Evaluation of a School-Based Attention Training Program for Improving Sustained Attention

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ABSTRACT— This study evaluated the impact of a theory-driven cognitive attention training program, *Keeping Score!*, in improving students' sustained attention capacity. Training was based on sustained updating. Students engaged this process by mentally keeping score during an interactive game of table tennis without external aids. Students (9–11 years) were assigned to a 6-week training program ($n = 18$) or an active control ($n = 18$). Assessments of sustained attention/working memory and parent ratings of executive function were completed at pretraining, post-training, and 6-week follow-up. We found no evidence to support the efficacy of training (i.e., there was no statistically significant time × group interaction effects for any outcome). Overall, these findings add to the mixed body of literature supporting the efficacy of cognitive attention training for improving children's attentional capacity. One possibility for why the training program was unsuccessful is perhaps that cognitive attention training may not be sufficient for enhancing sustained attention.

Sustained attention (SA) refers to the endogenous maintenance of alertness and focus over time, particularly in monotonous and repetitive conditions (Robertson, et al., 1997). It influences the efficacy of other attentional functions (e.g., selective attention and divided attention) and cognitive capacity in general (Raz & Buhle, 2006; Sarter, Givens, & Bruno, 2001). In school, the importance of SA for learning has been demonstrated in studies that show an association between students' SA capacity and their academic achievements (Steinmayr, Ziegler, & Träuble, 2010). However, despite its importance, poor SA is a relatively common problem in childhood with as many as 24% of children exhibiting frequent inattention (Döpfner, Breuer, Wille, Erhart, & Ravens-Sieberer, 2009). Attentional problems compromise educational outcomes in students diagnosed with attention deficit hyperactivity disorder (ADHD) and in students not formally diagnosed with the disorder (DuPaul, Gormley, & Laracy, 2014; Rabiner, Murray, Skinner, & Malone, 2010). This evidence highlights the strong need to develop interventions aimed at enhancing settudents' SA capacity.

CURRENT SCHOOL-BASED INTERVENTIONS

School-based interventions for attention problems include intervention strategies targeting behavioral, academic, and self-regulation outcomes (DuPaul et al., 2014). Although these interventions have demonstrated some success in improving students' behavioral outcomes (for review, see DuPaul et al., 2014), none of these interventions are directed at enhancing attentional capacity. If we can increase a student's attentional capacity, then their performance in other areas for which attention is a prerequisite should also improve (e.g., academic achievement). This paper evaluates an attention training program, Keeping Score!, in improving objective measures of SA and the closely related executive function, working memory (WM), in addition to parent ratings of executive functioning behavior.

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ATTENTION TRAINING AS AN INTERVENTION FOR IMPROVING ATTENTION

Cognitive attention training is a promising intervention for enhancing attentional capacity in students (Tang & Posner, 2009). Training provides structured opportunities for exercising aspects of attention using the repetitive practice of a cognitive task designed to exercise brain networks related to attention (Posner, Rothbart, & Tang, 2015). The premise of training is that repetitive practice produces adaptions in the underlying neuroanatomical networks linked to the task, which may strengthen the cognitive function(s) underpinned by the targeted neural network (Kerns, Eso, & Thomson, 1999; Tamm, Epstein, Peugh, Nakonezny, & Hughes, 2013). Brain imaging research that compares neural activation before and after training provides some support for training (e.g., Kim et al., 2009; Sánchez-Pérez et al., 2019). Moreover, given that attention is a core cognitive function that underlies the acquisition of other skills, it is hypothesized that the effects of training may transfer to untrained tasks linked with the trained skill (Peng & Miller, 2016). Research has demonstrated the effectiveness of this type of training in certain cognitive domains such as spatial reasoning in improving both near and far transfer measures (Hawes et al., 2022). However, the extent of far transfer of some training (e.g., WM training) to untrained tasks is a matter of ongoing debate (Shipstead, Redick, & Engle, 2012).

COGNITIVE ATTENTION TRAINING

Table 1 presents a description of attention training programs used to enhance attention in children. As can be seen from the table, several programs have been employed. Most of these programs target "combined attention" (i.e., they aim to improve more than one attentional component). An overview of the results of studies evaluating the impact of these programs is presented in Table 2. The pattern of results regarding the efficacy of attention training is mixed. Some studies have shown that training increases scores on measures of attention (e.g., Kerns et al., 1999; Semrud-Clikeman et al., 1999) and that the effect of training transfers to untrained areas such as ADHD symptomology (e.g., Tamm et al., 2013) and academic achievement (e.g., Kerns et al., 2010; Shalev et al., 2007). However, other studies have found that training does not improve attention (e.g., Rueda et al., 2012; Steiner et al., 2011) and that training does not improve measures of far transfer (e.g., Kirk et al., 2016).

SCHOOL-BASED ATTENTION TRAINING USING NON-DIGITAL GAMEPLAY

Most training programs are digital and require practice of video game-like attention tasks. These tasks can be game-based (use a game) or gamified (use game-like elements such as leaderboards, points, and levels in a non-game context). However, in a school setting, training attention using non-digital gameplay may have many benefits. Non-digital gameplay refers to games (organized play with rules and a goal/challenge; Klopfer, Osterweil, & Salen, 2009) that do not use digital technologies and typically involves physical interaction and the use of tangible objects. Examples of non-digital games include board games, card games, and sports. One benefit of attention training based on this type of gameplay is that school personnel are not restricted by access to digital technologies (e.g., computers, tablets, and software packages). Currently, many schools and classrooms do not have on-demand access to such technologies (von Gillern & Alaswad, 2016). Moreover, interventions based on or embedded into non-digital gameplay can be implemented across different scenarios, and children routinely engage in such activities throughout the school day. Another benefit of this type of training is that children typically enjoy playing these types of games, which can influence their engagement, motivation, and satisfaction with the activity (von Gillern & Alaswad, 2016). Therefore, attention training implemented using non-digital gameplay is likely to be engaging, accessible, and easily implemented in the school environment.

SUSTAINED UPDATING: TRAINING SA BASED ON THE INTERPLAY BETWEEN SA AND WM

Executive functions are a collection of interrelated cognitive processes, which are associated with the prefrontal cortex and underlie goal-directed behavior (Gioia, Isquith, Guy, & Kenworthy, 2015). Numerous processes have been linked with the term, including WM, inhibition, shifting, planning, and attention (e.g., Anderson, 2002; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). SA and WM are closely intertwined executive functions, which work in concert to maintain purposive, goal-directed behavior (Slattery, Ryan, Fortune, & McAvinue, 2022). WM typically refers to the maintenance and manipulation of internal information needed for an ongoing cognitive task. Thus, a key part of WM is the *maintenance* of information in mind. However, the information we store in WM is vulnerable to decay. One mechanism to keep information active and maintained in WM is via a sustained attention 'refreshing' process (Barrouillet, Bernardin, & Camos, 2004; Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Barrouillet, Portrat, & Camos, 2011). Many regard sustained attention as the cornerstone of WM processes and most theories of WM include a sustained attention component. These theories include multicomponent WM (Baddeley, 2000), attention-control WM (Engle, Kane, & Tuholski, 1999), embedded-process WM

Table 1
Description of Attention Training Programs used to Improve Attentional Capacity in Children

Training Program	*Category*	*Type*	*Description*
Tali Train (Kirk, Gray, Ellis, Taffe, & Cornish, 2016; Kirk, Gray, Ellis, Taffe, & Cornish, 2017; Kirk, Spencer-Smith, Wiley, & Cornish, 2021)	Commercial	Combined	Gamified tablet-based training program designed to train sustained, selective, and executive attention using four tasks: a visual search task, a vigilance task, a conflict resolution/interference control task, and a response inhibition task. All tasks were adaptive. An interactive guide provided visual and verbal instructions as well as support and encouragement. There was an inbuilt reward system to encourage motivation.
Pay Attention! (Kerns et al., 1999; Tamm et al., 2010; Tamm et al., 2013)	Commercial	Combined	Face-to-face intervention designed to train sustained, selective, alternating, and divided attention using various visual and auditory sustained, selective, alternating, and divided attention tasks. All tasks were adaptive. Participants received feedback on their performance.
Computerized Progressive Attention Training (Kerns, MacSween, Vander Wekken, & Gruppuso, 2010; Shalev, Tsal, & Mevorach, 2007; Spaniol, Shalev, Kossyvaki, & Mevorach, 2017)	Research	Combined	Computerized training program designed to train sustained attention, selective attention, orienting of attention, and executive attention. The program included four tasks based on tasks known to measure these functions (i.e., Computerized Continuous Performance Task, Conjunctive Search Task, Combined Orienting and Flanker Task and Shift Stroop-like Task). Participants advanced in levels of difficulty according to prespecified criteria. Feedback was included and translated into points earned.
Executive Attention Network Training (Rueda, Checa, & Cómbita, 2012)	Research	Combined	Computerized training program consisted of 11 exercises targeting tracking/anticipatory, attention focusing/discrimination, conflict resolution, inhibitory control, and sustained attention. Exercises were designed to be child friendly and involved playing with a joystick or a mouse. All exercises were adaptive.
How to Improve Your Mental Skills (Navarro et al., 2003)	Research	Sustained attention	The goal of this computerized program was the practice and development of relaxation, attention and concentration skills. The program had two sections: 1) relaxation practice and 2) attention and concentration training. The attention training section included three games with three difficulty levels (easy, moderate and hard).
Attention Process Training (Semrud-Clikeman et al., 1999)	Research	Combined	The program was hypothesized to target focused, sustained, selective, alternating, and divided attention (although this is not reported in the paper). The program consisted of visual and auditory attention tasks. Participants received guidance on the development of effective strategies and goals to improve their performance. Training also included a problem-solving component.
Play Attention (Steiner, Frenette, Rene, Brennan, & Perrin, 2014; Steiner, Sheldrick, Gotthelf, & Perrin, 2011)	Commercial	Sustained attention	This neurofeedback program was designed to train participants to increase beta waves and suppress theta waves while playing computer games. Exercises were adaptive so when the theta-to-beta ratio decreased (i.e., participants exhibited increased attention), the participant progressed onto the next exercise. Immediate feedback in relation to how well the child was paying attention was embedded into the computer program.
Braintrain (Rabiner et al., 2010; Steiner et al., 2011; Steiner et al., 2014)	Commercial	Combined /sustained attention	A commercially available computerized program designed to train cognitive function using various exercises. Steiner et al. (2011, 2014) employed exercises that targeted attention and working memory. Rabiner et al. (2010) employed exercises that trained auditory and visual sustained attention. All exercises were adaptive and included immediate feedback built into the program.
AixTent (Lange et al., 2012; Tucha et al., 2011)	Research	Combined	Computerized training program targeting vigilance, selective attention, and divided attention. Exercises were simple computer games and were adaptive in nature. No specific information (other than the names of exercises) was provided on the nature of the training exercises (i.e., how exercises actually trained attention).

