partial η^2 = .01), and no Time × Group interaction (F[2, 54] = .05, p = .95, partial η^2 = .01). Finally, for *Resource Management*, there was a main effect for Time (F[1, 53] = 21.44, $p < .001$, partial η^2 = .29), no effect for Group (F[2, 53] = 1.88, p = .16, partial η^2 = .07), and no Time × Group interaction (F[2, 53] = 2.69, p = .08, partial η^2 = .09).

Discussion

We conducted this experiment to test the hypothesis that NeuroTracker training would lead to gains in simple WM span and MATB-II performance. The former would replicate our earlier findings, whereas the latter would test far transfer to multitasking. We found partial support for our hypothesis. Specifically, training on both the NeuroTracker and the adaptive dual n-back task led to gains in simple verbal WM span, but not on simple matrix WM span. Our pattern of findings is largely similar to Vartanian et al. (2016) in two ways. First, in that study, training on NeuroTracker led to gains in verbal, visual, and matrix span, whereas the effects associated with training on the adaptive dual n-back task were in the predicted direction but did not reach statistical significance. We suspect that the small sample size (n = 41) and the associated low statistical power was likely the reason why the effects of the adaptive dual n-back task on verbal (p = 06), visual (p = .06), and matrix (p = .18) span did not reach statistical significance. Combined, the findings from the present experiment and Vartanian et al. (2016) suggest that the observed gains in simple verbal WM span are reliable. Furthermore, the gains observed in simple verbal WM span likely occurred because both training tasks targeted the maintenance function of WM—a process shared by the requirements of both multiple object tracking and the adaptive dual n-back task.

Second, across both studies, NeuroTracker and the adaptive dual n-back task registered stronger effects on simple verbal than matrix WM span. It is not immediately clear why that is the case, given that both training approaches clearly require visuospatial processing. Our span measures were strongly correlated at baseline in both studies, consistent with evidence that verbal and visuospatial WM capacity measures reflect a primarily domain-general construct (Kane et al. 2004). It is quite likely that when training is effective, then gains (of varying magnitude) should be observed across both span measures. A possible reason for why we observed gains

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[2] In response to a reviewer's request, we examined whether there was a difference in pre-post training for any of the three groups on simple matrix span. The difference approached statistical significance for the adaptive dual n-back condition (t[19] = − 2.06, p = .05, d = − .46), but not for the NeuroTracker (t[21] = − 1.19, p = .25, d = − .20) or passive control (t[21] = − 1.23, p = .23, d = − .19) condition.

[3] All Cohen d values were computed using the following online calculator: https://www.psychometrica.de/effect_size.html.

