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Three-dimensional multiple object tracking improves young adult cognitive abilities associated with driving: evidence for transfer to the useful field of view

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Objectives **3-dimensional multiple object tracking (3D-MOT) and the useful field of view (UFOV) both claim to measure and train cognitive abilities, such as selective and divided attention implicated in driving safety. 3D-MOT is claimed to improve even young adult cognitive ability. If true, one would expect to observe the transfer of 3D-MOT training to UFOV performance mediated by way of shared underlying cognitive mechanisms.**

Methods **We test this notion by assessing whether ten 30-min sessions of 3D-MOT training spread across 5 weeks improves UFOV performance relative to an active control group trained on a visual task and a challenging puzzle game (participants aged between 23 and 33 years old).**

Results **The 3D-MOT training group exhibited significantly improved UFOV performance whereas the active control group exhibited only a small, statistically nonsignificant improvement in the task.**

Conclusions **This suggests that 3D-MOT and UFOV performance are likely dependent on overlapping cognitive abilities and helps support the assertion that these abilities can be trained and measured even in young adults. Such training could have implications for improving driver safety in both young and older adults.** ***NeuroReport*** **33: 504–508 Copyright © 2022 The Author(s). Published by Wolters Kluwer Health, Inc.**

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Introduction

Multiple object tracking (MOT) is an experimental paradigm originally developed by Pylyshyn and Storm [1] to study visual attention and the human capacity to simultaneously track multiple moving objects while ignoring distractors. Faubert and Sidebottom [2] later adapted this paradigm into a perceptual-cognitive training program called 3-dimensional multiple object tracking (3D-MOT) implemented in commercially available software known as NeuroTracker. Research has implicated sustained and distributed attention [3,4] and visual working memory processes [5] during MOT tracking but the purported benefits of such training are still under investigation.

The speed at which individuals can reliably track multiple targets can be increased through training [2]. Hypothesized benefits of such training are numerous: from delaying age-related deficits in cognitive function to improving the attentional function of healthy adults and individuals with attentional disorders. Increased tracking speed alone does not unambiguously support the idea that the attentional processes solicited during 3D-MOT improve more generally, however. Indeed, in 2014 the Stanford Center on Longevity and the Berlin Max Planck Institute for Human Development issued a joint statement highlighting the need for additional systematic research investigating the potential benefits of software-based cognitive training programs [6]. They stressed the importance that learning, "should not be restricted to the acquisition of a specific skill but should instead be measurable in an array of tasks linked by their reliance on a particular ability." To this point, a large and growing body of literature suggests that 3D-MOT training transfers fundamental cognitive abilities such as attention and working memory span along with numerous real-world behaviors whose performance is underpinned by effective attentional function [7–12]. Results from studies using other computerized cognitive training programs such as the useful field of view (UFOV) provide further support, but continued research is necessary to address all the limitations highlighted by the joint statement.

The UFOV has emerged as a gold standard for assessing attentional ability in the elderly, especially in driving safety contexts. Ross *et al.* [13] investigated whether the

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speed of processing training had an impact on driving cessation rates across 10 years in the context of the large-scale, multisite Advanced Cognitive Training for Independent and Vital Elderly study. They found that such training reduced the likelihood that drivers defined as at-risk for future mobility decline quit driving in the following 10 years. Additionally, it was found that individuals that underwent this training had a 28% reduced risk of developing dementia in the 10 years that followed relative to controls [14]. While the UFOV is frequently referred to as a test of visual speed of processing, two of its three subtests (UFOV2 and UFOV3) implicate selective and divided attention through the introduction of a secondary peripheral detection task and peripheral distractors in the third subtest. This additional attentional demand may explain why a meta-analysis by Woutersen et al. [15] found strong correlations between UFOV3, visual speed of processing and attention. Their analysis suggests that UFOV3 performance may be even more related to attentional ability than it is to the visual speed of processing.

Given this link between attentional function and UFOV ability, one should expect that cognitive training aimed at improving the specific forms of attention solicited by UFOV subtests, if successful, should be reflected by improved UFOV performance. Such a finding would provide additional convergent validity for the claims of both 3D-MOT and UFOV training programs. Few studies have looked at the link between 3D-MOT training and UFOV ability. Thus, the purpose of the present study is to determine whether or not 3D-MOT training transfers to UFOV performance in young adults.