Table 2
Overview of Studies Evaluating the Impact of Attention Training Programs in Enhancing Cognitive Capacity and Functioning in Children

N; *participants; age; % male; country*	*Randomization; groups; training duration*	*Training modifications; setting; assessment stages*	*Objective measures*	*Subjective measures*	*Results, Brief summary of cognitive and behavioral outcomes*
Studies using Tali Train					
Kirk et al. (2016)					
76; intellectual disability and attentional difficulties; 4–11 years; 60%; Australia	Yes; 2 groups—attention training ($n=38$), active control (placebo program; $n=38$); 25 × 20-min sessions over 5 weeks (500 min)	NA; Carried out under the supervision of parent/guardian at home; pretraining, post-training, and follow-up (3 months post-randomization)	**Sustained attention, selective attention, and attention control:** Visearch task and Vigilan task of the Wilding Attention Battery (WATT)	**Behavioral attention:** The Strengths and Weaknesses of ADHD symptoms and Normal behavior scale (SWAN; parent and teacher versions)	Participants in the training group showed significantly greater improvements in selective attention than participants in the control group. These improvements were maintained at follow-up. No improvements were found in sustained attention, attentional control, or inattentive behavior.
Kirk et al. (2017)					
Same as Kirk et al. (2016)	Same as Kirk et al. (2016)	Same as Kirk et al. (2016)	**Cardinality:** Give-a-number protocol (GAN); **informal and formal numerical concepts**: Test of Early Mathematics Ability-Third Edition (TEMA-3); **receptive vocabulary:** Peabody Picture Vocabulary Task-Fourth Edition (PPVT-4); **phonological abilities:** Letter Knowledge and Rhyme Detection subscales of the Phonological Abilities Test (PAT)	**Executive function:** Behavior Rating Inventory of Executive Functioning (BRIEF; parent); **working memory:** Working Memory Scale (WMRS; teacher version); **behavioral/emotional issues:** Developmental Behavior Checklist (parent-rated)	Training did not have an immediate effect on academic skills but improvements in numeracy skills were reported at 3-month follow-up. No improvements were found in ratings of executive functioning, working memory or behavioral/emotional issues.
Kirk et al. (2021)					
107; community sample; 5–9 years; 61.22%; Australia	Yes (randomization at class level); 3 groups—attention training ($n=39$), active control (placebo program; $n=35$) and passive control (education as usual; $n=33$); 25 × 20-min sessions over 5 weeks (500 min)	NA; teachers delivered the training in the classroom; pretraining, post training and 6-month follow-up.	**Visual attention:** Balloon Hunt and Hide & Seek Visual subtests of the Test of Everyday Attention for Children (TEACh-2); **auditory selective attention:** Hide and Seek Auditory (TEACh-2); **sustained attention:** Simple Reaction Time (TEACh-2); **executive attention:** Sustained Attention to Response Task (TEACh-2); **verbal working memory:** Backward Digit Recall subtest of the Automated Working Memory Assessment (AWMA); **visuospatial working memory:** Odd One Out (AWMA); **numeracy:** Test of Early Mathematics Ability-II	**Inattention/ hyperactivity:** SWAN (parent and teacher versions)	At posttest, the training group exhibited reduced inattention and hyperactivity in the classroom compared with controls, and reduced hyperactivity at home compared with no-contact controls. Reduced hyperactivity in the classroom was maintained at follow-up when compared with no-contact controls. No improvements were found on objective tests of attention, working memory or numeracy relative to the active control group.
Studies using Pay Attention!					
Kerns et al. (1999)					
14; ADHD; 7–11 years; 57.14%; Canada	No; 2 groups—attention training group ($n=7$) and active control group (completed computer-based activities; $n=7$); 16 × 30-min sessions over 8 weeks (480 min)	Participants received a small reward after each session; Sessions were conducted after school in the school building or in a laboratory space; pretraining and post-training.	**Freedom from distractibility and planning:** Coding, Digit Span, Mazes subtests of the WISC-III; **auditory sustained attention:** Attention Capacity Test; **sustained/selective visual attention:** underlying task subtests 2, 4, and 14; **visual sustained attention:** children's continuous performance; **impulsivity/executive functioning:** Matching Familiar Figures Test; **inhibition, executive function and selective attention:** Day-Night Stroop Test; **visual–spatial ability:** Hooper Visual Organization Test; **academic efficacy:** age- and grade-appropriate arithmetic problems	**Inattention/impulsivity:** Attention Deficit Disorder Evaluation Scale Home and School Versions (parent and teacher)	The training group demonstrated improvements in aspects of freedom from distractibility/planning, auditory sustained attention, visual sustained attention and selective attention, inhibition, executive function, and selective attention and academic efficiency when compared with controls. No improvements were found in impulsivity/executive functioning (Matching Familiar Figures Test). There were no significant improvements in ratings of inattention/impulsivity. Descriptive statistics for post-training were not reported.

Table 2
Continued

Participants, N; age; % male; country	Groups and duration, Randomization; groups; training duration	Training modifications; setting; assessment stages	Objective measures	Subjective measures	Results, Brief summary of cognitive and behavioral outcomes
Tamm et al. (2010)					
23; ADHD; 8–14 years; NR; United States	No; 1 group—attention training ($n = 23$); 16 × 30-min sessions over 8 weeks (480 min)	Discussed how the targeted attentional skill could be applied at home/school; carried out in a clinic or after-hours school setting by an individual with relevant experience; Pre-training, post training and 9-month follow-up (a total of 9 parents completed the SNAP)	**Fluid reasoning:** Matrix reasoning WISC-IV; **working memory:** Digit Span and Letter-Number Sequencing WISC-IV; **IQ**: Vocabulary and Block Design; **listening comprehension:** Understanding Directions subtest of the Woodcock-Johnson Tests of Achievement-Third Edition (WJ-III); **problem solving:** Tower subtest of the Delis–Kaplan Executive Functioning System (D-KEFS); **inhibition:** Color-Inference subtest of the D-KEFS	**ADHD symptoms:** Swanson, Nolan, and Pelham (SNAP) DSM-IV ADHD Rating Scale (parents, teachers and clinicians); **executive function:** BRIEF (parents and teachers); **impairment:** Clinical Global Impressions (clinicians)	Improvements were reported in fluid reasoning, working memory (Digit Span), and inhibition from pre- to post-training. No other significant improvements were reported for objective measures. A reduction in inattention and hyperactivity was reported (parent and clinician ratings) and these effects were maintained at follow-up (parent ratings). Fewer symptoms were reported on several scales of the BRIEF (parent ratings).
Tamm et al. (2013)					
105; ADHD; 7–15 years; 67.62%; United States	Yes (stratified by gender, ADHD subtype, and medication status); two groups—attention training ($n = 54$) and waitlist control ($n = 51$); 16 × 30-min over 8 weeks (480 min).	Same as (Tamm et al., 2010). In addition, parents were provided with reading materials about the attentional skills being trained and how they could support implementation of the skill at home/school; NR; pretraining and post-training	**Attention:** Sky Search, Score!, Creature Counting, Sky Search DT, Score DT, and Code Transmission subtests of the TEA-Ch (collected for the attention training group only); **fluid reasoning/cognitive flexibility:** Matrix reasoning WISC-IV; **working memory:** Digit Span and Letter Number Sequencing (WISC-IV); **IQ:** Vocabulary and Block Design; **auditory working memory/listening comprehension:** Understanding Directions subtest WJ-III; **Problem solving:** Tower subtest D-KEFS; **inhibition/cognitive flexibility:** Color-Word Interference D-KEFS; **ability to pay attention:** Quotient ADHD system	**Inattention and hyperactivity:** SNAP-IV DSM-IV ADHD Rating Scale (parents, teachers and clinicians); **ADHD behavior:** Behavioral Assessment System for Children (BASC; parents and teachers); **impairment:** Clinical Global Impressions (clinicians); **ability to focus and shift attention:** Attentional Control Scale (participants); **executive function:** BRIEF (parents and teachers)	Participants in the training group showed significant improvements in sustained, selective, and alternating attention from pre- to post-training. The training group reported significantly improved scores on aspects of problem solving compared with the control group. No significant improvements were found any other objective measure. The training group demonstrated significant improvements in inattention and hyperactivity/impulsivity (parent/clinician ratings), attention problems (parent ratings), impairment (clinician ratings), ability to focus and shift attention (self-reported), and several scales of BRIEF (parent ratings) when compared with the control group. There were no improvements in teacher ratings of behavior.
Studies using Computerized Progressive Attention Training (CPAT)					
Shalev et al. (2007)					
36; ADHD; 6–13 years); 83%; Israel	Yes; two groups—attention training group ($n = 20$) or an active control group (played computer games and completed pencil and paper activities); $n = 16$; 16 × 60-min sessions over 8 weeks (960 min).	NA; Sessions (one-to-one) were supervised by a research assistant; pretraining and post-training	**Academic measures:** Passage copying, maths exercises, and reading comprehension (taken from schoolbooks of the relevant grade)	**Inattention and hyperactivity–impulsivity:** Parents' Rating Scale	The training group demonstrated significant improvements in passage copying, reading comprehension, and ratings of inattention compared with the control group.