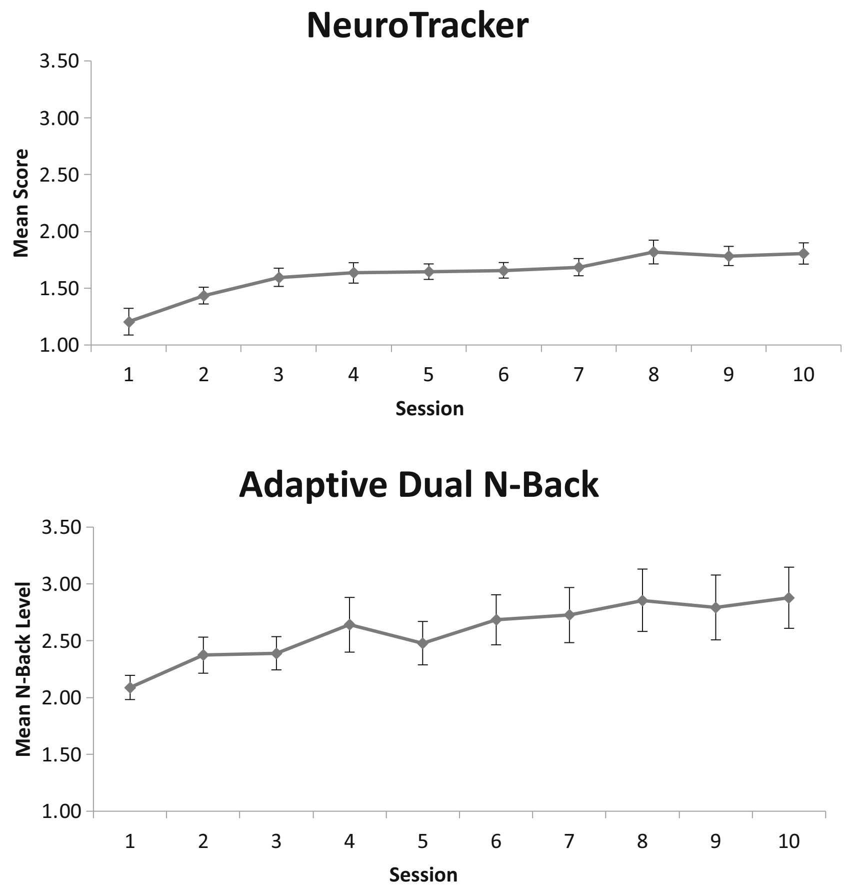

Fig. 3 Training profiles for the NeuroTracker and adaptive dual n-back conditions. The figures represent mean training profiles for each group. Note that despite similar scales, the *y*-axes represent a different metric for each task: For NeuroTracker it represents the average final score generated at the end of each session (i.e., accuracy as a function of speed), which is a composite measure of performance. For the adaptive dual n-back task, it represents the average *n* per session, which was calculated by averaging, for each participant, the levels of *n* associated with the 20 blocks completed in that session. Error bars represent ± 1 standard error of the mean (SEM)

in verbal span but not matrix span in the present study might be related to the difference in the difficulty level of each task. Specifically, at baseline, performance was considerably better on the simple verbal than matrix WM span task, $t(64) = 4.75$, $p < .001$, $d = .59$. It is therefore possible that due to greater difficulty, matrix span might require a training regimen of greater frequency and duration to exhibit improvement. Future studies can examine this possibility by examining the impact of more frequent and/or longer training durations on simple verbal and matrix WM span tasks.

In the Introduction, we discussed the difference between magnification models according to which those with the most cognitive resources at baseline will gain more from training (because they can learn more or learn more quickly), versus compensation models according to which those with lower initial cognitive resources can gain more from training (because they have more room to improve) (see Blacker et al. 2019). Vartanian et al. (2016) found that an identical regimen of training resulted in statistically significant gains in simple verbal, visual, and matrix WM span among Special Forces members who trained on NeuroTracker, whereas here we found that general CAF members who trained on NeuroTracker or the adaptive dual n-back task exhibited statistically significant gains in simple verbal WM span only. As such, our results appear to be more consistent with

