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Training with a three-dimensional multiple object-tracking (3D-MOT) paradigm improves attention in students with a neurodevelopmental condition: a randomized controlled trial

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Abstract

The efficacy of attention training paradigms is influenced by many factors, including the specificity of targeted cognitive processes, accuracy of outcome measures, accessibility to specialized populations, and adaptability to user capability. These issues are increasingly significant when working with children diagnosed with neurodevelopmental conditions that are characterized by attentional difficulties. This study investigated the efficacy of training attention in students with neurodevelopmental conditions using a novel three-dimensional Multiple Object-Tracking (3D-MOT) task. All students (ages 6–18 years) performed the *Conners Continuous Performance Task* (*CPT-3*) as a baseline measure of attention. They were then equally and randomly assigned to one of three groups: a treatment group, (3D-MOT); an active control group (visual strategy/math-based game, *2048*); and a treatment as usual group. Students were trained on their respective tasks for a total of 15 training sessions over a five-week period and then reassessed on the *CPT-3*. Results showed that post-training *CPT-3* performance significantly improved from baseline for participants in the treatment group only. This improvement indicates that training with 3D-MOT increased attentional abilities in students with neurodevelopmental conditions. These results suggest that training attention with a non-verbal, visual-based task is feasible in a school setting and accessible to atypically developing students with attentional difficulties.

1 | INTRODUCTION

Developmental theorists have stressed the importance of attentional capacity in typical cognitive development (Case, 1985). Attentional capacities vary across individuals, and these differences are exacerbated among individuals diagnosed with a neurodevelopmental condition (Melby-Lervåg & Hulme, 2013). In fact, most neurodevelopmental conditions are characterized by difficulties in attention (e.g., Attention Deficit and Hyperactivity Disorder (ADHD); Antshel, Zhang-James, & Faraone, 2013; Craig et al., 2016), or are associated with clinically significant difficulties in attention among other challenges. For example, difficulties in attention are prominent in Autism Spectrum Disorder (ASD; Antshel et al., 2013), learning disorders (Cantwell & Baker, 1991; Mayes, Calhoun, & Crowell, 2000), and intellectual disability (ID; Guerin, Buckley, McEvoy, Hillery, & Dodd, 2009). Fortunately, several cognitive-based training approaches have been developed to improve these difficulties (Sonuga-Barke, Brandeis, Holtmann, & Cortese, 2014); yet, the majority of these approaches have focused on training working memory instead of training attention directly (Melby-Lervåg & Hulme, 2013).

To date, there have been several reviews and meta-analyses exploring the efficacy of working memory training (Klingberg, 2010; Melby-Lervåg & Hulme, 2013; Rapport, Orban, Kofler, & Friedman, 2013; Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015; Shipstead, Redick, & Engle, 2012). Most of these studies, however, have been criticized for their lack of specificity

(Rapport et al., 2013; Redick et al., 2015). Improvements from working memory training have been found to transfer to separate tasks (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008), but these findings have been attributed to task expertise instead of a change in the underlying processes of working memory (Shipstead et al., 2012). Focusing on a cognitive process as broad as working memory may therefore be too general. Alternatively, targeting specific processes, such as sub-components of attention, should better illustrate the benefits of training by increasing the probability to transfer its effect to another measure of attention (i.e., near-transfer).

Cognitive training studies specifically targeting attention are scarce in comparison to those training working memory (Rabiner, Murray, Skinner, & Malone, 2010; Rapport et al., 2013). Of the few studies that have trained attention, most have focused on reducing attention-related symptomology by targeting its specific components (i.e., sustained, selective, and distributed attention; see Sonuga-Barke et al., 2014). Attention-based training involves strengthening processes by repeated exposure to a task that best targets attentional processes (Melby-Lervåg & Hulme, 2013; Sonuga-Barke et al., 2014). Findings from studies measuring post-training improvements using subjective ratings of attention (i.e., parent and teacher observations) have been mixed, with some studies reporting benefits (Rabiner et al., 2010; Shalev, Tsal, & Mevorach, 2007; Steiner, Frenette, Rene, Brennan, & Perrin, 2014; Tamm, Epstein, Peugh, Nakonezny, & Hughes, 2013), while other studies have not (Sonuga-Barke et al., 2013; Steiner, Sheldrick, Gotthelf, & Perrin, 2011).

This inconsistency may originate from the accuracy of the measures used to gauge cognitive enhancements. Positive results demonstrating transfer to subjective reports, or behavioral changes measured via observation (Rabiner et al., 2010; Shalev et al., 2007; Steiner et al., 2014; Tamm et al., 2013), have been criticized for improper blinding and Hawthorne effects (Rapport et al., 2013; Sonuga-Barke et al., 2013, 2014). This suggests that an objective measure of attention, rather than subjective reports, can provide a more accurate assessment of changes in attentional processes following cognitive remediation (Redick et al., 2015).

In addition to the methods used to assess transfer, the adaptability of training tasks presents another challenging issue within the cognitive training literature. In both attention and working memory training domains, an inability to adapt to the user's capability can result in disengagement. This is evident in studies that include clinical populations, wherein participants often feel overwhelmed by the task's difficulty (Holmes & Gathercole, 2014; Klingberg et al., 2005). Unlike traditional tasks, adaptive tasks increase in difficulty after a successful trial or training session, or decrease in difficulty after an incorrect or unsuccessful attempt. Adaptive tasks are therefore more accessible to students with low levels of cognitive functioning (Holmes & Gathercole, 2014), as they provide motivational benefits. Such benefits are achieved by balancing the task's difficulty with the individual's cognitive level or ability (Shipstead et al., 2012).

Research Highlights

- Cognitive training may be useful for improving attention, but findings across studies are inconsistent.
- We examined the efficacy of a 3D multiple object-tracking paradigm (*NeuroTracker–NT*) to improve the attentional abilities of students with a neurodevelopmental condition.
- Training with the *NeuroTracker* (*NT*) for 15 sessions, resulted in significantly improved performance on the *Conners Continuous Performance Task – 3rd Edition* (*CPT-3*) when compared to baseline; post-training *CPT-3* performance did not differ from baseline for either the active or passive control groups.
- Our results suggest that the *NeuroTracker* can improve attentional abilities in clinical populations and that this program can be implemented in school settings.