Table 2
Continued

Participants, N; age; % male; country	*Groups and duration, Randomization; groups; training duration*	*Training modifications; setting; assessment stages*	*Objective measures*	*Subjective measures*	*Results, Brief summary of cognitive and behavioral outcomes*
Kerns et al. (2010)					
12; fetal alcohol spectrum disorder (FASD); 8–15 years; 60%; Canada	No; 1 group—attention training group ($n = 10$); 30.5 (on average) × 30-min sessions over 9.5 weeks (915 min).	Participants received coaching to help reduce frustration, implement successful strategies and develop self-regulation skills; training (one-to-one) took place during the school day with a research assistant/teacher; pretraining and post-training	**IQ:** Kaufman Brief Intelligence Test-Second Edition; **working memory:** Spatial Span task (WISC-III-Neuropsychological Investigation), Children's Size Order task; **distractibility:** Sad and Happy Ghost (Test of Attentional Performance for Children; KiTAP); **divided attention:** Owls task (KiTAP) **Sustained attention:** Ghosts' Ball task (KiTAP), Score! (TEA-Ch); **attentional shifting and flexibility:** Dragons' House task (KiTAP); **alerting, orienting, and executive attention networks:** Attentional Network Test adapted for Children (ANT-C); **academic measures:** WJ-III tests of Math Fluency and Reading Fluency	A short follow-up evaluation questionnaire was administered at post-assessment (no more information was provided).	There were significant improvements in measures of distractibility, sustained attention, reaction time (ANT-C), reading and maths from pre- to post-training (mean scores at pretraining and post-training were not reported). No other significant improvements were reported.
Spaniol et al. (2017)					
15; autism spectrum disorder; 6–10 years; 80%; United Kingdom	Yes (matched for age, gender and intelligence); 2 groups—attention training ($n = 8$) and active control group (played computer games; $n = 7$); 13 (on average) × 45-min sessions over 2 months (585 min).	The CPAT orienting task was not used; Sessions (one-to-one) took place during the school day with a researcher. Pretraining and post-training.	**General ability:** Raven's-educational: Colored Progressive Matrices (CPM); **academic measures:** Tests in maths, reading comprehension and passage copying selected from an online database of tests used by schools in the UK.	**Behavioral symptoms of autism:** Childhood Autism Rating Scale (CARS; completed by teachers)	The training group demonstrated significant improvements in maths and passage copying when compared with the control group. No other statistically significant differences were found between the groups across time.
Studies using Play Attention and Braintrain					
Steiner et al. (2011)					
41; ADHD; mean age = 12.4 years ($SD = 0.9$); 52.2%; United States	Yes; 3 groups—neurofeedback group ($n = 13$), standard cognitive training group (Braintrain; $n = 13$), waitlist control group ($n = 15$); 23.4 (on average) × 45-min sessions over 4 months (1,053 min).	NA; training (administered in groups of two with both practicing either neurofeedback or Braintrain) was delivered during the school day and supervised by research assistants; pretraining and post-training	**Attention:** Integrated Visual and Auditory Continuous Performance Test	**ADHD symptomology:** Cognitive Problems/Inattention scale, Hyperactivity scale and the ADHD Index of the Conners' (parents, teachers, participants); **executive function:** BRIEF (parents and teachers); **Behavioral symptoms:** Hyperactivity and Attention Problems Scales of BASC-2 (parents, participants); **medication:** Usage and dosage	There were no significant improvements in objective measures of attention in either intervention group. The neurofeedback group, standard cognitive training group, and waitlist group all reported improvements in aspects of parent-rated ADHD symptomology. The neurofeedback group demonstrated improvements in aspects of parent-rated ADHD symptomology when compared with the waitlist control group. No improvements were found in teacher ratings for either intervention group from pre- to post-training or when compared with the control. However, the waitlist control demonstrated improvements in teacher-rated executive functioning from pre- to post-assessment.

Table 2
Continued

Participants, N; age; % male; country	*Groups and duration, Randomization; groups; training duration*	*Training modifications; setting; assessment stages*	*Objective measures*	*Subjective measures*	*Results, Brief summary of cognitive and behavioral outcomes*
Steiner et al. (2014)					
104; ADHD; neurofeedback group mean age = 8.4 (*SD* = 1.1), standard cognitive training group mean age = 8.9 (*SD* = 1.0), control group mean age = 8.4 (*SD* = 1.1); 67.31%; United States	Yes; 3 groups—neurofeedback group ($n = 34$), standard cognitive training group ($n = 34$), control (standard community care; $n = 36$); 40 × 45-min sessions over 5 months (1800 min).	Small incentives were provided at the end of each session and a prize at the end of the training period; training (one-to-one or groups of two children) took place during the school day supervised by a research assistant; pretraining and post-training	NA	**ADHD symptoms:** CPRS-3 AND CTRS-3; **executive function:** BRIEF (parents); **impairment related to ADHD:** Swanson, Kotkin, Agler, M-Flynn, and Pelham scale (SKAMP; teachers); **classroom behavior**: Behavioral Observation of Students in Schools (research assistants); **medication status:** Medication Tracking Questionnaire	The neurofeedback group demonstrated improvements over time in parent-rated inattention, aspects of executive functioning, and teacher ratings of classroom behavior compared with the controls. The neurofeedback group demonstrated significant improvements in aspects of parent-rated ADHD symptomology and executive functioning and teacher-rated attention compared with the cognitive training group. The cognitive training group demonstrated no improvements on outcome measures when compared with the control group.
Studies using Braintrain only					
Rabiner et al. (2010)					
77; teacher identified attentional difficulties: first graders (age not reported); 69% male; United States	Yes (randomization done within schools); 3 groups—computerized attention training ($n = 25$), computer assisted instruction (targeted reading and maths skills; $n = 27$), waitlist control ($n = 25$); 28 × 75-min sessions over 14 weeks (2,100 min).	Group rewards were provided for following rules. Students were prompted to evaluate their attentional focus in each session and received praise for concentrating. Sessions (held in groups of 4 to 6) were delivered in the afternoon by research assistants/school staff. Pre-training, post-training, and 6-month follow-up.	**Academic achievement**: Letter-word identification, Word Attack, Calculation, Math Fluency, Reading Fluency, Passage Comprehension and Applied Problems (WJ-III) and the Dynamic Indicators of Basic Early Literacy Skills; **intellectual ability**: Kaufman Brief Intelligence Test, Second Edition (KBIT-2)	**Attention**: DSM-IV Inattentive Scale Conners' Teacher Rating Scale-Revised; **classroom behavior and social–emotional functioning**: Hyperactive–Impulsive, Oppositional, Social Problems and Anxious/Shy of the CTRS-R:L; **daily academic performance**: Academic Performance Rating Scale (teachers)	The attention training group and computer-assisted instruction group were more likely than controls to show a moderate decline in teacher-rated inattention. Intervention effects on the Reading and Maths score on the WJ-III were not significant for either intervention. The computer-assisted instruction group also showed gains in reading fluency (Dynamic Indicators of Basic Early Literacy Skills) and teacher-rated academic performance compared with controls.
Studies using AixTent					
Tucha et al. (2011)					
48; ADHD ($n = 32$), typically developing ($n = 16$); 68.75%; attention training group mean age = 10.8 years (*SD* = 0.4), perception training group mean age 11 years (*SD* = 0.6), typically developing group mean age = 10.7 (*SD* = 0.4); Germany	Yes (children with ADHD assigned to either an attention training or perception training group); 3 groups—attention training ($n = 16$), visual perception training ($n = 16$) and typically developing children ($n = 16$); 8 × 60 min sessions over 4 weeks (480 min).	NA; Training was administered one-to-one (setting not reported); pretraining and post-training (the typically developing group was assessed only once and did not receive any training)	**Tonic and phasic alertness**: Alertness measure of Test Battery for Attentional Performance (TAP); **vigilance**: vigilance measure (TAP); **selective attention:** visual scanning measure (TAP); **divided attention:** divided attention measure (TAP); **flexibility:** alternating flexibility measure (TAP)	NA	The attention training group demonstrated significant improvements in aspects of vigilance, divided attention, and alternating flexibility from pre- to post-training. There were no significant improvements in the perception training group from pre- to post-training. There were significant differences in ipsative scores (represent change from pre- to post-training) between the attention training and perception training groups in aspects of vigilance and divided attention (errors of commission) with the attention training group demonstrating greater change from pre- to post-training.

Table 2
Continued

Participants, N; age; % male; country	*Groups and duration, Randomization; groups; training duration*	*Training modifications; setting; assessment stages*	*Objective measures*	*Subjective measures*	*Results, Brief summary of cognitive and behavioral outcomes*
Lange et al. (2012)					
Same as Tucha et al. (2011)	Same as Tucha et al. (2011)	Same as Tucha et al. (2011)	Same as Tucha et al. (2011) except alertness measures not reported in this study. Errors of omission and errors of commission are the only scores reported for each measure (but only errors of commission reported for flexibility).	Same as Tucha et al. (2011)	The attention training group demonstrated significant improvements in aspects of vigilance, divided attention, and flexibility from pre- to post-training. There were no significant improvements in the perception training group from pre- to post-training.
Studies using How to Improve your Mental Skills					
Navarro et al. (2003)					
155; primary and secondary school students; mean age for males = 12.4 years (*SD* = 0.93) and mean age for females = 12.2 years (*SD* = 1.02); 47.10%; Spain	No; three groups—attention training group (*n* = 51), active control (Tetris computer game; *n* = 53) and passive control (education as usual; *n* = 51); 10 × 20 min sessions (training duration not reported; 200 min)	NA; training (administered in groups of students) took place during the school day (NR who carried it out); Pretraining and post-training	**Attention:** Perception Difference Test (PDT); **continuous attention:** Spatial subtest of the Primary Mental Aptitude (S-PMA)	NA	In the training group, PDT and S-PMA scores significantly improved from pre to post training. Significant improvements were also found from pre to post in the active and passive control group. At post-training, the attention training group demonstrated significant improvements in PDT attention scores compared with the active and passive control groups but there were no differences between the groups in posttest S-PMA scores.
Studies using Attention Process Training					
Semrud-Clikeman et al. (1999)					
54; students with teacher- and parent-identified attentional difficulties (*n* = 33) and typically developing (*n* = 21); 8–12 years; 79.62%; United States	No; three groups—children with attentional difficulties were assigned to an attention training (ADHD intervention; *n* = 21) or a passive control group (ADHD control; *n* = 12). Typically developing controls (*n* = 33) received no intervention; 36 × 60-min sessions over 18 weeks (2,160 min).	NA; Sessions (in groups of 4–5) were held before or after school under the supervision of research assistants (two or three). Pretraining and post-training	**Visual attention (sustained attention, visual scanning, and inhibition)**: d2 test; **auditory attention (divided and sustained attention):** The Auditory Attention Task (Brief Test of Attention)	NA	At pretraining, the ADHD attention training and ADHD control groups demonstrated significantly poorer performance on the visual attention task compared with the typically developing group. At posttest, the ADHD controls performed significantly worse than both groups but there was no significant difference between the ADHD training group and typically developing group. The results for auditory attention followed a similar pattern (although statistics were not reported in full).
Studies using Executive Attention Network Training					
Rueda et al. (2012)					
37; typically developing; 5-year-old children; 54%; Spain	Yes (groups matched by gender, intelligence, and baseline performance on the Attention Network Test; 2 groups—attention training group (*n* = 19) and control group (watched cartoons; *n* = 18); 10 × 45-min sessions over 5 weeks (450 min).	NA; training (one-to-one) took place during the school day with a research assistant; pretraining, post-training, and follow-up (2 months after completion of post-training assessments).	**Impulsivity:** Delay of Gratification task; **decision-making:** Gambling task (simplified version of the Iowa Gambling Task); **General intelligence:** Kaufman Brief Intelligence Test (K-BIT); **Attention:** Attention Network Test (ANT; alerting, orienting and executive attention)	NA	The training group did not demonstrate significant improvements on any of the behavioral outcomes compared with the control group over time (i.e., there were no statistically significant interaction effects).