Methods

Participants

Twenty young adults between the ages of 23 and 33 (mean = 28.5 ± 3.97) years were recruited and randomly assigned to either a 3D-MOT training (EXP; $n = 10$) or active control group (CON; $n = 10$). All participants were told that they were recruited to test the effectiveness of a novel computer-based cognitive training program, were naïve to all training tasks in the study, and had a normal or corrected-to-normal vision. They were free of visual, sensory, motor and neurological impairments as well as any diagnosis of neurodevelopmental disorders. The study adhered to the tenets of the Declaration of Helsinki (last modified, 2013), all tests and procedures were approved by the ethics committee of the Université de Montréal (CERES; Comité d'éthique de la recherche en santé certificate n^{o} 16-130-CERES-D).

Stimuli and procedure

The pre- and post-training evaluations each lasted approximately 2 h. Measures of visual discrimination, UFOV and 3D-MOT ability were taken in both pre- and post-training sessions. The training phase of the study occurred between these two evaluations. All participants were required to travel to the laboratory for ten 30-minute training sessions at a rate of two per week for 5 weeks. Thus, the total training duration was 5 h per participant. The experimental group's training sessions consisted of three series of 20 3D-MOT trials. By comparison, the active control group underwent an alternate training of three series of visual discrimination tasks and the challenging open-source puzzle game 2048 (https://play2048.com/) during their sessions. All participants were completely new to 3D-MOT and 2048.

Experimental group: 3D-MOT

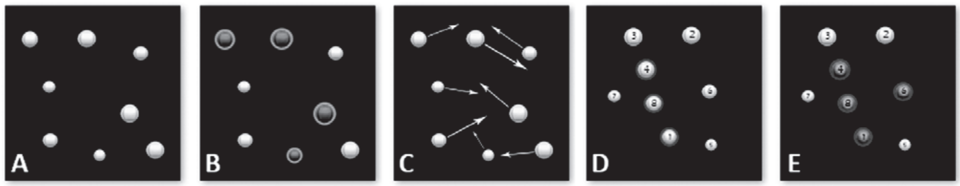
The task involved simultaneous tracking of four linearly moving, dynamically interacting spherical targets among four identical distractors for continuous 8 s. The stimuli were displayed on a 65-inch Panasonic 3D TV screen and subjects wore Panasonic active shutter 3D glasses while being seated on a chair placed 150 cm from the screen. Each trial can be broken down into five phases (Fig. 1). If a participant was able to successfully track all four targets, then the trial was registered as successful and the movement speed of the stimuli in the following trial increased. Otherwise, stimuli speed was decreased. These changes followed a 1-up 1-down adaptive staircase protocol [16] that varied speeds more greatly for early inversions than later ones to quickly identify the optimal speeds to train each participant. Performance on the task was defined by a final tracking speed threshold after 20 trials. The three series' values were subsequently averaged to have a final value for each session.

Active control group: visual discrimination and 2048

The first task used for the alternate training was a simple first-order, that is luminance-defined forced-choice orientation discrimination task using sine-wave gratings (see Legault and Faubert [7] for a description). Participants were required to identify if the sine-wave grating was displayed with either a vertical or horizontal orientation. They were subsequently provided with auditory feedback indicating if they were correct or not. The stimuli's luminance was modulated following a 2-up 1-down staircase procedure and the minimum luminance threshold obtained for the stimulus discrimination was estimated from the last six reversals of the staircase. This task was chosen because of its potential to induce perceptual learning without expected transfer to an attention-oriented task like UFOV [17].

Following three series of the discrimination task, the last remaining 15 min in each 30-min training session was spent by having active control participants play 2048. It is simple to understand a math-like puzzle game whose use as an active control task for the 3D-MOT task has previously been described in the literature [9]. The display and seating distance were identical to the experimental task.