The challenge of conducting an effective attention training program includes the selection of a task that is (i) designed to stimulate attentional processes necessary for improvement, (ii) tailored to the participant's capability, and (iii) accessible to individuals with a range of cognitive abilities. In addition to these challenges, the existing literature highlights important considerations for cognitive training, including specificity (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012), accuracy (Redick et al., 2015), accessibility (Shipstead et al., 2012), and adaptability (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012; Sonuga-Barke et al., 2014). We suggest that using a non-verbal, three-dimensional (3D) Multiple Object-Tracking (3D-MOT) paradigm is one way to address these specific challenges and important considerations.

MOT is primarily concerned with the ability to selectively attend to or visually track a distinct number of items among physically indistinguishable distractor items (Pylyshyn & Storm, 1988). This paradigm has been used to define the limits of attention (Alvarez & Franconeri, 2007) and understand processes of attention in typically and atypically developing individuals (Koldewyn, Weigelt, Kanwisher, & Jiang, 2013; O'Hearn, Hoffman, & Landau, 2010). For example, Oksama and Hyönä (2004) suggested that individual differences in MOT capability were accounted for by other higher-level cognitive processes. From there, research in MOT characterized individual differences in MOT capability by age (Trick, Perl, & Sethi, 2005) and between neurodevelopmental conditions (see Evers et al., 2014; Koldewyn, Jiang, Weigelt, & Kanwisher, 2013; O'Hearn et al., 2010). These studies support the sensitivity and versatility of MOT as a paradigm. It is therefore unsurprising that researchers have explored the use of this paradigm for training attention.

One specific example of a MOT paradigm includes the *NeuroTracker* (*NT*). The *NT* is unique in that it targets specific subcomponents of attention, adapts to a users' capability and provides immediate feedback after each trial (NeuroTracker, n.d.). Previous research has demonstrated that the *NT* improved cognitive functioning in adults (Parsons et al., 2014; Vartanian, Coady, & Blackler, 2016). In a sample of undergraduate students, Parsons et al., (2014) found that training with *NT* improved performance on standardized cognitive assessments associated with working memory (i.e., Wechsler Adult Intelligence Scale) and resting-state brain functioning associated with visual information processing. Additionally, Vartanian, Coady, and Blackler (2016) trained members of the military with the *NT* and observed improved performances on working memory span tasks compared to no improvements from participants that trained with an adaptive *n*-back task. However, this research is limited by small sample sizes (Parsons et al., 2014; Vartanian et al., 2016) and post-test measures invalidated by practice effects (Parsons et al., 2014). Moreover, little is known about about the efficacy of the *NT* for use in children and adolescents with attention difficulties.

To date, no cognitive training studies have considered task specificity, accuracy, adaptability and accessibility concurrently. Further, none have considered the effects of these factors when training attention in atypically developing individuals. The present study examined the efficacy and feasibility of a 3D-MOT paradigm (i.e., *NT*) to train attention in children and adolescents diagnosed with a neurodevelopmental condition, characterized by attention difficulties. We wanted to explore the efficacy of training attention with the *NT* task from a value-added approach (Mayer, 2014). Specifically, we wanted to test whether the addition of the *NT* task to the student's daily routine would improve attention. This study is one of few to incorporate *both* passive *and* active control groups to examine the efficacy of an attention training task with a sample size of at least 20 participants per group, consistent with current recommendations (Redick et al., 2015). Most importantly, participants trained on a task that specifically and accurately targeted subcomponents of attention, adapted to the user's capability, and was accessible to students of all levels of cognitive functioning. Moreover, this is the first to incorporate all these elements in a sample of children and adolescents with a neurodevelopmental condition. We assessed whether attention would improve with 15 *NT* training sessions over the course of a 5-week period. Based on previous studies using the *NT* (Parsons et al., 2014; Vartanian et al., 2016), we predicted that the treatment group would show an effect of near-transfer, defined as an increase in post-training performance on the *Conners Continuous Performance Task – 3rd Edition* (*CPT-3*; Conners, 2014).

2 | METHODS

2.1 | Participants

Participants (N = 129; n_{male} = 92; n_{female} = 37) were recruited from one elementary and two secondary schools (M_{age} = 13.23, SD_{age} = 2.11) in the province of Québec, Canada. These schools provide specialized services to students diagnosed with various neurodevelopmental conditions. Participating students were between the ages of 6 and 18 years, and all were diagnosed with a neurodevelopmental condition, confirmed by either a clinical or school psychologist. The primary diagnoses of the participating students were as follows; (i) Autism Spectrum Disorder (ASD; n = 41), (ii) Attention-Deficit/Hyperactivity Disorder (ADHD; n = 42), (iii) Intellectual Disability (n = 18), (iv) Language Disorder (n = 14), (v) Specific Learning Disorder (n = 3), and (vi) Other Neurodevelopmental Disorder (Other ND; i.e., rare genetic-based syndromes; n = 11; see Table 1). The three experimental groups were matched on age, as well as on Full Scale Intelligence Quotient (FSIQ) and Perceptual Reasoning Index (PRI) scores of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Wechsler, 2011). Despite these efforts, the active and passive control groups differed on the WASI-II Verbal Comprehension Index score (VCI) p = .002. The Research Ethics Board of McGill University approved the study protocol, and all parents provided informed consent for their child's participation.

2.2 | Outcome measure (near-transfer effect)

***Conners Continuous Performance Test – 3rd Edition* (pre-test and post-test measure):** Participants completed the *Conners Continuous Performance Test* (*CPT-3*), a computer-based assessment of attention that begins with a minute-long practice session followed by a 14-minute run consisting of 360 trials. As per *CPT-3* instructions, participants were told to respond to the letters that were flashed on the screen (by pressing the spacebar), but also to inhibit from responding to the letter "X".

The *CPT-3* provides a standardized assessment of attention by comparing performance to age- and gender-specific norms, which is ideal for conducting comparisons between individuals. The *CPT-3* is a valued resource because it can discriminate between individuals with deficits in attention (i.e., individuals with ADHD) and the general population. The assessment's test–retest reliability is similar to past versions (Soreni, Crosbie, Ickowicz, & Schachar, 2009). The *CPT-3* can therefore be used to (i) help identify deficits in attention, (ii) clarify issues when making decisions regarding diagnoses, (iii) screen an individual's level of attention for program placement purposes, and (iv) track progress or examine the effectiveness of a treatment (Conners, 2014).