Note: *N* refers to the number of participants assigned to the training and/or control groups. Primary and secondary cognitive and behavioral outcomes are reported. NA = not applicable, NR = not reported.

(Cowan, 1999), and component-process WM (Eriksson, Vogel, Lansner, Bergström, & Nyberg, 2015). For example, the attention-control theory posits that WM is not really about storage per se, but about the "capacity for controlled, sustained attention in the face of interference and distraction" (Engle et al., 1999, p. 104). According to this model and others (e.g., component-process WM), SA is required to actively maintain information in WM. SA, the ability to sustain mindful, conscious processing of task-relevant stimuli, supports the maintenance of information stored in WM by continually refreshing or activating its contents in order to pursue goal-directed activity. Neuroimaging studies provide support for this association, indicating that SA and WM rely on overlapping brain areas, with both functions related to increased activation in frontal and parietal regions (Eriksson et al., 2015; Robertson & Garavan 2004). Moreover, SA and WM show a close association at a behavioral level, demonstrating moderate to strong positive correlations (e.g., Buehner, Krumm, Ziegler, & Pluecken, 2006; McVay & Kane, 2009; Schweizer & Moosbrugger, 2004). However, it is important to acknowledge the task impurity problem in relation to the measurement of executive functions, particularly SA and WM. That is, the measurement of SA can include systematic variance attributable to WM (or vice versa), which can make it difficult to accurately measure one's variable of interest. However, this is the case for the measurement of all executive functions (Miyake & Friedman, 2012).

Given the close theoretical association between SA and WM, we designed a training mechanism (called sustained updating) to enhance SA. The mechanism was based on participants using their SA to continually activate or maintain the information held in WM. That is, the training mechanism required SA to maintain the contents of WM via refreshing. The attention training program evaluated here—Keeping Score!—required students to continually engage this training mechanism over sustained periods of time by mentally 'keeping score' during an interactive game of table tennis without external aids. WM is required to store and update the score of the game, while SA is required to actively maintain the score in mind (via refreshing) to prevent it from being forgotten. The training program therefore targets both SA and WM; however, our primary focus is SA enhancement. Table tennis was chosen as one possible implementation of the training mechanism. One advantage of this training mechanism is that it could be incorporated into any game, which involves keeping score. If this training is effective, future research could test the training mechanism in other forms of gameplay (e.g., mentally keeping score during a card game), and it could potentially be incorporated into these games throughout the school day in order to provide frequent opportunities to practice SA. In line with the theoretical foundations of attention training, we hypothesized that the attention training group would demonstrate improvements in SA capacity (primary outcome), WM capacity (secondary outcome), and ratings of executive functioning (i.e., behavioral regulation, emotion regulation, cognitive regulation, and global executive function; secondary outcomes) compared with the control group.

METHOD

The study was granted ethical approval by the relevant research ethics committee. We report how we determined our sample size, all data exclusions (none), all manipulations, and measures (Simmons et al., 2012).

DESIGN

This was a cluster-randomized controlled pilot study. Classes were randomly allocated to the training or control group based on class groups (three class groups of fourth-class students and one class group of fifth-class students) using an Excel function. Randomization was done at the class group level to ensure that participants were naïve to group allocation and for practical reasons (e.g., taking groups of students out of class at the same time). Enrolment and randomization to groups were carried out by the first author.

PARTICIPANTS AND SELECTION

Participants were typically developing children with lower attentional ability identified through a previous study on the cognitive predictors of academic achievement in Irish primary school children (Slattery, Ryan, Fortune, & McAvinue, 2021; $N = 104$). Fourth- and fifth-class students (9–11 years) were invited to participate based on their SA score ($n = 64$), as measured by a composite score on the Fixed Sustained Attention to Response Task (SART; Manly et al., 2003; Robertson et al., 1997). In the Fixed SART, the numbers 1–9 individually appear on screen in ascending order. Participants are required to press the spacebar for every number that appears (go trial) except for the number 3 (no-go trial). Three measures from the SART (errors of commission, errors of omission, and reaction time standard deviation) were averaged after standardization (raw scores were converted to z scores with a mean of 0 and *SD* of 1) to compute a composite SA score (for more information, see Slattery et al., 2021). Those with the lowest scores were invited first followed by the next lowest until the end of the recruitment period. This was done to recruit children with lower, rather than higher, attentional ability. The composite

SA scores of participants who took part in this study ranged from −0.24 to 0.71 ($M = -0.48$, $SD = 0.82$). SA scores in the previous study ranged from −0.26 to 1.05 ($M = 0.00$, $SD = 0.84$). Students were eligible to participate if parents provided informed consent and children gave written informed assent (see Figure 1 for participant flowchart). At the end of the recruitment period, the final sample comprised 36 participants aged from 9.60 to 11.77 years ($M = 10.35$, $SD = 0.63$).

Demographic characteristics are presented in Table 3. Groups were matched on all variables except for age, $t(21.01) = 3.52$, $p = .002$. The participants in the control group were significantly older than the participants in the training group. Note, the participants were matched on all outcome variables at baseline (see Section 16).

SAMPLE SIZE

We planned for a sample size of 60 to meet the recommendation of 20 observations per group to assess the impact of training (Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015). The sample size was smaller because of slow recruitment. A subsequent power analysis (calculated with G*Power 3; Faul, Erdfelder, Lang, & Buchner, 2007) with a medium effect size (partial eta squared = 0.06) and power of .8 indicated that the minimum sample required to detect a significant time × group interaction effect was 28. A revised sample size of 36 (18 participants in each group) was targeted to detect a medium effect and account for dropouts. A medium effect size was chosen as opposed to a small effect size given that the training was designed to be

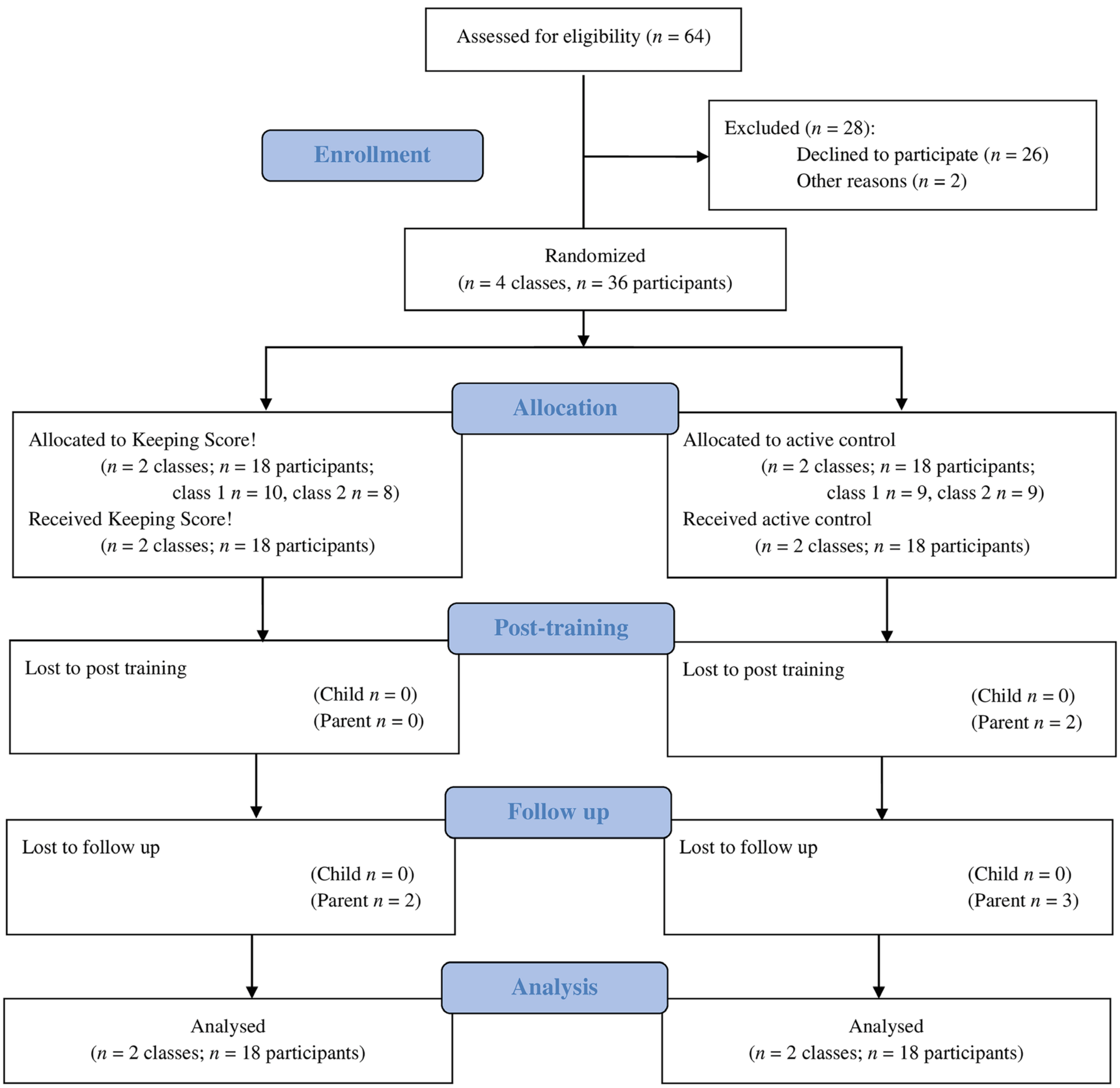

Fig. 1. CONSORT flow diagram. Parents were lost because of failure to return the behavioral rating scale.

Table 3
Demographic Characteristics

	Training	*Active control*
Age (*M*, *SD*)	10.03 (.25)	10.67 (.73)
Gender		
Male	9 (50%)	9 (50%)
Female	9 (50%)	9 (50%)
Nationality (*n*)		
Irish	17 (94.4%)	16 (88.9%)
Dual nationality	1 (5.6%)	1 (5.6%)
Other	0	1 (5.6%)
Special educational needs (*n*)		
No diagnosis	17 (94.4%)	16 (88.9%)
ADHD	1 (5.6%)	0
Autism	0	1 (5.6%)
Dyslexia	0	1 (5.6%)
Comorbidity (*n*)		
No comorbid diagnosis	18 (100%)	17 (94.4%)
Comorbid diagnosis[a]	0	1 (5.6%)
Maternal educational level (*n*)		
Junior Certificate or equivalent	2 (11.1%)	3 (16.7%)
Leaving Certificate or equivalent	3 (16.7%)	1 (5.6%)
Diploma or Certificate	6 (33.3%)	9 (50%)
Primary Degree	2 (11.1%)	0
Postgraduate Degree	2 (11.1%)	3 (16.7%)
Missing Data	3 (16.7%)	2 (11.1%)
Fixed SART Selection Variable (*M, SD*)	−.2079	−.4895

[a] One participant had a comorbid diagnosis of autism and dependent personality disorder. Missing data was because of non-complication.

used in a school context. Our rationale was that a medium effect size would justify the necessary investment of time and resources required to implement the training in schools.