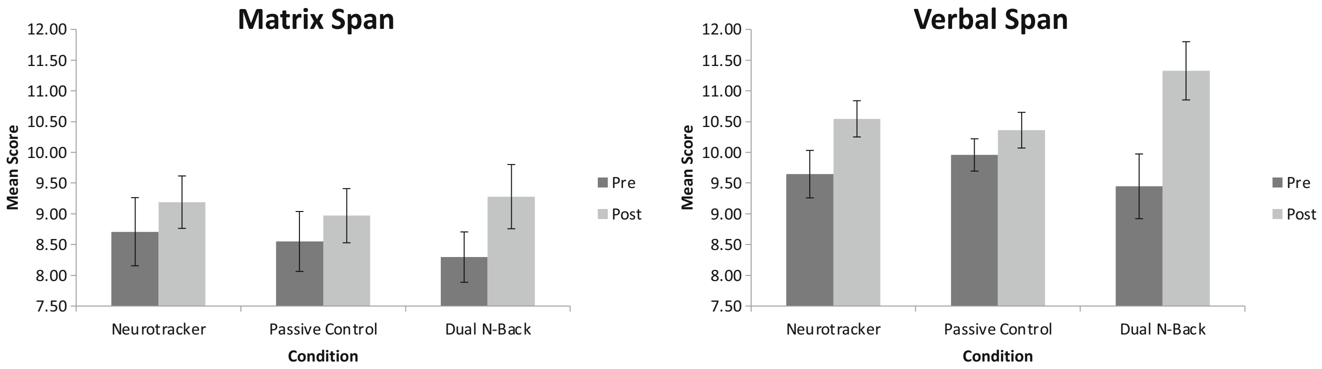

Fig. 4 Working memory performance across conditions and time. Error bars represent ± 1 SEM

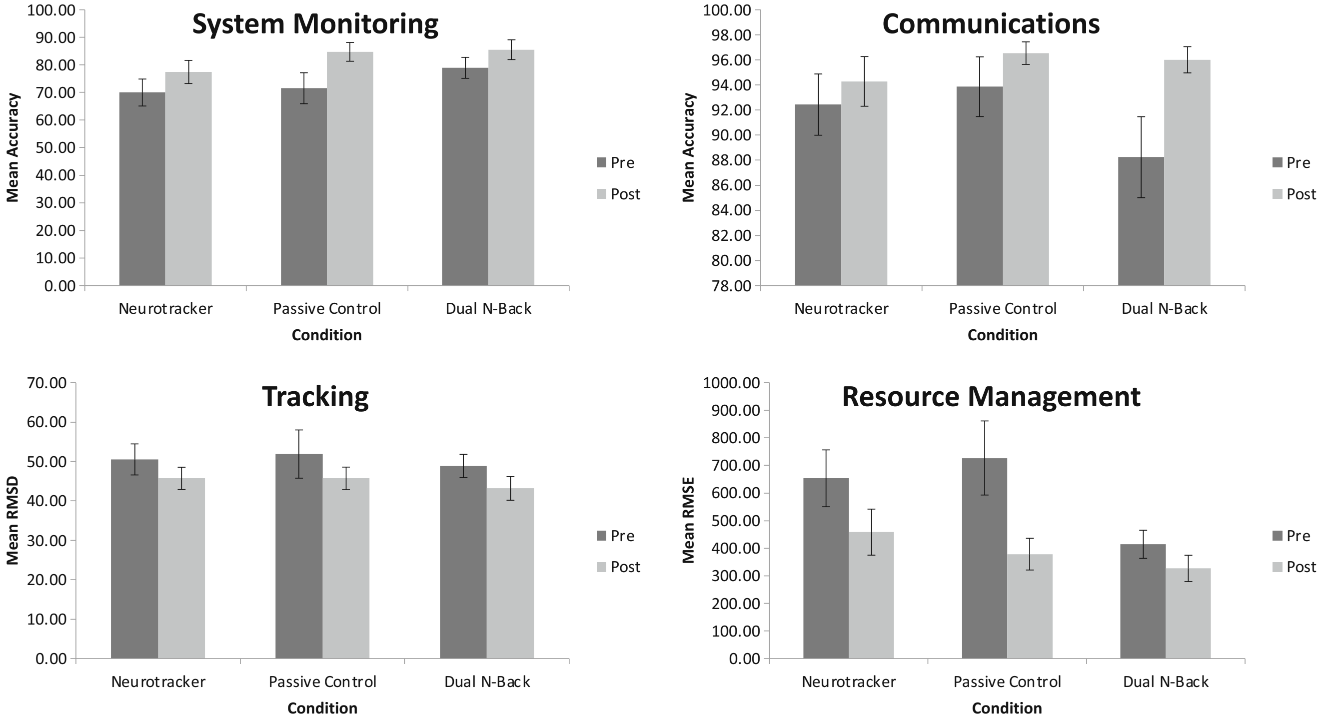

Fig. 5 MATB-II performance across conditions and time. RMSD, root mean square deviation; RMSE, root mean square error

the magnification than compensation view, suggesting that the likelihood of benefitting from cognitive training might be greater among Special Forces members than general CAF members. However, it is important to note that the evidence provided to date does not allow one to make a definitive inference about this issue and that further work is necessary to determine the extent to which a given person with a specific level of baseline cognitive ability may benefit from cognitive brain training.