The *CPT-3* provides different indices of attention through assorted variables. For the purpose of this study, we have decided to focus on d', the task's primary variable and a measure of inattentiveness and inhibition. Specifically, d' is defined as the ability to distinguish targets and non-targets as they are presented to the participant. For this variable, a normalized t-score is calculated by the raw score, where a higher t-score indicates a poorer performance (i.e., the poorer the participant was able to discriminate between targets and non-targets). A measure of inattentiveness and inhibition via the d' t-score can be described as good (t-score 0 to 45), average (45 to 54), below average (55 to 59), or poor (greater than 60). Participants scoring 60 and above are considered to have

TABLE 1 Participant characteristics

	NT (*n* = 43)		*2048* (*n* = 43)		TAU (*n* = 43)		Total (*N* = 129)	
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	13.13	**2.01**	13.43	2.04	13.08	2.30	13.23	2.11
Pre *d′*	60.16	**8.19**	61.49	8.48	57.98	8.85	59.88	8.57
Post *d′*	56.61	**10.23**	61.70	9.03	57.95	9.85	58.72	9.89
FSIQ	78.86	**14.20**	72.81	12.68	79.60	14.02	77.09	13.88
PRI	83.56	**16.01**	77.07	17.97	82.53	16.27	81.05	16.92
VCI	77.58	13.78	70.91	12.36	80.84	13.47	76.44	13.76

Diagnoses	*NT* (*n* = 43)	*2048* (*n* = 43)	TAU (*n* = 43)	Total (*N* = 129)
ASD	16	8	17	41
ADHD	13	17	12	42
Intellectual Disability	6	8	4	18
Learning Disorder	1	0	2	3
Language Disorder	4	4	6	14
Other ND	3	6	2	11

Note. Means and standard deviations. *N* = 129 (*NT* [treatment group]: 35 male; *2048* [active control]: 25 male; treatment as usual [passive control| 34 male.). Pre and Post *d′* is a measure of detectability in the Conners' *Continuous Performance Test* (*CPT-3*). Bottom half of table represents clinical diagnoses by experimental group: ASD, Autism Spectrum Disorder; ADHD, Attention Deficit Hyperactivity Disorder; Other ND, Other Neurodevelopmental Condition.

atypical attention, suggesting the presence of an attention problem (Conners, 2014).

2.3 | Interventions

3D Multiple Object-Tracking paradigm: *NeuroTracker* (*NT*; treatment group): Participants wore 3D glasses and sat in a chair that was approximately 5 feet from a 50″ HDTV with 3D compatibility. *NT* trials were broken down into five parts, as presented in Figure 1. Trials began with the presentation of eight spheres, which were arbitrarily positioned throughout the 3D visual field (Figure 1a). Three of the eight spheres were designated as targets and changed colour from yellow to orange. Participants were instructed to keep track of these identified spheres (Figure 1b). Once the spheres returned to their original colour (yellow), they moved randomly throughout the virtual volumetric space for 8 seconds (Figure 1c). After 8 seconds of movement, the spheres stopped and were numbered. In order to successfully complete the trial, participants had to identify the original spheres that were highlighted at the beginning of the trial using a number pad (Figure 1d). Finally, upon verification of the tracked objects, feedback was provided to the participant by highlighting the *correct* spheres (Figure 1e). Task speed was generated using a 1-up 1-down staircase procedure (Levitt, 2005). Dependent on correct or incorrect responses, the speed of the spheres increased or decreased with each trial. If the participant failed to identify the target spheres, the speed of the subsequent trial decreased. However, if the participant correctly identified all target spheres, the speed of the subsequent trial increased. Initial speed was set at 68 centimeters per second (cm/s) and depending on previous trial performance, item speed for the subsequent trial was either increased or decreased after respective correct and incorrect responses. Possible speeds ranged from 0.68 cm/s to 544 cm/s. Performance

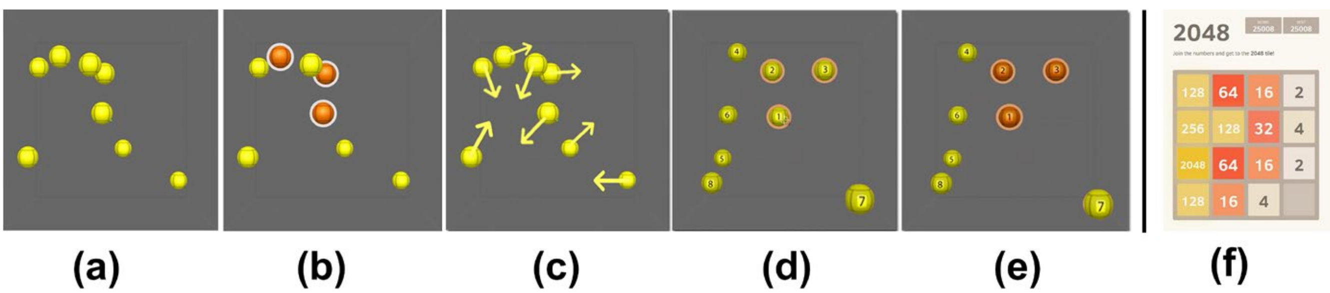

FIGURE 1 A procedural representation of training and active control tasks. NeuroTracker (a–e): a) The 8 spheres are presented in the visual field. b) The three target spheres are highlighted and participants are told to track these items. c) The spheres move randomly throughout the visual field. d) Numbers appear on all 8 spheres and the participant must identify the three target spheres. e) Feedback is given to the participant and correct spheres are highlighted. 2048: F) Participants must combine like tiles to form its multiple. The objective is to obtain a tile of 2048.

was defined by the average speed at which participants successfully tracked *all* three target spheres.

***2048* (active control group):** Participants played *2048*, a popular computer game designed as a math-like puzzle. The objective was to reach the number 2048 by combining like numbers across tiles (see Figure 1f). The game was presented on a 13″ MacBook Pro laptop, using a Google Chrome browser. Participants used the keyboard arrows to move the tiles and played until there were no more possible moves (i.e., no like numbers adjacent to one another).