TRAINING GROUP

The training was based on real-world gameplay and delivered face-to-face in groups of three participants. The participants played a game of table tennis for 15 min with two players and one spectator (see Figure 2). The game was played as normal with one point awarded to the player for every score achieved. All 3 players, including the spectator, were asked to keep the score of the game in their minds during each 5-min round. At the start of each session, the participants were told that they had two objectives (1) to play and win the game and (2) to silently keep the score of the game. The researcher watched the game, called out the name of the child who scored each point (to avoid confusion), and accurately kept score, using a notepad. At the end of every round, the researcher paused play and asked each child to write down the score they were holding in their mind. The researcher then revealed the true score, asked the participants to swap roles, and commenced another round. The physical and social aspects of the game were employed to enhance motivation. We chose to rotate roles based on the social design principles of gameplay to foster engagement with the activity (e.g., Plass, Homer, & Kinzer, 2015) and our goal to establish a fun game/play environment, which incorporated practice of the training mechanism.

ACTIVE CONTROL GROUP

The control group was the same as the training group, except for the core training mechanism; children were not required to mentally keep score (see Figure 3). The researcher kept score by continually calling out the updated score as each point was won. The spectator was simply told to wait their turn. In this study, this control group was matched to the training group in every way except for the sustained updating element. As such, it provided a robust test of the training mechanism.

OUTCOME MEASURES

Primary Outcome Measures

Test of Everyday Attention for Children—Second Edition (TEA-Ch2; Manly et al., 2016)

The primary outcome measure was SA assessed using the TEA-Ch2. Vigil, Cerberus, and SART subtests were employed. The participants were required to count slow, irregularly paced auditory stimuli during the Vigil subtest. The outcome variable was the total number of correctly recalled stimuli. For the Cerberus subtest, the participants listened to short clips and pressed the spacebar as quickly as possible when they heard a bark (target auditory stimulus) while ignoring other sounds. The outcome variable was mean reaction time in msecs weighted for accuracy. For the SART, the participants were asked to press the spacebar for every shape that appeared on screen but to withhold their response on the appearance of a triangle. The outcome variable was errors of commission. Scaled scores adjusted for age and sex were used. These subtests have adequate reliability and validity (Manly et al., 2016) and have been widely used to measure sustained attention in children and adolescents (e.g., Chamorro & Janke, 2022; Hellebrekers et al., 2022; Kirk et al., 2021; Muggli et al., 2021).

Secondary Outcome Measures

Wechsler Intelligence Scale for Children—Fifth Edition (WISC-V; Wechsler, 2014)

Digit Span Forward was used to assess short-term memory. The participants were asked to repeat a dictated

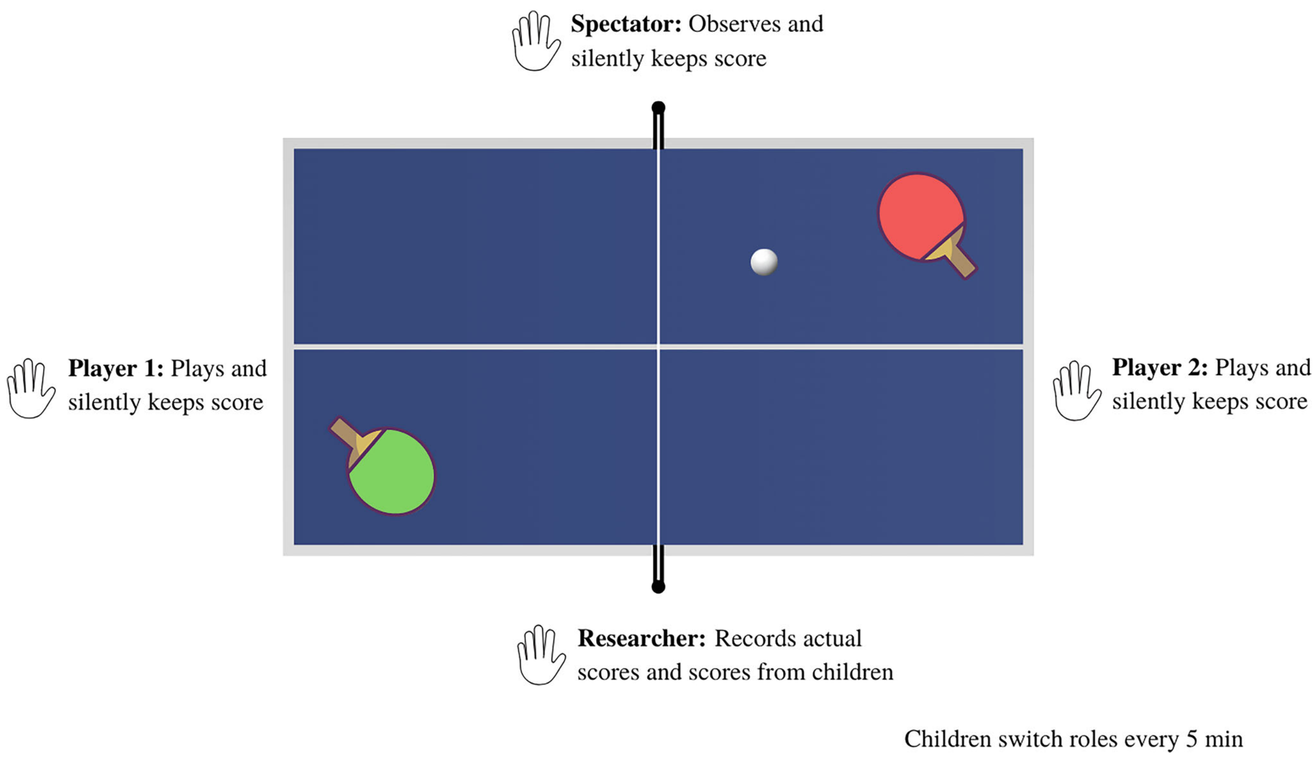

Fig. 2. Graphic representation of the training group.

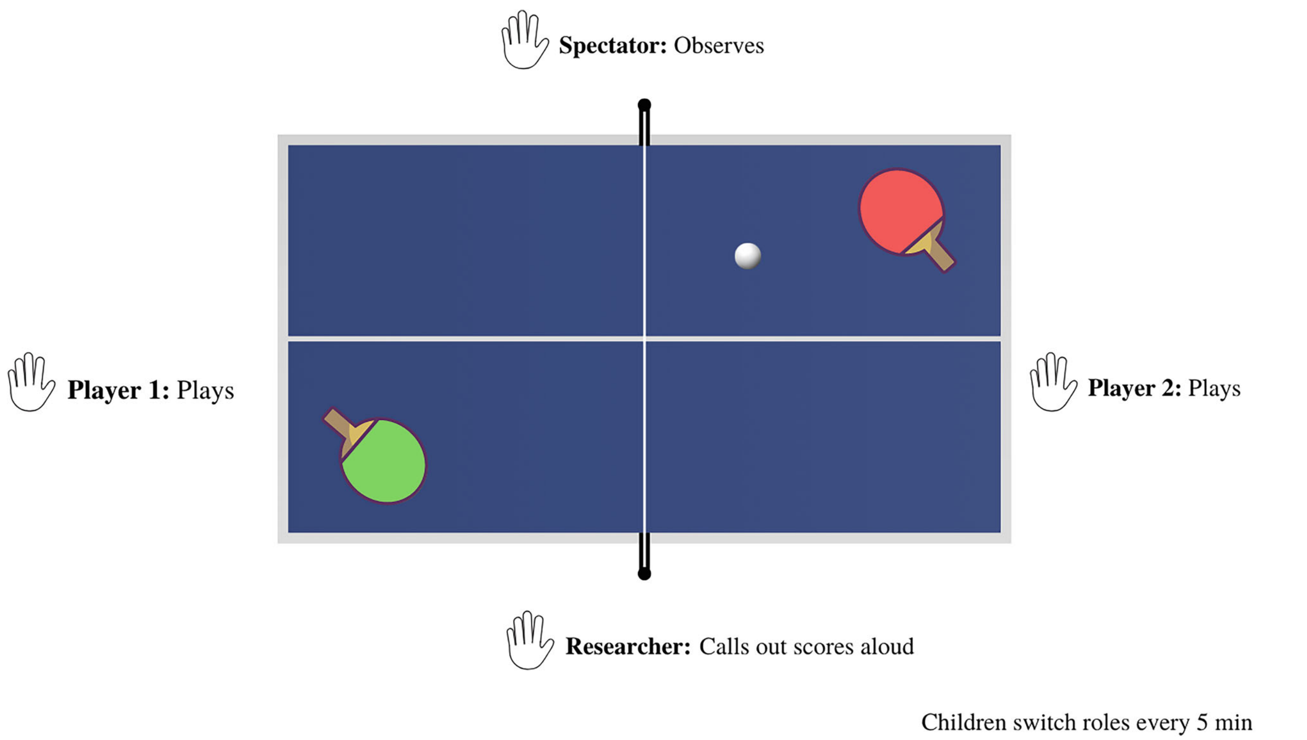

Fig. 3. Graphic representation of the control group.

string of numbers in the same order. Digit Span Backward was used to measure WM. The participants were asked to repeat a dictated string of numbers in reverse order. The total raw score was used as the outcome variable for both measures.

Adaptive Composite Complex Span (ACCES; Gonthier, Aubry, & Bourdin, 2018)
The ACCES measures WM capacity in children. The task comprises computerized verbal and visuospatial subtests. We used the Operation Span and Symmetry Span subtests. The Operation Span subtest required participants to decide whether mathematical operations were correct while memorizing letters. The Symmetry Span subtest required participants to remember spatial locations while deciding whether geometric shapes were symmetrical. At the end of a trial, the participants had an unlimited amount of time to recall the to-be-remembered items in serial order. The participants completed six trials for each subtest. The number of problem-stimulus pairs within a trial varied between two and eight. The total number of stimuli correctly recalled by participants was used as the outcome variable for each subtest.

Behavior Rating Inventory of Executive Function—Second Edition (BRIEF-2; Gioia et al., 2015)
Parents completed the BRIEF-2 assessing executive functioning. The Parent Form contains 63 items rated on a three-point Likert scale. T-scores (adjusted for age and sex) were calculated for the Behavioral Regulation Index, Emotion Regulation Index, Cognitive Regulation Index, and Global Executive Composite.