Fig. 1



The five phases of a 3-dimensional multiple object tracking trial: (a) presentation of eight spheres arbitrarily positioned in the virtual cube, (b) identification of the target spheres, (c) removal of the identification and beginning of dynamic sphere movement, (d) end of sphere movement and introduction of numerical labels used for participant target identification and (e) the targets are highlighted to provide feedback to the participant.

Outcome measures

Useful field of view

The test consists of three subtests, intended to measure: (1) processing speed, (2) processing speed under divided attention conditions and (3) processing speed under selective attention conditions [18]. Scores ranged from 16.7 to 500 ms for each subtest, representing the minimum display duration thresholds at which participants could perform each task as determined by an adaptive two-step size staircase. Thus, a lower score reflects better performance. Participants were seated 24 inches away from a 17" eMachines monitor with 1024×768 resolution and a 60 Hz refresh rate. UFOV7 software was used for all testing.

Statistical analyses

One significant outlier in the control group was identified using boxplots of pretraining UFOV scores and removed from subsequent analyses (following [19]). We added participants' UFOV scores across all three subtests as young adults tend to exhibit floor effects[1] with very little variability on the first two subtests [20], and conducted statistical analyses on total UFOV scores after confirming that this aggregate measure did not violate the assumption of normality. To compare post-training 3D-MOT, UFOV and perceptual discrimination task improvement between both groups, we conducted a univariate analysis of covariance tests with pretraining scores entered as a covariate (following recommendations of [21]). 2048 performance change was analyzed by way of a paired samples *t*-test on the first and last training session highest scores.

Results

3D-MOT training improves useful field of view ability

As shown in Table 1, independent samples *t*-tests revealed no significant group differences in pretraining 3D-MOT absolute thresholds [t (17) = 0.07; P = 0.95], perceptual discrimination [t (17) = −0.84; P = 0.42] or UFOV performance [t (17) = −1.06; P = 0.97]. Figure 2 shows that 3D-MOT scores were significantly better in the experimental group compared to the active control group following training [F (1,16) = 16.65; P < 0.001, $\eta_p^2 = 0.51$]. Similarly, a paired samples *t*-test comparing control group pretraining 2048 (M = 2601.33; SD = 529.25) and post-training (M = 5510.67; SD = 2158.13) performance revealed a statistically significant improvement [t (8) = −3.805; P = 0.005]. As shown in Table 1, between-group post-training perceptual discrimination scores differed in absolute terms which may suggest that perceptual learning occurred in the control group, but this difference was not statistically significant [F (1,16) = 2.81; P = 0.11, $\eta_p^2 = 0.15$]. Considering that the static, first-order grating stimuli employed are generally used to test low-level visual processing, a floor effect could be involved. It is also possible that the study simply lacked sufficient statistical power to establish that this learning occurred. The observed improvements in experimental 3D-MOT and control 2048 performance demonstrate that both groups were actively engaged in their respective training sessions. Finally, we looked at scores on the untrained UFOV task. Levene's test was NS [F (1,17) = 0.03, P = 0.87] indicating that the assumption of homogeneity of variance had not been violated. The experimental group demonstrated significantly greater post-training UFOV performance relative to the control group [F (1,16) = 6.52; P = 0.02, $\eta_p^2 = 0.29$].

Discussion

The present study suggests that UFOV and 3D-MOT both taps into common underlying cognitive abilities and that 3D-MOT training improved one or more of these abilities such that it transferred to UFOV performance. Given the important role of attention in both 3D-MOT and the UFOV subtest 3, one possible interpretation is that the present results are explained by the enhancement of shared attentional processes. UFOV3 is claimed to solicit selective and divided attention: both of which underlie MOT ability. Previously, this had been demonstrated in specific clinical populations such as individuals with multiple sclerosis [22]. The present study demonstrates a similar transfer in young adults and against an active control group. As such, one may expect some overlap in the potential applications of UFOV and 3D-MOT