2.4 | Other measures

Wechsler Abbreviated Scale of Intelligence – Second Edition: The Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Wechsler, 2011) was administered to all participants. The WASI-II was chosen because it serves as a measure of general intelligence for individuals between the ages of 6 and 89 years. A Full-Scale Intelligence Quotient score (FSIQ) was derived from verbal and non-verbal subtests included in the respective Verbal Comprehension Index (VCI) and Perceptual Reasoning Index (PRI; Wechsler, 2011).

2.5 | Procedure

First, all participants were administered the WASI-II and then completed the *CPT-3* to obtain a measure of IQ and a baseline score of attention, respectively. After pre-assessment, participants were randomly and equally divided into the three parallel groups (1:1:1): *NT* (treatment; *n* = 43), *2048* (active control; *n* = 43), and treatment as usual (TAU; passive control; *n* = 43; see Figure 2 for Consort Diagram), using a simple computer random number generator in Microsoft Excel. During the training period, participants in the treatment and active control groups were retrieved from their classroom at random times throughout school hours. They were accompanied to the testing room and trained on *NT* or played *2048*. Participants in the treatment and active control groups were called out of class every other day for a total of 15 sessions over the course of 5 weeks.

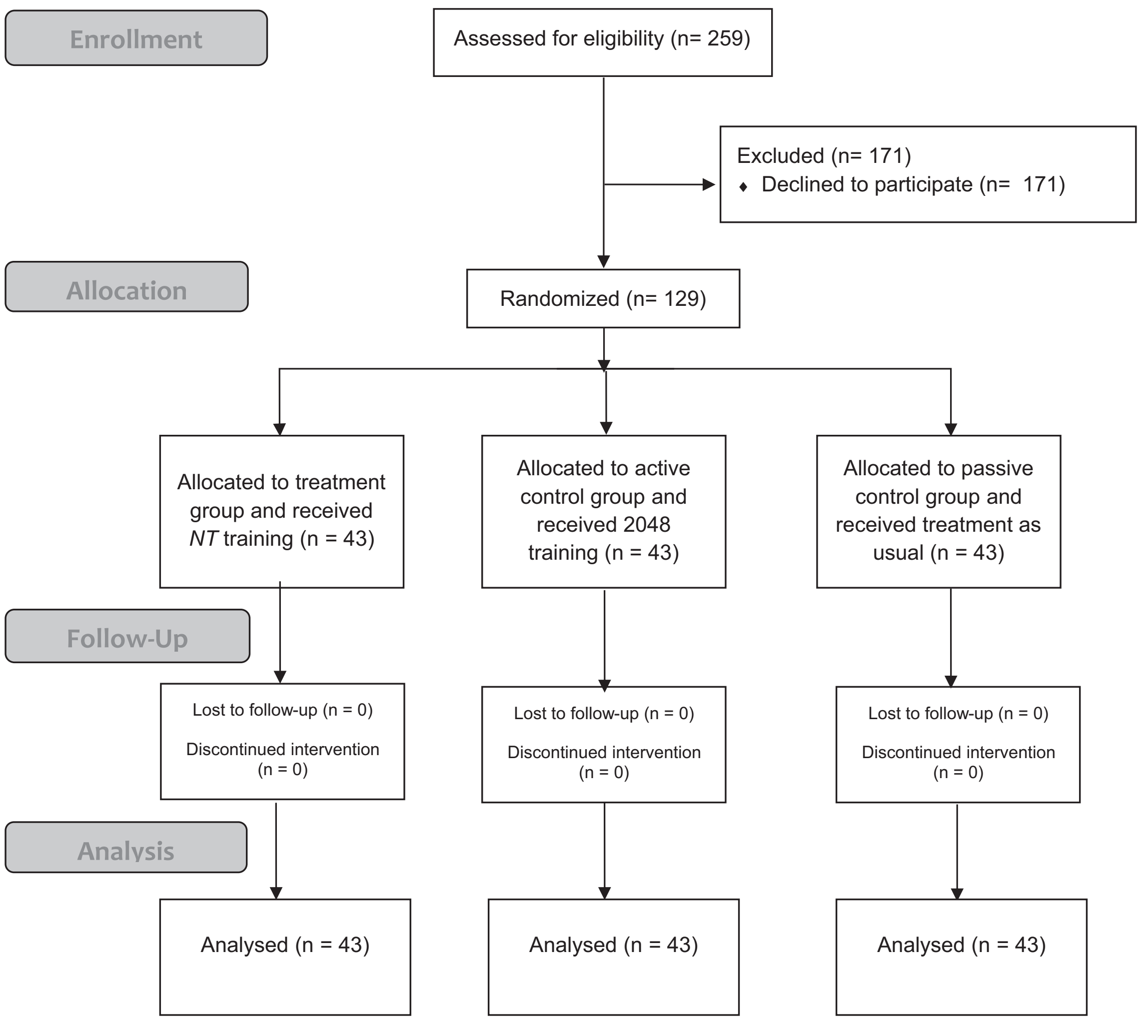

FIGURE 2 CONSORT flow diagram

Upon completion of the 5-week training program, all participants were reassessed on the *CPT-3*.

***NT* training procedure:** On the first day of training, participants were escorted out of class, told that they would play a game, and given a practice trial of the training task. A trained research assistant read the instructions and participants were given up to six practice trials. In these trials, participants were asked to follow one of eight spheres to ensure that they understood the concept of the game. Participants were required to obtain two out of three correct trials to move on to training. If unsuccessful, instructions were reread to the participant. They were then required to correctly identify the target item in at least two out of three trials to qualify for the study. All 43 participants in the treatment group qualified for the study. In each training session, participants played the *NT* until two average speed threshold scores were obtained. Thresholds scores were defined as the average speed at which participants could track all target items. These two threshold scores obtained per session were averaged together and plotted to track progression. Performance feedback (i.e., the average speed threshold score) was displayed on the 3D-TV after each training session. An average session lasted approximately 7 minutes.

***2048* training procedure:** Similar to the *NT* group, participants were escorted out of the classroom and told that they were going to play a game. A trained research assistant read the rules of the game to the participants and demonstrated how to respond using the keyboard arrows. Participants were then asked to practice the game to verify whether they understood the concept. The session began once participants demonstrated their understanding and the game was restarted. Participants played until they received two "game-over"(s) or exceeded a time limit of 7 minutes. A *2048* training session lasted 7 minutes on average. Similar to the *NT* training condition, the participant's score appeared on the screen once they had no more remaining moves (i.e., "game-over"). These scores were recorded to track progression.