OTHER MEASURES

Manipulation Check
After the training, the participants in the training group rated the extent to which they engaged with training, “When you were taking part in Keeping Score!, were you trying hard to keep track of the scores in your mind?”, on a scale ranging from 1 (almost never) to 4 (always). On average, participants scored 3.22 ($SD = 0.54$) indicating that participants engaged with training. This measure was administered in the intervention group only.

Training Performance
A performance score was recorded for those in the training group by calculating the discrepancy between the true or actual score and the score given by the participant.

PROCEDURE

All the participants received 15-min sessions, three times a week for 6 weeks (18 sessions) during class time (total training duration 270 min). Training duration and intensity was based on previous literature (e.g., Tullo et al., 2018). Tullo et al. (2018) reported positive effects of training on sustained attention following 15 7-min sessions over a five-week period (total duration 105 min). In this study, assessments occurred at baseline, post-training and an approximate 6-week follow-up. Assessments were individually administered in single sessions in the following order: Vigil (TEA-Ch2); Cerberus (TEA-Ch2); SART (TEA-Ch2); Digit Span Forward (WISC-V); Digit Span Backward (WISC-V); Symmetry Span (ACCES); and Operation Span (ACCES). Testing and training took place in the school and were carried out by the same researcher who was aware of group allocation.

STATISTICAL ANALYSIS

All analyses were conducted using R version 4.0.2 (R Core Team, 2020). Data and full reproducible analysis code are available on the OSF (https://osf.io/nfvuz/). Independent samples *t*-tests and chi square tests were performed to determine whether there were any significant differences between the groups on outcome measures at baseline. Second, to examine whether Keeping Score! improved performance on neuropsychological measures and behavior ratings, we ran a series of 2 × 3 mixed analyses of variance (ANOVAs), with one between-subjects factor, group (training, control), one within-subjects factor, time (baseline, posttest and 6-week follow-up), and one covariate, participant age (non-age-standardized measures only), for each measure. Generalized eta squared was used as a measure of effect size (Bakeman, 2005). This measure of effect size is comparable across commonly used research designs in psychology and education (Olejnik & Algina, 2003). According to Lakens (2013), generalized eta squared can be interpreted in line with Cohen's benchmarks (small = 0.01, medium = 0.06 and large = 0.14) and related to other effects in the literature for comparison. ANOVAs were calculated using the afex package (Singmann et al., 2020).

RESULTS

Preliminary Analyses
Analyses were undertaken to check the assumptions of normality and homogeneity of variances. All indicators suggested that data were within recommended guidelines (see Appendix A; Table A1).

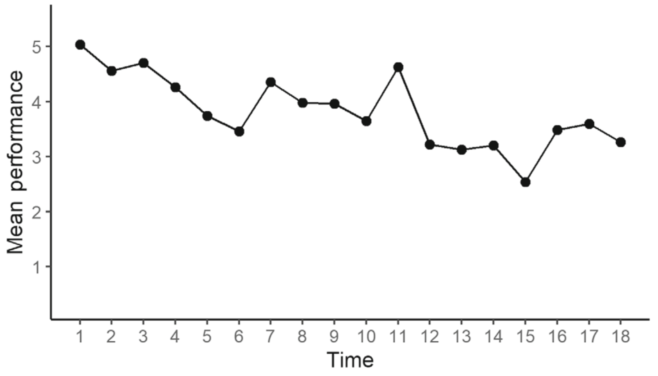

Fig. 4. Average discrepancy between the true score and child's score over time. This graph depicts the discrepancy between the actual or true score (recorded by the researcher) and the score children were holding in mind over the 18 sessions. Lower scores indicate higher accuracy.

Compliance

There was variability in the number of weekly sessions completed and the time taken to complete all sessions because of absence from school. Most participants (69%) completed the program in 6 weeks, while 28% completed it within 7 weeks and a further 3% ($n = 1$) completed it within 8 weeks. The average number of weekly sessions was 2.87 ($SD = 0.21$; range = 0 to 4). There were no significant differences between the training ($M = 6.39$, $SD = 0.61$) and control groups ($M = 6.28$, $SD = 0.46$) in the average number of weeks taken to complete the program $t(34) = 0.618$, $p = .541$.

Training Performance

Figure 4 depicts the discrepancy between the actual or true scores and the scores children were holding in mind over the 18 sessions. Lower scores indicate higher accuracy. The discrepancy tends to decrease over time, suggesting students' ability to keep score improved during the training period. The average score that students were required to keep track of in each round was 29 points ($SD = 2.9$, range = 23–33.7).

Differences Between the Groups at Baseline

A series of independent samples t-tests were used to examine whether there were any significant differences between the groups on outcome measures at baseline. No significant differences were found (see Table 4).

Primary Outcome Measures

Mixed ANOVAs were used to examine the intervention effect on each SA measure. Table 5 presents the results for each cognitive outcome measure. Across all SA outcome measures, there was no significant time × group interaction effect; all $ps > .05$). Two significant main effects were found. For Cerberus, there was a significant main effect of time. Compared with baseline, scores were significantly higher at posttest, $t(35) = 2.71$, $p = .011$, and follow-up, $t(35) = 3.23$, $p = .003$. For the SART, there was a significant main effect of group. The training group had a higher mean score compared with that of the control group. Figure 5 graphically represents the results of each SA outcome.

Secondary Outcome Measures

Mixed ANCOVAs controlling for age were used to evaluate the impact of the intervention on short-term memory and WM. Age was controlled for, as the measures did not account for age. There was no significant main effect of age or no significant time × age interaction effect on any outcome (all $ps > .05$; see Figure 6). There were significant main

Table 4
Group Differences on Outcome Measures at Baseline

Outcome	*Training*, M (SD)	*Control*, M (SD)	*Test of difference*
Sustained attention			
Vigil	10.28 (2.70)	9.61 (2.83)	$t(34) = 0.723$, $p = .474$
Cerberus	10.67 (3.99)	10.67 (4.34)	$t(34) = 1.96$, $p = .062$
SART	9.94 (1.43)	8.11 (3.69)	$t(34) = 0.000$, $p = 1.00$
Short-term/WM			
Forward Span	8.56 (2.09)	8.56 (2.04)	$t(34) = 0.000$, $p = 1.00$
Backward Span	8.17 (2.36)	7.78 (1.99)	$t(34) = 0.535$, $p = .596$
Operation Span	17.39 (5.55)	17.56 (5.16)	$t(34) = 0.093$, $p = .926$
Symmetry Span	11.06 (3.73)	11.44 (3.07)	$t(34) = 0.341$, $p = .735$
Ratings of Executive Function			
Behavioral Regulation Index	52.18 (13.52)	49.46 (11.73)	$t(33) = 0.502$, $p = .619$
Emotional Regulation Index	56.35 (13.00)	53.38 (12.95)	$t(33) = 0.519$, $p = .607$
Cognitive Regulation Index	51.81 (11.19)	50.93 (11.74)	$t(33) = 0.020$, $p = .984$
Global Executive Composite	54.44 (12.41)	51.77 (12.72)	$t(33) = 0.358$, $p = .723$

Table 5
Scores on Objective Measures for the Training and Control Groups and Factorial ANOVA Results

SA		n	*Baseline* M	SD	*Posttest* M	SD	*Follow-up* M	SD	*Time effect* df	F	p	η^2_G	*Group effect* df	F	p	η^2_G	*Group × time* df	F	p	η^2_G
Vigil	T	18	10.28	2.70	9.56	2.64	9.11	3.68	2, 67.83	1.20	.308	0.016	1, 34	0.38	.543	0.006	2, 67.83	0.14	.871	0.002
	C	18	9.61	2.83	8.89	3.95	9.00	2.93												
Cerberus	T	18	10.67	3.99	11.83	3.79	13.22	4.14	1.84, 62.58	6.33	**.004**	0.060	1, 34	0.00	.986	<0.001	1.84, 62.58	0.40	.652	0.004
	C	18	10.67	4.34	12.44	2.98	12.67	3.71												
SART	T	18	9.94	1.43	11.06	2.53	10.39	2.66	1.65, 56.03	3.18	.058	0.026	1, 34	5.48	**.025**	0.103	1.65, 56.03	1.09	.332	0.009
	C	18	8.11	3.69	8.83	2.55	9.33	2.14												
STM/WM																				
FS	T	18	8.56	2.09	9.00	1.94	9.39	2.00	1.98, 65.34	7.72	**.001**	0.041	1, 33	0.21	.652	0.005	1.98, 65.34	0.10	.907	<0.001
	C	18	8.56	2.04	9.44	2.57	9.78	2.02												
BS	T	18	8.17	2.36	9.17	2.09	8.44	2.64	1.81, 59.84	2.99	.063	0.030	*1, 33*	0.16	.690	0.003	1.81, 59.84	0.65	.509	0.007
	C	18	7.78	1.99	8.50	1.54	8.56	2.06												
OS	T	18	17.39	5.55	18.94	4.17	18.56	4.73	1.78, 58.81	2.65	.085	0.018	1, 33	0.34	.565	0.008	1.78, 58.81	0.56	.555	0.004
	C	18	17.56	5.16	18.83	4.82	18.78	4.85												
SS	T	18	11.06	3.73	12.17	3.43	14.39	3.57	1.97, 65.08	13.02	**< .001**	0.148	1, 33	1.35	.254	0.022	1.97, 65.08	0.82	.442	0.011
	C	18	11.44	3.07	14.33	3.97	15.56	4.63												

Note: Mean scores of the training and control groups on measures of sustained attention, short-term memory, and working memory from baseline to 6-week follow-up and factorial ANOVA results. BS = Backward Span; C = control group; FS = Forward Span; OS = Operation Span; SS = Symmetry Span; SA = sustained attention; STM = short-term memory; T = training group; WM = working memory. Statistically significant p values are denoted in bold font.

effects of time for two measures. For the Digit Span Forward, compared with baseline, scores were significantly higher at posttest, $t(35) = 2.55$, $p = .015$, and follow-up, $t(35) = 3.60$, $p = .001$). For the Symmetry Span task, scores significantly improved from baseline to posttest, $t(35) = 2.92$, $p = .006$, baseline to follow-up, $t(35) = 4.97$, $p < .001$, and posttest to follow-up, $t(35) = 2.36$, $p = .024$. For parent ratings of executive functioning, there was no significant time × group interaction effect, nor any main effect of time or group for any measure (see Table 6; Figure 7).

Sensitivity Analysis

We reran all models excluding participants diagnosed with neurodevelopmental disorders ($n = 3$) to examine whether their inclusion impacted the results. Similar to the main analyses, there were no statistically significant time × group interaction effects (see Appendix B; Table B1).

