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RESEARCH NOTE

3D Multiple Object Tracking Boosts Working Memory Span: Implications for Cognitive Training in Military Populations

Oshin Vartanian
Defence Research and Development Canada, Toronto, Ontario, Canada, and University of Toronto Scarborough

Lori Coady
Canadian Armed Forces, Ottawa, Ontario, Canada

Kristen Blackler
Defence Research and Development Canada, Toronto, Ontario, Canada

Recently, there has been much theoretical and applied interest in the prospects of cognitive training for improving cognition. NeuroTracker is a relatively recent training device for improving dynamic attention in athletes by training 3D multiple-object tracking skills. We examined its effectiveness for improving working memory (WM) span in members of the Canadian Armed Forces (CAF) by randomly assigning participants to the experimental (NeuroTracker), active control (adaptive dual *n*-back task), or passive control (no contact) conditions. NeuroTracker training resulted in significant gains in verbal, visual, and matrix span. No gain was observed in the active or passive control group. These results suggest that NeuroTracker could be a useful training tool for increasing WM span in military samples. Future studies could examine the effects of NeuroTracker training on militarily relevant performance measures that draw on WM span.

Keywords: working memory, cognitive training, attention

Defined as "a multicomponent system for active maintenance of information in the face of ongoing processing and/or distraction" (Conway et al., 2005, p. 770), the construct of working memory (WM) has assumed a central role in psychology. Individual differences in WM capacity have been linked to performance on a wide range of elementary and higher order cognitive tasks (see Baddeley, 2003). Perhaps most interestingly from an applied perspective, whereas earlier conceptualizations perceived short-term memory and WM to be largely fixed capacities (for review, see Ma, Husain, & Bays, 2014), there is now evidence to show that repeated training on tasks that target WM can lead to gains in WM skills. The malleability of WM has opened the door to using WM training to improve WM performance and/or capacity (Klingberg, 2010).

NeuroTracker is a relatively recent training device designed to improve specific aspects of attention, particularly among athletes. The task is designed to train 3D multiple-object tracking skills by requiring that participants track four of eight spherical targets as they move through 3D space (see Figure 1). To do well, participants must integrate high-level mental resources, including motion tracking and selective (i.e., focusing ability), distributed (i.e., divided focus), dynamic (i.e., tracking moving stimuli), and sustained (i.e., maintained focus over time) aspects of attention. There is some evidence to

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Oshin Vartanian, Defence Research and Development Canada, Toronto Research Centre, Toronto, Ontario, Canada, and Department of Psychology, University of Toronto Scarborough; Lori Coady, Canadian Armed Forces, Ottawa, Ontario, Canada; Kristen Blackler, Defence Research and Development Canada, Toronto Research Centre, Toronto, Ontario, Canada.

Correspondence concerning this article should be addressed to Oshin Vartanian, Defence Research and Development Canada, Toronto Research Centre, 1133 Sheppard Avenue West, Toronto, ON M3K 2C9, Canada. E-mail: oshin.vartanian@drdc-rddc.gc.ca

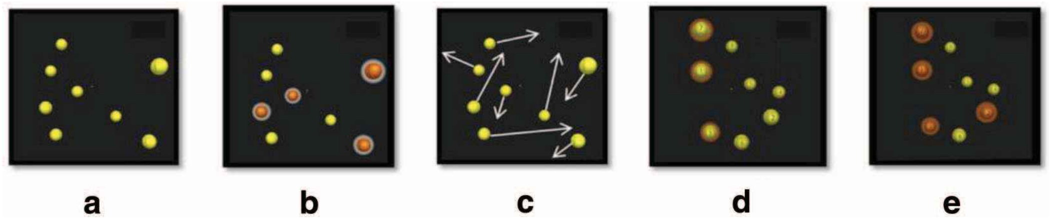

Figure 1. Five steps of each trial in the NeuroTracker task. (a) Presentation phase where eight spheres are shown in a 3D volume space, (b) indexing phase where four spheres (targets) change color (red) and are highlighted (hallo) for 1 s, (c) movement phase where the targets indexed in stage b return 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 four 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). See the online article for the color version of this figure.

suggest that 3D multiple-object tracking speed thresholds are an indicator of the quality of high-level brain function (Legault & Faubert, 2012). Importantly, training is adaptive such that speed is adjusted automatically as a function of performance to ensure that participants perform at the upper threshold of their ability.

Evidence has shown that training on NeuroTracker leads to improvements in performance in 3D object tracking in novices and professional athletes (Faubert, 2013; Faubert & Sidebottom, 2012). For example, Faubert (2013) has shown that the performance of professional athletes (i.e., soccer players from the English Premier League, ice hockey players from the National Hockey League, and rugby players from the French Top 14 Rugby League), elite amateurs (i.e., persons enlisted in the National Collegiate Athletic Association university sports program and a European Olympic sport-training center), and nonathlete university students improves across sessions, with professional athletes exhibiting a steeper learning slope as a function of training.