3 | RESULTS

3.1 | Pre-assessment analyses

First, we investigated whether there were any differences in age and IQ across the treatment (*NT*), active control (*2048*), and treatment as usual (TAU) groups at baseline. In terms of age, a one-way ANOVA revealed no statistically detectable difference across the three experimental groups: $F(2, 126) = 0.44$, $p = .644$, partial $\eta^2 = .007$. In terms of IQ, results revealed a marginally significant between-groups difference for global intelligence (FSIQ) scores: $F(2, 126) = 3.20$, $p = .044$, partial $\eta^2 = .029$. However, post-hoc Tukey HSD analyses revealed no significant differences across groups for FSIQ. There was no statistically detectable between-group difference in non-verbal IQ (PRI): $F(2, 126) = 1.85$, $p = .161$, partial $\eta^2 = .048$; however, as previously stated, there was a significant difference in verbal IQ (VCI): $F(2, 126) = 6.31$, $p = .002$, partial $\eta^2 = .091$. Post-hoc Tukey HSD revealed a difference for VCI between the TAU and active control groups (*2048*), $p = .002$, Cohen's $d = 0.77$, 95% CI [0.32, 1.20] (see Figure 3a).

We also examined whether there were any differences on the baseline measure of attention using the d' *t*-scores of the *CPT-3*. A one-way ANOVA confirmed that there were no significant differences in baseline attention of participants across experimental groups, despite the range of neurodevelopmental conditions within each group: $F(2, 126) = 1.87$ $p = .159$, partial $\eta^2 = .029$ (see Figure 3a). We further examined whether there were any differences on the baseline d' *t*-scores on the *CPT-3* due to the group differences in

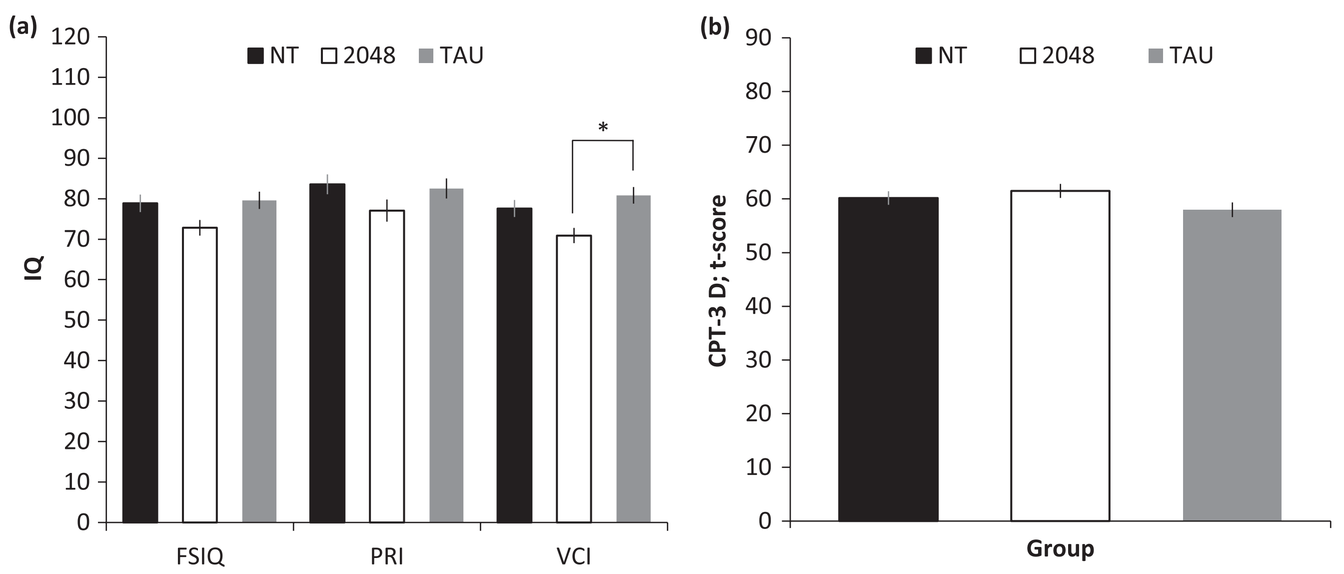

FIGURE 3 Means and standard error (error bars) for WASI-II and *CPT-3* across all three groups. **A)** IQ scores compared across global, (FSIQ), non-verbal (PIQ), and verbal intelligence (VCI). TAU group and *2048* group differed on VCI sub-scale, *$p = .002$, Cohen's $d = 0.77$. **B)** Participant CPT-3 d' *t*-scores compared across three groups. The higher the *t*-score, the worse the performance.

Verbal IQ. We used a one-way ANCOVA with VCI as the covariate. Although the covariate VCI was significant, $F(2, 125) = 5.44$, $p = .021$, partial $\eta^2 = .042$, there was no reliable effect of group: $F(2, 125) = .78$, $p = .461$, partial $\eta^2 = .012$ (see Figure 3a). Again, this demonstrated that there were no statistically detectable differences in baseline attention across all three experimental groups, as measured by *d′* scores on the *CPT-3*.

3.2 | *NeuroTracker* and *2048* training

NeuroTracker (*NT*) and *2048* scores were recorded after each training session. These scores were plotted to track the daily progression of performances for both groups (see Figure 4a). The *NT* thresholds showed a reverse logarithmic trend, characteristic of a typical learning curve. These scores mapped onto the following log equation: y = 11.08ln(x) + 57.79) at $R^2 = .901$ (Figure 4a [left axis]). A paired samples *t* test between session 1 (*M* = 62.69, *SD* = 41.03) and session 15 (*M* = 88.33, *SD* = 43.47) was conducted to measure overall progression. This analysis revealed a 41% improvement in the *NT* average speed threshold scores from the first to final training session, $t(42) = -5.45$, $p < .001$, Cohen's $d = 0.832$, 95% CI [0.39, 1.27].