DISCUSSION

Currently, there is no attention training program widely used in schools to improve students' SA capacity. This study examined the efficacy of a school-based attention training program, Keeping Score!, in improving students' SA. Training required students to keep score mentally during an interactive game without external aids. The training mechanism employed (sustained updating) was based on the close theoretical association between SA and WM. Throughout training, SA was required to actively maintain the score of the game in mind via refreshing the contents of WM, while WM was required to store and update the score. The training group did not demonstrate statistically significant improvements in objective measures of SA, short-term memory, and WM or parent ratings of executive functioning relative to an active control group. These findings further add to the mixed body of literature regarding the efficacy of attention training in improving students' attentional capacity. The first part of this discussion addresses potential explanations for our null results, followed by an examination of whether SA capacity can be trained using cognitive attention training and other popular training approaches in an effort to understand our results.

Potential Explanations for our Null Results

There was some evidence that students improved on the training task over the training period; however, training effects did not transfer to other SA or WM tasks. There are various accounts that could be offered to explain the null findings. Explanations relating to the parameters of the training program include (1) the training mechanism may have become obscured within the gameplay context, (2)

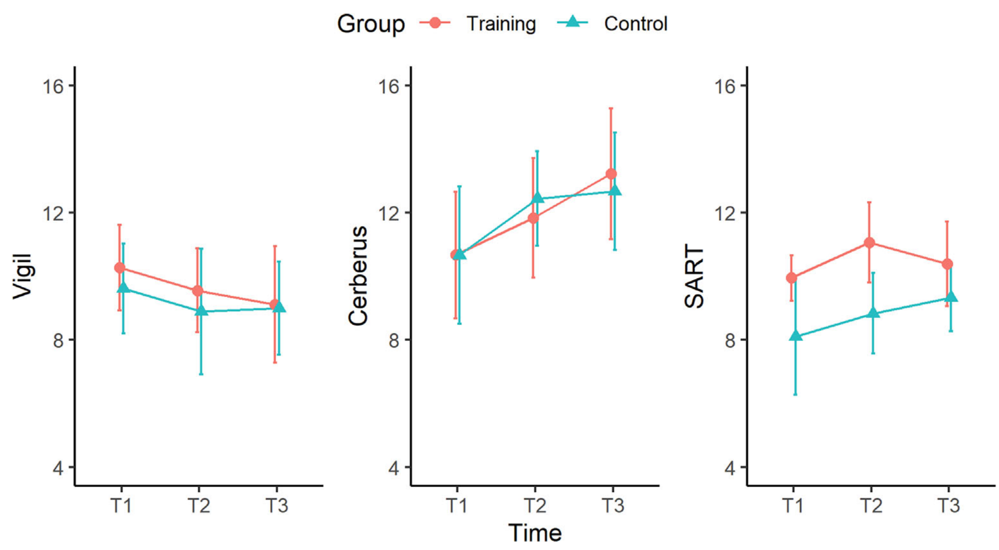

Fig. 5. Sustained attention scores for the training and control groups. Mean Vigil (total correct), Cerberus (mean reaction time in msecs weighted for accuracy), SART (no-go trial responses) scaled scores for the training group and control group at each assessment session. Error bars represent 95% confidence intervals.

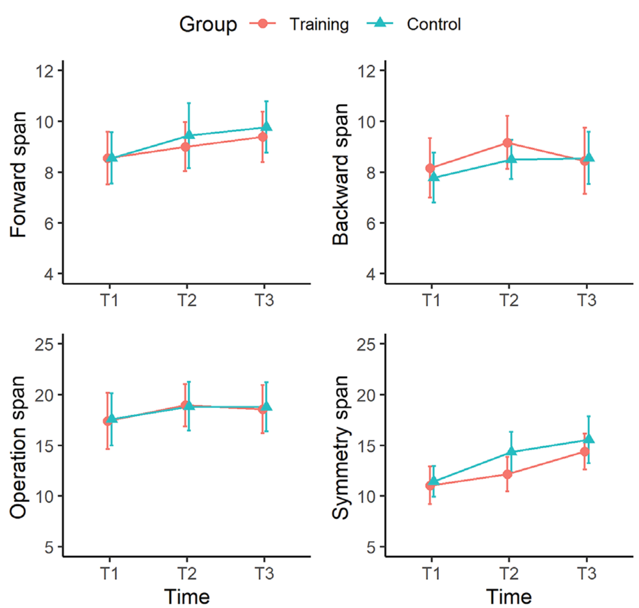

Fig. 6. Short-term memory and working memory scores for the training and control groups. Mean short-term memory and working memory scores for the training group and control group at each assessment session. Error bars represent 95% confidence intervals.

impure training in SA, (3) relatively low training duration, and (4) consistent level of task difficulty throughout the training period. First, it is possible that the training context (i.e., playing the game and rotating roles) was too complex and the training mechanism (i.e., keeping score) got lost. As such, children did not actually engage the training mechanism during training and, thus, did not practice sustaining their attention. However, our engagement measure administered after the training period showed that overall children did engage with the training. Nonetheless, an alternative individual-based gameplay context that incorporates the mechanism such as a card game may have been better. This is because table tennis requires players to engage a range of physical skills (e.g., hand eye coordination) and demands a high level of physical exertion as they play the game, whereas a card game does not typically require such physicality. Future research should consider the complexity of the gameplay situation. Second, the training context required participants to divide their attention (i.e., play the game and practice the training mechanism). It is possible that it would have been better to train SA in a purer context (i.e., a training context where the sole focus is on the specific training task or activity without any additional tasks that may distract participants such as an individual-based activity that does not incorporate complex gameplay with physical and social aspects); however, the current training context was employed to continually challenge participants' ability to sustain their attention. Third, the training program had a relatively short training duration (270 min) compared with other programs (see Table 2). While this training duration was based on previous literature (e.g., Tullo et al., 2018), a longer training duration may have been required for training effects to transfer. However, it is worth noting that many training programs with longer durations have found no improvements in SA following training (e.g., Kirk et al., 2016). And fourth, according to Diamond and Lee (2011), for training to result in improvements in outcome measures, it is crucial to challenge participants by increasing the difficulty level over the course of training. The present training did not increase in difficulty, but the

Table 6
Scores on Subjective Measures for the Training and Control Groups and Factorial ANOVA Results

Ratings		n	*Baseline* M	*Baseline* SD	*Posttest* M	*Posttest* SD	*Follow-up* M	*Follow-up* SD	*Time effect* df	*Time effect* F	*Time effect* p	*Time effect* η^2_G	*Group effect* df	*Group effect* F	*Group effect* p	*Group effect* η^2_G	*Group × time* df	*Group × time* F	*Group × time* p	*Group × time* η^2_G
BRI	T	17	52.18	13.52	51.41	11.53	54.53	12.92	1.63, 45.65	1.96	.159	0.008	1, 28	0.04	.850	0.001	1.63, 45.65	1.30	.279	0.005
	C	13	49.46	11.73	53.15	15.66	52.85	14.93												
ERI	T	17	56.35	13.00	54.24	9.22	57.41	12.66	1.91, 53.53	0.81	.444	0.006	1, 28	0.14	.710	0.004	1.91, 53.53	0.29	.740	0.002
	C	13	53.38	12.95	54.15	14.19	55.69	15.88												
CRI	T	16	51.81	11.19	54.25	10.85	54.13	11.32	1.61, 43.39	3.28	.057	0.010	1, 27	0.12	.727	0.004	1.61, 43.39	1.33	.271	0.004
	C	13	50.93	11.74	50.85	11.05	54.08	12.93												
GEC	T	16	54.44	12.41	55.50	11.49	56.56	12.75	1.64, 44.24	2.04	.150	0.007	1, 27	0.28	.603	0.009	1.64, 44.24	0.11	.854	<0.001
	C	13	51.77	12.72	52.62	13.56	54.85	15.14												

Note: Mean scores for the training and control groups on the main indices of the BRIEF-2 as rated by parents from baseline to 6-week follow-up and factorial ANOVA results. BRI = Behavioral Regulation Index; CRI = Cognitive Regulation Index; ERI = Emotional Regulation Index; GEC = Global Executive Composite. Missing data is because of non-completion.

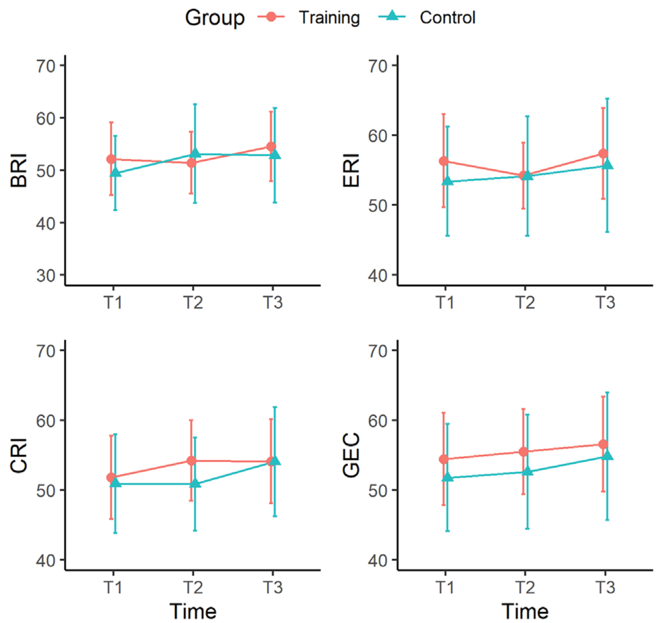

Fig. 7. Parent ratings of executive functioning for the training and control groups. Mean parent ratings of executive function for the training group and control group at each assessment session. BRI = Behavior Regulation Index; CRI = Cognitive Regulation Index; ERI = Emotion Regulation Index; GEC = Global Executive Composite. Error bars represent 95% confidence intervals.

training task itself consistently posed a challenge to participants, as evidenced by participants not reaching ceiling performance in accurately keeping score.

It is also necessary to acknowledge that our training mechanism may not have actually trained SA. The training mechanism was built upon our theoretical understanding of SA, and its close theoretical association with WM. Thus, the validity of the training mechanism depends on the validity of our theoretical assumptions. As previously discussed, training exercised SA by requiring participants to maintain the score in mind via refreshing the contents of WM. However, recent research conducted by Tsukahara and Engle (2023) found that SA (assessed using a novel task) was not related to differences in WM capacity. This challenges the notion that the maintenance of information in WM is dependent on SA. To explain their findings, the authors propose based on previous research that the maintenance of information in WM may be because of differences in encoding information or the retrieval of information from long-term memory. Nevertheless, it is important to note that this research is in its early stages, and further research is needed to understand fully the role SA plays in the maintenance of information in WM.