We did not observe any training-related gain in multitasking based on MATB-II performance. A similar finding has emerged from another study that measured multitasking by focusing on a concurrent route recall and auditory monitoring task to mimic real-world vehicle pursuit (Harris et al. 2020b). There could be a number of reasons for this. First, a task analysis of MATB-II suggests that it likely draws broadly on all aspects of executive functions (i.e., inhibitory control, WM updating, and task switching). It is therefore possible that to observe improvements in performance, all three components of executive functions must be targeted in training. Second, practice durations and frequencies in previous studies involving WM training have varied greatly, ranging from one 20- or 30-min session to 20 h spread over 10 weeks (see Buschkuehl et al. 2012; Klingberg 2010; Morrison and Chein 2011). Our design was largely based on durations of training in previous NeuroTracker and adaptive dual n-back studies, and our focus on a short and concentrated regimen of training was intended to assess the feasibility of training in military settings where the implementation of lengthy training regimen is impractical. Future studies should examine the impacts of training duration and frequency to isolate a combination of factors that maximize the likelihood of transfer to specific tasks of interest.

Here it is also useful to take a broader view of the present findings within the larger cognitive brain training literature, especially the research involving WM training. By now, several large-scale meta-analyses and reviews of the behavioral literature have shown that WM training can lead to *near transfer*—defined as performance improvements on short-term and WM tasks that are similar to the trained task (Melby-Lervåg and Hulme 2013; Melby-Lervåg et al. 2016; Morrison and Chein 2011; Redick et al. 2015; see also Soveri et al. 2017). Evidence for near transfer suggests that WM training likely targets cognitive processes that are commonly shared by most short-term memory and WM tasks, such as maintenance and updating of information. In contrast, there is little reliable evidence to suggest that WM training can lead to *far transfer*—defined as observing performance benefits in outcome measures that are contextually, structurally, or superficially dissimilar to the trained task (Perkins and Salomon 1994). In the design of our experiment, we attempted to address some of the key methodological problems of earlier studies, including exclusive reliance on a passive control condition (for discussion see Morrison and Chein 2011; Shipstead et al. 2012). The conclusion that we can safely draw from our study is that training on tasks that target WM exhibits near transfer to simple verbal WM span but not far transfer to multitasking performance. Indeed, more evidence is needed to conclude that cognitive brain training can show reliable far transfer to target tasks of interest (Melby-Lervåg and Hulme 2013; Owen et al. 2010; Sala and Gobet 2017; Sala et al. 2019).

From an applied perspective, given that an important motivation behind our experiment was to assess the feasibility of NeuroTracker training for improving performance on militarily relevant tasks, it is important to consider what such tasks might consist of, and what the necessary research steps might be before an inference regarding far transfer to militarily-relevant tasks could be made. Although our own work has shown that NeuroTracker training can reliably boost simple verbal WM span, performance in many demanding and time-sensitive operational settings (e.g., close quarters combat) requires both the ability to maintain access to critical information (i.e., storage), as well as the ability to disengage from or block outdated information—a combination of abilities referred to as *executive attention* (Shipstead et al. 2016). As such, it would appear that to observe far transfer to such tasks, multiple aspects of cognition related to executive attention might need to be targeted and trained, highlighting the need for a holistic and comprehensive approach to improving performance on militarily relevant tasks. The findings of the present experiment and those conducted earlier are a step in that direction, but more research is necessary to evaluate the contribution of each targeted intervention and their interaction to performance in real-world settings. In particular, despite evidence regarding near transfer, more evidence is needed to enable one to conclude that cognitive brain training can exhibit reliable far transfer to militarily relevant tasks.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study protocol was approved by the Human Research Ethics Committee of Defence Research and Development Canada.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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