Unlike the *NT*, the *2048* scores fit a linear equation: y = 30.35(x) + 1428.10, at $R^2 = .595$ (see Figure 4a [right-axis]). A paired samples *t*

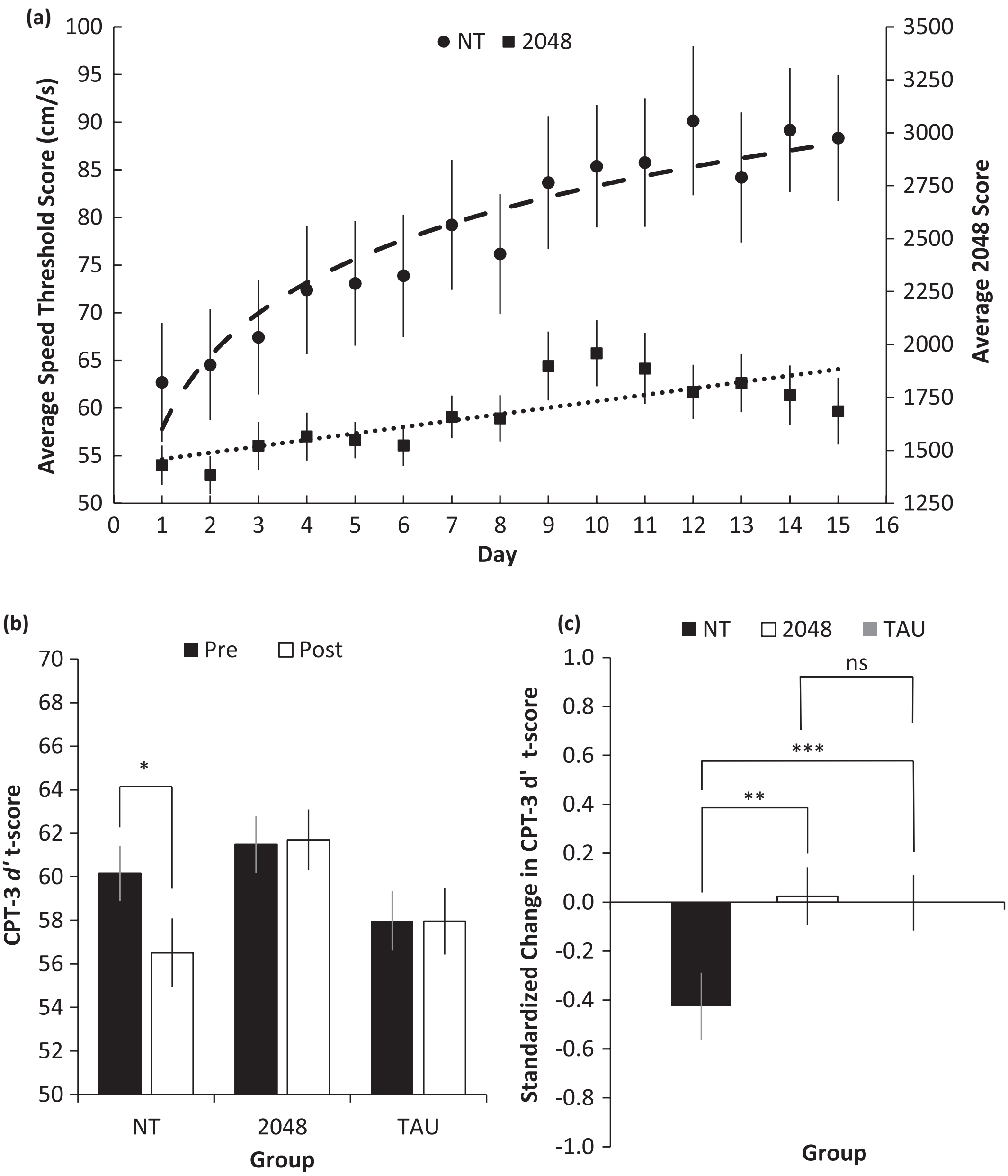

FIGURE 4 Means and standard error (error bars) for: **A)** Daily progression in *NeuroTracker* (left y-axis) and *2048* (right y-axis) training groups (Day 1 – 15) are graphed. NT performance mapped onto: y = 11.08ln(x) + 57.79 at R2 = .901. **B)** Differences in pre- and post-test *d*′ scores by experimental group. *$p = .005$, Cohen's $d = .456$. **C)** Transfer effect across three groups on CPT-3 d' t-score. **$p = .033$, Cohen's $d = 0.524$; ***$p = .048$, Cohen's $d = 0.497$.

test between session 1 (M = 1429.47, SD = 633.49) and session 15 (M = 1648.58, SD = 1029.96) revealed no significant difference between the first and last training sessions on *2048* (active control group), $t(42) = -1.55$, $p = .128$, Cohen's d = 0.236, 95% CI [−0.19, 0.66].

3.3 | Transfer

Pre- and post-test changes on the *CPT-3* were calculated as the standard deviation change: post-test score minus pre-test score, divided by the standard deviation of all participants' pre-test scores ($\text{post-test}_i - \text{pre-test}_j$ / 8.57). As expected, the *NT* group was the only group to see a significant difference between pre- and post-test: $t(42) = 2.99$, $p = .005$, Cohen's $d = .456$, 95% CI [0.03, 0.88]. There was no significant difference in the *2048*: $t(42) = -.209$, $p = .835$, Cohen's $d = -.032$, 95% CI [−0.39, 0.45]; or TAU group: $t(42) = .023$, $p = .981$, Cohen's $d = .004$, 95% CI [−0.42, 0.43]; (see Figure 4b).

The effect of transfer was further explored using a one-way ANOVA, which demonstrated that the groups differed on the standardized change in *CPT-3 d′ t*-scores, $F(2, 126) = 4.043$, $p = .020$, partial $\eta^2 = .060$. Post-hoc Tukey HSD comparisons revealed a significant difference between *NT* and *2048*, $p = .033$, Cohen's $d = 0.524$, 95% CI [0.09, 0.95]; as well as *NT* and TAU, $p = .048$, Cohen's $d = 0.497$, 95% CI [0.06, 0.92]. There was no significant difference between *2048* and TAU, $p = .987$, Cohen's $d = .035$, 95% CI [−0.39, 0.46]. Figure 4c represents a bar-graph comparison of standardized change between each experimental group.