Other explanations for our null results include our outcome measures not being sensitive enough to detect training effects and our limited power to detect a small effect size because of the study's small sample size. The outcome measures or tasks we employed are valid and reliable measures of SA and WM, which are widely used in the literature, so in our view, this explanation seems unlikely. In many ways, the finding that effects did not transfer is not totally unsurprising given that in the cognitive training literature, researchers typically agree that repetitive practice of a task leads to improvements in that same task, but the extent of transfer to other tasks is a matter of debate (Katz et al., 2018). This pattern was evident in the current study with respect to participants improving on the training task but not demonstrating transfer to other tasks. The study also had a small sample size, which is a limitation. As previously mentioned, we had enough power to detect a medium effect size but did not have enough power to detect a small effect size as statistically significant. However, our descriptive statistics indicated no trends in terms of the training group improving more than the control group. A consideration for future research may be that the effect could have been potentially increased by adjusting training factors such as increasing the length of the training program or using a sample of participants with established sustained attention deficits (e.g., students diagnosed with ADHD) who had the greatest room for sustained attention improvement (Diamond & Lee, 2011). An additional weakness of this study was the difference between the training and control groups in terms of age. The participants in the control group were older than the participants in the training group. Note, these differences were accounted for statistically with age-standardized tests and the inclusion of age as a covariate in non-age-adjusted measures.

Another reason for why the training program did not work is that cognitive attention training may not be sufficient for improving SA. This explanation should be considered given the lack of consistent success of attention training programs in improving SA capacity. At any given moment, one's capacity to sustain attention is influenced by arousal (e.g., wakefulness, sleep quality, and circadian rhythm), motivation (e.g., intrinsic interest or extrinsic reward), emotional (e.g., stress, anxiety, and depression) and cognitive factors (e.g., cognitive control; McAvinue et al., 2015). Thus, our capacity to sustain attention is largely determined by 'in the moment factors' such as wakefulness, which are not targeted by cognitive attention training programs. At a neural level, sustained attention is predominantly linked to a right lateralized network, including the frontoparietal network, the salience network, and the default mode network. Cognitive attention training primarily targets the cognitive control aspects of SA involving the frontoparietal network with the repetitive practice of tasks designed to exercise this system. Therefore, as highlighted in a recent systematic review by Slattery, O'Callaghan, Ryan, Fortune, and McAvinue (2022), training that focuses on one specific network may be too limited in scope to enhance sustain attention capacity.

Can SA be Trained?

Broadly speaking, there are two different approaches that have been used to enhance attention: cognitive attention training, and attention state training (Tang & Posner, 2009). All the training programs discussed so far can be categorized as cognitive attention training. This type of training involves the repetitive practice of a cognitive task designed to exercise specific brain networks related to attention (Posner et al., 2015). Attention state training, on the other hand, uses certain forms of experience (e.g., physical exercise and meditation) to develop a brain state that may influence the operations of the many neural networks related to attention (Posner et al., 2015). Meditation is one state training approach that has shown some promise in enhancing SA capacity (Slattery, O'Callaghan, et al., 2022). For example, focused attention meditation uses Buddhist contemplative techniques and involves the voluntary focusing of attention on a chosen object (Lutz, Slagter, Dunne, & Davidson, 2008). This involves monitoring attentional focus, detecting distraction, disengaging attention from the source of distraction, and redirecting and deploying attention to the chosen object (Lutz et al., 2008). Focused attention meditation may be successful in enhancing SA capacity as it targets the many neural networks implicated in SA (Fortenbaugh, DeGutis, & Esterman, 2017). Furthermore, as focused attention meditation targets an altered state of mind and body (development of a brain state to support attention) this can likely impact the energetic factors discussed earlier including motivation and alertness which influence SA. Therefore, while SA may prove difficult to enhance through cognitive attention training in children, some forms of attention state training may offer a viable alternative.

Strategies to Boost SA

Another possibility for enhancing students' SA to task demands is to provide them with a behavioral strategy to boost alertness transiently. One such strategy-based training is self-alert training. The goal of this training is to teach participants to temporarily boost their alertness levels at regular intervals in order to reorient attention to current task demands. The self-alerting protocol includes three components: a shift in posture, a deep breath, and a silent self-instruction to focus. The first two components serve to increase physiological arousal, while the third is a metacognitive tool used to harness the boost in arousal in order to sustain attention to task demands (McAvinue et al., 2012). Milewski-Lopez et al. (2014) found that this protocol as implemented as part of an alertness training program (training included psychoeducation of alertness, self-alert training and goal setting) for adults with everyday attention and memory difficulties led to improvements in SA. Therefore, self-alert training may represent a promising mechanism for boosting children's alertness levels in the moment to help them to sustain attention to task demands.

CONCLUSION

This study evaluated the efficacy of a school-based attention training program for improving attention in children. The training mechanism was based on the close theoretical association between SA and WM. If effective, we envisaged that the training mechanism could be incorporated into many games throughout the school day to provide practice in SA. The results provided no evidence to support the efficacy of the training program in enhancing SA, WM, or executive functioning behavior. One possibility for why the training program was unsuccessful is perhaps that cognitive attention training may not be sufficient for enhancing SA. Overall, these findings add to the mixed body of literature supporting the efficacy of cognitive attention training programs for improving children's attentional capacity.

CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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APPENDIX A

Preliminary Analyses

A.1. Normality

The Shapiro–Wilk test confirmed that a number of scores within each group were not normally distributed (see Table A1). However, Field (2013) suggests that the F statistic is relatively robust to violations of normality when group sizes are equal. In the current study, the training ($n = 18$) and control group ($n = 18$) had an equal number of participants for all sustained attention and working memory measures. As such, violations to this assumption were not viewed as problematic. All other scores within each group were normally distributed (all ps > .05).

A.2. Homogeneity of Variances

The Levene's test indicated that the assumption of homogeneity of variances was violated for SART scores at Time 1, $df(1,34) = 6.75$, $p = .014$. Again, this was not viewed as problematic as Field (2013) suggests the ANOVA is fairly robust to violations of this assumption when sample sizes are equal. No other variable violated this assumption (all ps > .05).

Table A1
Non-Normally Distributed Scores

Group	*Time*	*Outcome*	*Statistic*	p
Training	1	Forward Span	0.890	.039
Control	1	Forward Span	0.769	< .001
Control	3	SART	0.83	.004
Control	1	ERI	0.87	.019
Control	2	ERI	0.82	.005

Note: SART = Sustained Attention to Response Task, ERI = Emotion Regulation Index.

A.3. References

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APPENDIX B

Table B1
Sensitivity Analysis: Objective/Subjective Measures for the Training and Control Groups and Factorial ANOVA Results

		Baseline		*Posttest*		*Follow-up*		*Time effect*				*Group effect*				*Group × time*			
SA		M	SD	M	SD	M	SD	df	F	p	η^2_G	df	F	p	η^2_G	df	F	p	η^2_G
Vigil	T	10.29	2.78	9.53	2.72	9.18	3.78	2.00, 62.00	0.52	.597	0.008	1, 31	0.27	.605	0.005	2.00, 62.00	0.29	.747	0.004
	C	9.38	2.78	9.13	3.88	9.25	2.65												
Cerberus	T	10.47	4.01	11.71	3.87	13.53	4.05	1.91, 59.06	7.43	.002	0.74	1, 31	0.08	.775	0.002	1.91, 59.06	0.55	.572	0.006
	C	10.31	4.45	12.00	2.76	12.44	3.88												
SART	T	9.88	1.45	11.06	2.61	10.35	2.74	1.66, 51.45	2.92	.072	0.28	1, 31	4.38	**.045**	0.089	1.66, 51.45	0.74	.460	0.007
	C	8.31	3.32	9.06	2.38	9.38	2.16												
STM/WM																			
FS	T	8.71	2.05	9.00	2.00	9.29	2.02	1.91, 57.43	5.37	**.008**	0.027	1, 30	0.10	.749	0.003	1.91, 57.43	0.09	.911	<0.001
	C	8.44	2.13	9.06	2.29	9.50	1.93												
BS	T	8.35	2.29	9.18	2.16	8.35	2.69	1.70, 50.89	2.79	.079	0.028	1, 30	0.08	.784	0.002	1.70, 50.89	0.48	.593	0.005
	C	7.75	2.11	8.63	1.59	8.38	2.09												
OS	T	17.18	5.65	18.65	4.09	18.47	4.86	1.77, 53.15	2.36	.111	0.019	1, 30	0.06	.801	0.002	1.77, 53.15	0.32	.699	0.003
	C	17.31	4.47	18.63	4.50	18.56	4.70												
SS	T	11.12	3.84	12.42	3.37	14.53	3.62	1.98, 59.41	10.19	**<.001**	0.130	1, 30	0.80	.379	0.015	1.98, 59.41	0.55	.579	0.008
	C	11.50	3.27	14.19	4.20	15.06	4.68												
EF Ratings																			
BRI	T	52.71	13.98	52.24	12.20	54.81	13.29	1.63, 43.97	2.42	.110	0.010	1, 27	0.03	.871	<0.001	1.63, 43.97	1.27	.286	0.005
	C	50.50	11.29	52.29	15.39	53.47	14.02												
ERI	T	56.53	13.02	54.29	9.22	57.38	13.07	1.91, 51.63	0.74	.478	0.006	1, 27	0.13	.719	0.004	1.91, 51.63	0.25	.770	0.002
	C	53.06	11.64	53.43	13.90	56.47	14.84												
CRI	T	50.88	9.41	53.76	10.30	53.00	10.75	1.63, 42.42	3.92	**.035**	0.013	1, 26	0.00	.972	<0.001	1.63, 42.42	1.51	.234	0.005
	C	51.13	11.07	50.07	11.00	54.00	12.15												
GEC	T	53.59	11.34	55.12	11.06	55.80	12.82	1.66, 43.14	2.37	.114	0.009	1, 26	0.10	.752	0.004	1.66, 43.14	0.10	.871	<0.001
	C	51.94	11.73	53.64	13.57	55.13	14.16												

Note: Mean scores of the training and control groups on measures of sustained attention, short-term memory, working memory, and ratings of executive functioning from baseline to 6-week follow-up and factorial ANOVA results. BRI = Behavioral Regulation Index; BS = Backward Span; C = control group; CRI = Cognitive Regulation Index; ERI = Emotional Regulation Index; FS = Forward Span; GEC = Global Executive Composite; OS = Operation Span; SA = sustained attention; SS = Symmetry Span; STM = short-term memory; T = training group; WM = WM.