Although the aforementioned studies have shown that NeuroTracker training can improve 3D multiple-object tracking skills, two recent studies have focused on the relationship between those skills and actual athletic performance. Mangine et al. (2014) administered NeuroTracker training to a group of elite National Basketball Association players prior to the beginning of the regular season and examined the relationship between the key dependent variable derived from training (i.e., visual tracking speed) and accumulated basketball-specific measures over the course of the entire regular season. NeuroTracker performance was correlated with the number of assists, steals, and the assists-to-turnover ratio. More recently, Romeas, Guldner, and Faubert (2016) assigned university soccer players to an experimental condition that trained on NeuroTracker, an active control condition that viewed 3D soccer videos, or a passive control condition. The training sessions were sandwiched between soccer games, enabling the researchers to rate three essential soccer skills (passing, dribbling, shooting) exhibited by each player before and after training. The results revealed a significant improvement (15%) in passing accuracy for the NeuroTracker group between pre- and post-training, demonstrating that 3D multiple-object tracking training can transfer to superior on-the-field performance by athletes.

Although the primary focus of NeuroTracker training is attention, it has recently been shown that the platform also targets WM. For example, Parsons et al. (2016) have shown that compared to a passive control condition, 10 sessions of training can enhance WM—measured by the letter-number sequence and spatial span subscales of the Wechsler Adult Intelligence Scale (Wechsler, 1997). This is perhaps not surprising, given that optimal performance necessitates that participants maintain the visuospatial positional information about the four targets relevant in the face of ongoing processing and/or distraction (see Figure 1). Doing so requires storing, updating, and inhibiting (irrelevant) information—activities that constitute the defining subcomponents of WM function.

Within the military context, WM has been identified as an important mental capacity for various occupations (e.g., Paullin, Ingerick, Trippe, & Wasko, 2011). Indeed, in recognition of its relevance to military performance, the Department of Defense has been evaluating WM tests for inclusion in the Armed Services Vocational Aptitude Battery—the evaluation tool used by the U.S. military services for enlistment qualification and the classification of recruits into military occupations (see Held, Carretta, & Rumsey, 2014). In addition, it is also known that military stressors such as the prospect of being shot (Taverniers, Smeets, Van Ruysseveldt, Syroit, & von Grumbkow, 2011) or the predeployment interval (Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010) can deplete WM capacity. This suggests that interventions that can increase WM capacity in members of the military could play an important role not only in augmenting cognitive performance but also as a countermeasure against stress-related reductions in mental capacity. However, despite its effectiveness in civilian samples, it is currently not known whether NeuroTracker training will lead to improved WM span within a military population. We hypothesized that NeuroTracker training would lead to significant gains on measures of WM span in a sample drawn from the Canadian Armed Forces (CAF).

Method

Participants

CAF volunteers ($N = 41$) participated in this study. Our protocol was approved by Defence Research and Development Canada's Human Research Ethics Committee.

Materials and Procedure

Following written informed consent to participate in the study, all participants completed the background information form to enable us to characterize the sample's demographics (see Table 1). Baseline testing began with the assessment of crystallized and fluid intelligence using Shipley-2 (Shipley, Gruber, Martin, & Klein, 2009). This was done because psychometric intelligence is strongly correlated with WM capacity and various measures of attention, and therefore it was necessary to ensure that the training conditions were equated in terms of these two dimensions of intelligence. Next, we administered three WM span tasks that were modifications of the tasks reported in Harrison et al. (2013). For *word (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 they saw in the order they were presented in. Blocks ranged from three to nine 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 three to nine matrices. For *visual span,* participants were presented with one arrow at a time that pointed in one of eight directions. At the end of each block of arrows, participants were instructed to recall the directions of the arrows in the order in which they were presented. Blocks ranged from three to nine arrows. 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 three span tasks was randomized.