3.4 | Potential biases for transfer

Diagnostic profiles: A two-way ANOVA was conducted with condition (*NT*, 2048, and TAU) and diagnosis (ASD, ADHD, Intellectual Disability, Language Disorder, and other genetic-based disorders) as factors with standardized change in CPT-3 *d′ t*-scores as the outcome measure. Participants diagnosed with a learning disorder were removed from this analysis because there were too few to be included in each of the three experimental groups. This resulted in the sample being reduced to 126 participants. The ANOVA revealed a significant main effect of experimental group: $F(2, 111) = 4.03$, $p = .020$, partial $\eta^2 = .068$. However, there was no reliable main effect of diagnosis, $p = .125$, nor meaningful interaction between group and diagnosis, $p = .171$.

To help balance the diagnostic groups, we examined whether there were any differences between experimental groups and diagnostic profiles of participants with either ASD (n = 41) or ADHD (n = 42). The main effect of experimental group remained significant, $F(2, 77) = 4.14$, $p = .021$, partial $\eta^2 = .096$. However, there was no meaningful main effect of diagnosis, $p = .209$, nor a statistically detectable interaction between condition and diagnosis, $p = .187$. These results demonstrated that all participants benefitted equally from *NT* training, regardless of their neurodevelopmental condition.

IQ: We explored whether FSIQ influenced the change in pre- to post-test *CPT-3* performance. Even with the addition of this covariate, results revealed a statistically detectable difference between experimental groups: $F(2, 125) = 4.88$, $p = .009$, partial $\eta^2 = .072$. The treatment, *NT* group had a significant standardized change in *CPT-3* score compared to both the active (*2048*): $p = .004$; and the passive (TAU) groups: $p = .019$. There was no significant difference between the 2048 and TAU groups: $p = .549$. In addition, a simple bivariate correlation was used to examine whether FSIQ was associated with the standardized change in *CPT-3* scores. These results revealed that the relationship between FSIQ and the change in *CPT-3* scores was not statistically detectable: $r(127) = .160$, $p = .07$. This suggested that IQ did not influence the change from pre- to post-test scores on the *CPT-3* task.

Age: Finally, we explored the possible influence of age on the change from pre- to post-test scores on the *CPT-3*. After controlling for age, the main effect of experimental group remained, $F(2, 125) = 4.15$, $p = .018$, partial $\eta^2 = .062$, suggesting no meaningful influence of age on the effects of training.

4 | DISCUSSION

We investigated how attention was trained in children and adolescents diagnosed with neurodevelopmental conditions, using a non-verbal and adaptable 3D-MOT paradigm (*NeuroTracker*, *NT*) in a school-based setting. Our results revealed that attention improved with training on the *NT*, as indicated by improved performances on the *Conners Continuous Performance Task 3rd Edition* (*CPT-3*). Further, the improvements in performance on the *CPT-3* were exclusive to the *NT* group. That is, there was no improvement in CPT-3 performances in either active (*2048*) or passive (treatment as usual; TAU) control groups. These results contribute significantly to the existing literature, which is currently limited to findings from studies using training paradigms that lack: (i) specificity in targeting desired cognitive processes, (ii) accuracy in assessing change, (iii) accessibility to all levels of cognitive functioning, and (iv) adaptability to the user's ability.

We designed our training protocol using a value-added approach (see Mayer, 2014). The common criticisms associated with a value-added approach highlight that improved benefits from training can be biased by the: (i) act of taking the participant outside of the classroom, consequently providing special treatment; (ii) addition of something novel to their daily routine; (iii) increase in motivation to perform well on the outcome measure to satisfy the researcher; and (iv) presence of Hawthorne effects (Rapport et al., 2013; Sonuga-Barke et al., 2014). For these reasons, an active control group was used, where participants played *2048* to eliminate the confounds associated with this type of approach. The *2048* task was chosen because it was a suitable, intuitive, computer-based, additive task; however, it was not designed to directly tap into the attentional resources that were targeted for remediation.

Unlike the *2048* task, a MOT paradigm is indicative of one's attention resource capacity (Alvarez & Franconeri, 2007). Our results showed that participants learned and improved significantly from the first to last training sessions with the *NT*. Therefore, this change in performance suggests an improvement in attention resource capacity. Furthermore, this improvement emphasizes the importance of adapting task difficulty to the participant's capability (Holmes & Gathercole, 2014; Jaeggi, Buschkuehl, Jonides, & Shah, 2011). This is important because Jaeggi et al. (2011) found that adapting task difficulty to the participant's level of skill affected whether they improved on the training task itself. Unlike the *2048* task, the *NT* adapted to the participant's individual capability and, therefore, kept them within an optimal zone for learning. This adaptability produced a learning curve in the *NT* group, but not in the *2048* group. This finding is consistent with previous research suggesting that adaptive tasks are valuable for training (Klingberg, 2010). Therefore, the *NT*'s accuracy in targeting attention, as demonstrated by previous research in MOT (Alvarez & Franconeri, 2007; Scholl, 2009), and its capability to adapt to a participant's daily performance are considered important factors in achieving an effect of transfer (Sonuga-Barke et al., 2014).

To our knowledge, no other study has assessed or demonstrated a near-transfer effect between the *NT* and another objective measure of attention in students with a neurodevelopmental condition. Since transfer effects resulting from subjective reports are not as reliable as those from objective, validated and reliable measures (Rapport et al., 2013; Sonuga-Barke et al., 2013, 2014), we selected the *CPT-3* as our clinically validated measure of attention (Conners, 2014). Although they are administered in different ways, both the *NT* and *CPT-3* measure similar underlying mechanisms of attention. While the *NT* requires the tracking of select targets among distractor items, the *CPT-3* involves responding to select letters and inhibiting responses to irrelevant ones. By targeting specific processes of attention, this study improves upon previous research training working memory, which has been criticized for its lack of specificity (Rapport et al., 2013; Redick et al., 2015). An example of this can be seen in Chase and Ericson (1982) wherein the effects of training were manifested from a learned, task-specific strategy rather than improvements in the underlying mechanisms of working memory (Shipstead et al., 2012). A study by Dahlin et al. (2008) provides another example of this type of confound. Participants trained their working memory by recalling list items with increasing difficulty and this was found to transfer to a separate, non-trained *n*-back working memory task. Unlike these studies in which improvement may relate more to task-expertise than training itself (Shipstead et al., 2012), the near-transfer effect between the *NT* and *CPT*-3 suggests that they may access similar cognitive processes. However, more research is needed to further identify the benefits of the *NT* in tapping underlying subcomponents of attention. The selection of an active control measure similar to the *NT*, but distinct in its targeted subcomponents, could be used to demonstrate the value of this approach in training attention. This idea is consistent with the notion that a task that isolates the same mechanisms that it wishes to train should result in an effect of near-transfer (Melby-Lervåg & Hulme, 2013; Sonuga-Barke et al., 2014). Although the *NT* has been described as a robust measure of sustained, selective, and distributed attention, more research is needed to clarify whether these specific task characteristics contributed to the gains in *CPT-3* performance.