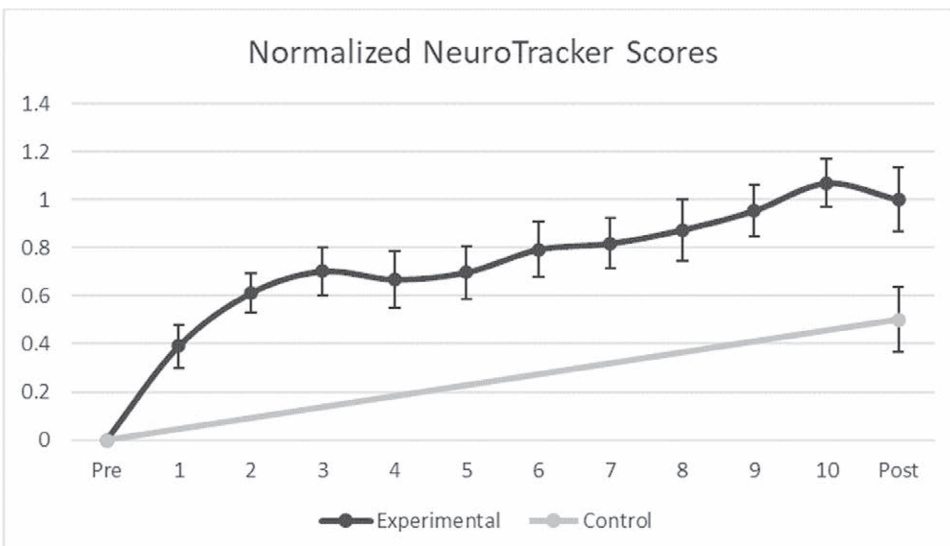
[1]As UFOV scores represent minimum display duration detection thresholds, a "floor effect" reflects excellent performance in this context.

Table 1 Summary of the experimental group (EXP.) and control group's (CON.) mean pre- and post-training data with one standard error (±).

	Experimental group (n=10)			Control group (n=9)			
Measure	Pre	Post	Change	Pre	Post	Change	Significance
3D-MOT	1.04±0.12 z=0.016	2.01±0.17 z=0.59	0.97±0.12 Δz=0.58	1.03±0.15 z=−0.15	1.40±0.12 z=−0.66	0.37±0.09 Δz=−0.51	**<0.001**
UFOV total	92.62±9.17 z=−0.24	73.68±7.60 z=−0.55	−18.94±7.82 Δz=−0.31	106.72±9.6 z=0.26	102.51±6.11 z=0.61	−4.21±10.48 Δz=0.35	**0.02**
Perceptual discrimination	0.023±0.002 z=−0.189	0.021±0.002 z=0.34	−0.002±0.002 Δz=0.53	0.036±0.016 z=0.21	0.017±0.002 z=−0.38	−0.02±0.016 Δz=−0.59	0.11

Within-group mean change scores and *P* values for between-group comparisons are also provided. Z-scores computed from aggregated Experimental and Control data are provided below each raw score to ease comparison across different measures and their relative change post-training. 3D-MOT scores represent maximum log displacement speed thresholds at which the four targets could be successfully tracked. UFOV scores represent the sum of UFOV subtest 1–3 minimum stimulus duration thresholds in milliseconds. Perceptual discrimination scores represent the threshold contrast required to discriminate horizontal vs. vertical Gabor patches.
3D-MOT, 3-dimensional multiple object tracking; UFOV, useful field of view.

Fig. 2



Normalized learning curves (session scores – initial score) with group means and standard error bars for 3D-MOT. While the control group improved on the task, the relative magnitude of this improvement was only about half that of the experimental group.

assessment and training. Indeed, recent evidence suggests that 3D-MOT is useful for identifying at-risk drivers in a similar fashion to the UFOV but in both young and older adults alike [23,24]. It has even been suggested that the more dynamic nature of MOT implicates additional cognitive abilities such as sustained attention, which may improve its predictive power vis-à-vis accident propensity [25]. It is as-of-yet unknown whether 3D-MOT training offers the same reported long-term protection against driving cessation and dementia but the current results provide a strong rationale for further investigation.

Conclusion

We have successfully demonstrated the transfer of cognitive training to another task designed to measure similar cognitive abilities. This result offers convergent validity for UFOV and 3D-MOT and provides further rationale for exploring 3D-MOT's potential as an evaluation of driver safety.

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Conflicts of interest

J.F. is the inventor of the commercial version of the multiple object tracking task used in this study, NeuroTracker. In this capacity, he holds shares in the company.

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