Immediately following the completion of baseline testing, participants were randomly assigned to the experimental ($n = 13$), active control ($n = 14$), or passive control ($n = 14$) condition. Participants in the experimental condition were instructed to complete ten 10-min training sessions within a 2-week period. The NeuroTracker unit was stationed in a room at the training base. Each participant

Table 1
Sample Demographics Broken Down by Condition

	NeuroTracker	Active control	Passive control
Gender			
Male	13	14	14
Female	0	0	0
Age (y)			
21–25	0	0	1
26–30	1	3	2
31–35	5	3	6
36–40	3	7	1
41–45	2	1	3
46–50	2	0	1
Status			
Regular force	13	14	13
Reservist	0	0	1
Rank			
NCM (Private, Cpl/MCpl, Sgt)	8	8	12
Senior NCM (WO, Master WO, Chief WO)	3	2	2
Junior officer	1	4	0
Years of service			
6–10	4	2	3
11–15	1	4	6
16–20	3	7	3
21–25	3	1	1
26–30	1	0	1
Education			
Less than high school diploma	0	0	1
High school diploma	6	8	7
College diploma	4	1	6
University undergraduate degree	1	5	0
Shipley-2 standard score, *M* (*SD*)			
Verbal (crystallized intelligence)	108 (7)	106 (11)	111 (11)
Block Design (fluid intelligence)	113 (11)	114 (9)	113 (15)

Note. Parametric and nonparametric tests demonstrated that there was no statistically significant difference between the three groups on any demographic or ability variable (*p*s > .05). Cpl = corporal; MCpl = master corporal; NCM = noncommissioned member; Sgt = sergeant; WO = warrant officer.

trained individually. In accordance with instructions from the manufacturer, the room used for this purpose was quiet and relatively dark, because too much light can interfere with the motion capture camera. Each participant was equipped with 3D glasses to enable depth perception on the screen. Participants were instructed to sit upright on a chair placed in front of a 65-inch 3D projection screen (Panasonic). Given the size of the projection screen and in consultation with the manufacturer of NeuroTracker (CogniSens, Inc.), the chair was placed 5.5 feet from the screen.

NeuroTracker is designed to offer different types of training, each meant to exercise different abilities. In this study, we focused on *core* training, where each session unfolded in the form of twenty 8-s repetitions—repeated twice. The difficulty (i.e., speed of target motion) was 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 was provided with a personalized laptop and instructed to complete ten 10-min training sessions within the same 2-week period. The participants in the active control condition were instructed to complete these sessions in isolation and in a quiet location. Because the laptop given to the active control group recorded dates and times of session completion, the training regimen could be verified upon the completion of the study.[1] The specific WM task completed by participants in the active control condition was a variant of the *n*-back (i.e., referred to as "adaptive dual *n*-back" because auditory and visual information was presented simultaneously on each trial). The *n*-back is a measure of WM performance that is correlated with WM capacity (Conway et al., 2005). On each trial of this task, the participant was presented with a letter through the auditory channel and saw one of 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 interstimulus interval was fixed at 2,500 ms. So, for example, on 1-back, there was a match if the present item (letter and/or location) matched the one presented one position earlier; on 2-back, there was a match if it matched 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. Participants in the passive control condition did not engage in any systematic training in the 2-week period.

Practice durations and frequencies in previous studies involving WM training have varied greatly, ranging from one 20- or 30-min session to 20 hr spread over 10 weeks (see Buschkuehl, Jaeggi, & Jonides, 2012; Klingberg, 2010; Morrison & Chein, 2011). Our design consisting of 10-min sessions was based on durations of training in previous NeuroTracker studies. In addition, given the target population, our decision to focus on a short and concentrated regimen of training was motivated by our desire to assess the feasibility of training in settings where the implementation of a lengthy training regimen is impractical.

Following the completion of the 2-week training regimen, all participants returned to the original testing location to complete the three span tasks again in random order.

Results

As shown in Table 1, the groups did not differ on any demographic or cognitive variable. The training profiles for the experimental and active control groups are depicted in Figure 2. For the NeuroTracker group, a repeated-measures analysis of variance (ANOVA) demonstrated that performance improved across the training sessions, $F(9, 108) = 11.34$, $p < .001$, partial $\eta^2 = .49$. A test of within-subjects contrasts demonstrated a significant linear trend, $F(1, 12) = 70.11$, $p < .001$, partial $\eta^2 = .85$. Similarly, for the active control group, a repeated-measures ANOVA demonstrated that performance improved across the 10 training sessions, $F(9, 99) = 4.61$, $p < .001$, partial $\eta^2 = .30$. A test of within-subjects contrasts demonstrated a significant linear trend, $F(1, 11) = 26.94$, $p < .001$, partial $\eta^2 = .71$. Thus, in both conditions, performance on the trained task improved across sessions.

At baseline, the correlations among the three measures of span were as follows: word-visual, $r(39) = .57$, $p < .001$; word-matrix, $r(39) = .46$, $p = .002$; and visual-matrix, $r(39) = .54$, $p < .001$. For each group separately, we calculated the change (i.e., post-pre score) for each span measure as a function of training. Span performance was calculated using the Partial-Credit Unit Scoring (PCU) method, where PCU expresses the mean proportion of elements within a trial recalled cor-

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[1] Our preference would have been to have all training occur in the same location. Unfortunately, due to logistic difficulties, it did not appear feasible to administer daily training to all participants in the same lab space. This presents a limitation of our design.