In addition, the simplicity of the task is important when training attention with students diagnosed with a neurodevelopmental condition, or other situations when task comprehension is a challenge. Overloading a user's attention by adding a social component, complex scenarios, and lengthy instructions can obstruct learning (Chandler & Sweller, 1996). For example, *CogniPlus* trains divided attention by immersing the user in the role of a security officer who is responsible for detecting threats across multiple sources (Schuhfried, n.d.). This can be problematic for a child diagnosed with ASD, as they struggle with perspective taking and theory of mind (Van Hecke, Oswald, & Mundy, 2016). Distracting the user with superfluous content redirects attention from important information to irrelevant aspects of the task, which may negatively affect transfer. This exemplifies the issue of finding an equilibrium between an engaging task versus an existing, validated psychometric measure. As demonstrated by the *NT*, the specificity and accuracy of this psychometric measure can be accessible to students with a neurodevelopmental condition by adapting to the participant's capability. The transfer effect from the *NT* to *CPT-3* suggests that a non-verbal task with minimal instruction is optimal for children and adolescents with neurodevelopmental conditions.

Like most MOT tasks, the *NT* provides an optimal balance between an empirical and ecological measure of real-world attention (Faubert & Sidebottom, 2012; Scholl, 2009). Specifically, the *NT* is a measure of visual attention that taps into selective, sustained and distributed domains, and these sub-components of attention are critical to classroom functioning. The average student must selectively attend to relevant stimuli while ignoring distractors, as well as sustain and distribute their attention throughout class (i.e., teacher's instructions, worksheet, etc.). It is important to reduce deficits in these domains, as attention is significantly intertwined with learning. For instance, a student's ability to pay attention is a primary predictor of academic achievement (Duncan et al., 2007). It would therefore be worthwhile to explore how the *NT* directly targets attention in the classroom. Then, future research questions can be centered on whether training with the *NT* can transfer to mathematics, reading comprehension, and overall classroom functioning.

There were several important considerations made when designing this study. Similar to other research in the field of cognitive training, this study focuses on the transfer to a single measure of attention instead of multiple measures of attention. We chose the *CPT-3* because it is a stable measure of attention, with a high level of test–retest reliability (Soreni et al., 2009). Furthermore, it is effective for monitoring the progression of performance over the course of treatment (Conners, 2014). Our results show that performance on this measure did not decline in either control group. This suggests that improvements on the *CPT-3* stemmed from the treatment task rather than from the random variance across all three groups (Redick et al., 2015). Although multiple measures would have been more ideal to control for the variability in pre- and post-testing, we are confident that our changes in *CPT-3* performance can be attributed to the *NT* training task because of its sensitivity to detect changes after an intervention (Conners, 2014).

Another important consideration was the careful selection of an active control task. In cognitive training, an active control task is implemented to simulate the same level of engagement as the treatment task. The *NT* and *2048* tasks differ from one another: the *NT* task involves tracking moving objects, while the *2048* task requires the user to complete a math-like strategic puzzle. If we were to equate both tasks, it would be difficult to pinpoint or isolate the effects of *NT* on training attention. By doing so, the research question would become: "What aspects of the *NT* allow for transfer to another measure of attention?" This research question would not explore the added benefit provided to either training group on the outcome measure of specific attentional processes. Instead, the results demonstrate that a task that was designed to specifically target attention and adapt to the participants' capability improved performance on a separate attention-based task, while the control task did not.

In addition to considerations made in terms of design, some consideration could be made in terms of individual differences and their influence on training. Previous research has demonstrated that intelligence can influence training outcomes (Redick et al., 2015) and, specifically, cognitive training benefits individuals with a higher IQ compared to those with a lower IQ (Jaeggi et al., 2011; Rode, Robson, Purviance, Geary, & Mayr, 2014). However, our results demonstrate that IQ scores did not influence cognitive training with *NT* in any meaningful way. It is possible, though unlikely, that the low levels of IQ in our sample, averaging between one and two standard deviations below the general population, may have influenced this finding. Future research could compare the benefits of training between a typically developing sample of participants with an average IQ and an atypically developing sample of participants with lower IQs to understand potential benefits in training gains.

The diversity of neurodevelopmental conditions in our participant sample could be seen as another potential limitation. Our results highlight an improvement in attention in a sample of students diagnosed with various neurodevelopmental conditions. Attention-training studies typically choose to focus on one specific neurodevelopmental condition (i.e., ADHD; Sonuga-Barke et al., 2014), rather than assessing and training cognitive processes in participants with varied neurodevelopmental conditions. This approach is restrictive as it fails to represent the range of needs and heterogeneity of students enrolled in specialized schools, most of which have problems with attention as either a primary or a secondary concern. Incorporating this type of focused approach raises many questions concerning the feasibility and practicality of training programs, and its generalizability as a school-based intervention. In the present study, we established that collectively, participants could successfully train with the *NT* task and demonstrate meaningful progress after each training session. In addition, the near-transfer effect from the *NT* to *CPT-3* further suggests that the task is accessible to all levels of cognitive functioning and is ideal for use in a school that provides specialized services to students with neurodevelopmental conditions.

In conclusion, the present study found an effect of transfer from the 3D-MOT training task (*NeuroTracker*) to the *Conners Continuous Performance Task – 3rd Edition*, a standardized, reliable, and valid measure of attention. This effect of transfer can be attributed to our chosen training task, which was designed to target specific components of attention, adapt to the user's capability and is accessible to students with a wide range of cognitive ability. These findings suggest that the methodology presented here can be used to further explore the relationship between attention training and other validated measures of attention and academics.

CONFLICTS OF INTEREST

JF is the Chief Science Officer at Cognisens Inc., which produces a commercial version of the NeuroTracker used in this study. AB is a scientific adviser for CogniSens Inc., which produces the commercial version of the NeuroTracker used in this study.

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