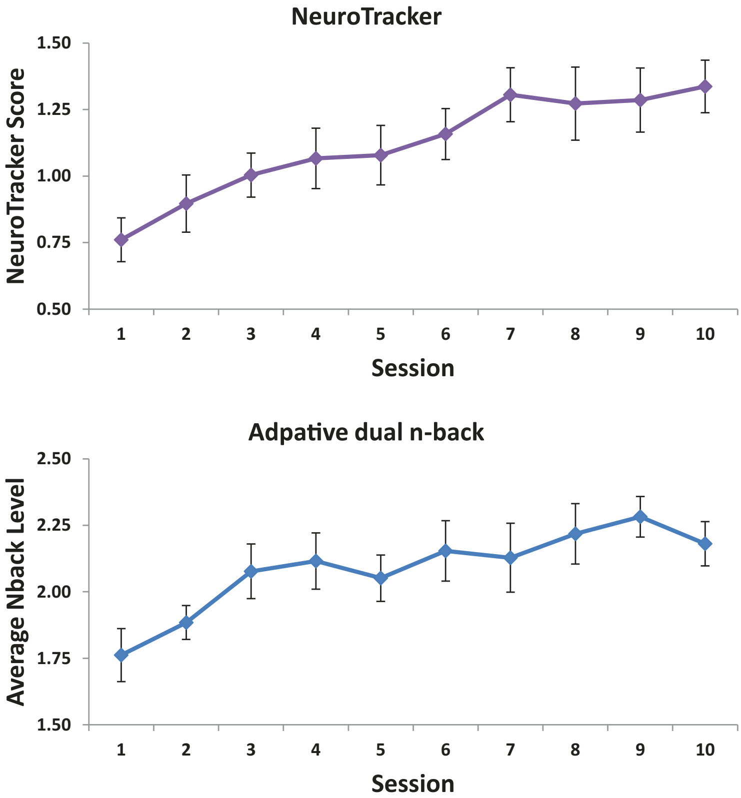

Figure 2. Training profiles for each condition. Error bars represent *SEM*. See the online article for the color version of this figure.

rectly (Conway et al., 2005). For the NeuroTracker group, training resulted in a significant increase in word span, $t(12) = 3.45$, $p = .005$, $d = .96$; visual span, $t(12) = 2.18$, $p = .050$, $d = .60$; and matrix span, $t(12) = 2.85$, $p = .015$, $d = .79$. In contrast, for the active control group, training did not alter word span, $t(12) = 2.11$, $p = .056$, $d = .56$; visual span, $t(12) = 2.11$, $p = .057$, $d = .58$; or matrix span, $t(12) = 1.42$, $p = .180$, $d = .39$. Similarly, for the passive control group, training did not alter word span, $t(12) = 0.50$, $p = .626$, $d = .07$; visual span, $t(12) = 1.36$, $p = .198$, $d = .45$; or matrix span, $t(12) = 1.70$, $p = .115$, $d = .49$.[2]

Discussion

Our results demonstrated that a 10-day regimen of core NeuroTracker training can lead to gains in verbal, visual, and matrix WM span, registering medium to large effect sizes in the process. These results extend the NeuroTracker literature by demonstrating that training can benefit WM capacity in a military sample. In addition, the observation that span measures were strongly correlated at baseline and that NeuroTracker training led to gains in all measures is consistent with evidence that verbal and visuospatial WM capacity measures reflect a primarily domain-general construct (e.g., Kane et al., 2004).

Some limitations of our study must be taken into consideration while interpreting the results. First, our sample size was relatively small, and therefore the results require replication. Second, although previous studies involving Neu-

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[2] These significance patterns did not change when we instead conducted ANOVAs and entered Shipley-2 verbal and block design scores as covariates for verbal and visual/matrix span, respectively.

roTracker training have typically involved 10-min training sessions, that specific duration might not be necessarily optimal for observing training-related gains in nonathletic settings. Nevertheless, given the operational environment of military units, it was important to test the efficacy of a training intervention that can be implemented within brief sessions. Third, observing gains on measures of WM span can be seen as an intermediate step toward the measurement of gains on outcome measures of actual operational significance that draw on WM span. Should the results observed in the present study prove reliable in replication, the next steps could involve examining the effects of NeuroTracker training on military-specific measures of performance, as has been done in the athletic domain (see Mangine et al., 2014; Romeas et al., 2016). Importantly, given that there likely exist differences in the extent to which various occupations and tasks within the military draw on WM capacity, specific aspects of NeuroTracker training (e.g., frequency, duration, aspects of attention) can be customized to facilitate transfer to outcome measures of interest.

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