Journal of Cognitive Enhancement (2022) 6:170–182
https://doi.org/10.1007/s41465-021-00229-0

ORIGINAL RESEARCH

The Role of Age, Cognitive Ability, and ADHD Symptoms on Outcomes of Attention Training in Primary School Children

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Received: 5 July 2021 / Accepted: 15 October 2021 / Published online: 22 October 2021

Abstract
Attention training can improve children's attention; however, certain child characteristics may influence differential outcomes. This study explored the influence of age, general cognitive ability, and ADHD symptoms on attention outcomes following attention training. Ninety-eight children (5–9 years) were randomized to participate in attention training, placebo, or usual school activities for 20 min daily during class over 5 weeks. Child cognitive assessments and parent/teacher behavioral questionnaires were completed pre-, post-, and 6 month post-intervention. Linear mixed-effects models indicated that for the attention training condition, younger age was associated with greater improvement in cognitive attention post-intervention and older age with less improvement, while more ADHD symptoms were associated with greater reductions in teacher-rated inattentive/hyperactive behavior post-intervention and fewer ADHD symptoms were associated with fewer improvements in cognitive attention post-intervention. General cognitive ability was not associated with outcomes. Child characteristics may influence attention training outcomes; however, larger studies are needed.

Keywords Attention · Cognitive training · Individual differences · Inattention · Hyperactivity

Digital attention training programs have garnered interest to improve aspects of attention performance for clinical child populations (Kirk et al., 2016, 2017; Shalev et al., 2007; Steiner et al., 2011; Tamm et al., 2013), as well as typically developing children (Kirk et al., 2021). There is evidence that attention training can improve aspects of children's attention in the short-term (Kirk et al., 2016, 2021; Tamm et al., 2013), but not all studies report these benefits (Bikic et al., 2018; Moore et al., 2018; Steiner et al., 2014). Reviews (Simons et al., 2016; Rossignoli-Palomeque et al., 2018) and meta-analyses (Sala & Gobet, 2017; Sala et al., 2019) suggest inconsistent findings across cognitive training studies may reflect methodological limitations such as using a non-randomized design and no long-term follow-ups, as well as differences in interventions such as the skill targeted and the training dose (Scionti et al., 2020). Evidence from meta-analyses and a few small sample cognitive training studies suggest child characteristics, such as age (Peng & Miller, 2016; Sala & Gobet, 2017; Sala et al., 2019; Tamm et al., 2013), general cognition (Gathercole et al., 2019; Jaeggi et al., 2014), and clinical status (Peng & Miller, 2016; Scionti et al., 2020; van der Donk et al., 2016), may influence training outcomes. Although child characteristics may influence outcomes of attention training (Kirk et al., 2020; Peng & Miller, 2016), and therefore be useful markers to assist in predicting potential benefits prior to training commencement, to date, this has not been examined in typically developing children.

Initial evidence from a meta-analysis of attention training studies in adults and children ($n = 15$, age range 4.35 to 84.5 years (Peng & Miller, 2016)) showed that age significantly moderated the effect of training on both subjective (teacher, researcher, or parent ratings/interviews) and objective measures (computerized cognitive assessments; $r^2 = 0.42$) of attention. Specifically, younger age was associated with greater benefits of attention training. One study to date that has examined the association between child characteristics and attention training outcomes in children diagnosed with Attention Deficit Hyperactivity Disorder (ADHD; $n = 105$, 7–15 years) showed that older age (but not general cognitive ability, ADHD subtype, medication status or gender) moderated the effect of attention training

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on behavioral but not cognitive outcomes (Tamm et al., 2013). Although the findings suggested that older children benefited more from attention training, this effect was only observed on one of ten outcome measures. Furthermore, several meta-analyses of cognitive training have not identified age as a significant moderator of training outcomes in childhood populations (Kassai et al., 2019; Scionti et al., 2020; Takacs & Kassai, 2019). The association between age and training outcomes in children is therefore unclear and yet to be examined for attention training outcomes in typically developing children.

Furthermore, the influence of general cognitive ability on children's attention training outcomes has also not yet been examined; however, it has been associated with outcomes of other cognitive training interventions in both clinical (Minder et al., 2019; Soderqvist et al., 2012; van der Donk et al., 2016) and typically developing children (Gathercole et al., 2019). Some studies have observed that children with poorer (compared with higher) cognitive ability benefit more from training (Dahlin, 2011; Loosli et al., 2012; Titz & Karbach, 2014), thought to be associated with larger scope for gains (compensation account; Lövdén et al., 2012). However, more recent studies report that higher pre-training general cognitive ability is associated with greater gains for typically developing children following working memory training (Gathercole et al., 2019) and for children with ADHD following executive function training (Minder et al., 2019). Thus, a minimum cognitive capacity may be required to benefit from cognitive training (magnification account; Lövdén et al., 2012). To date, the influence of general cognitive ability on attention outcomes in typically developing children following attention training has not been studied.

Child clinical status may also influence training outcomes. In meta-analyses, sub analyses suggest that individuals with a diagnosis of ADHD who receive attention training experience greater improvements in attention compared to those with no clinical diagnosis (Peng & Miller, 2016; Scionti et al., 2020). While few empirical studies have investigated the influence of child clinical status, clinical characteristics such as ADHD subtype (van der Donk et al., 2016) and autism spectrum disorder (ASD) symptom severity (de Vries et al., 2018) have been associated with select behavioral and academic outcomes following executive function training. Specifically, children with ADHD-inattentive type (compared with ADHD-combined type) and children with fewer ASD symptoms have shown greater improvements following executive function training (de Vries et al., 2018; van der Donk et al., 2016). In contrast, ADHD subtype (combined or inattentive type) was not associated with behavioral or cognitive outcomes following attention training in children with ADHD (Tamm et al., 2013). Thus, the influence of clinical status on attention training outcomes is currently unclear.

In a double-blind cluster-randomized control trial, we have previously evaluated the effectiveness of a digital attention training program (Tali Train) delivered in class compared with a placebo and usual school activities in primary school children ($N = 98$, 5–9 years; Kirk et al., 2021). We found that children who participated in attention training showed select benefits in inattentive and hyperactive behaviors in the classroom compared to both control conditions immediately after 5 weeks of training, and this benefit was observed at 6-month post-intervention compared with the usual school activities. There was little evidence of a training-related benefit for cognitive attention skills, specifically selective attention (i.e. the ability to selectively attend to aspects of the environment), sustained attention (i.e. the ability to sustain attention on a task over time and maintain a high state of sensitivity to incoming information) and executive attention (i.e. the ability to control attention on a fixed goal while ignoring conflicting information), or inattentive and hyperactive behaviors at home. It is possible that certain subgroups of children in this study may have benefitted more from attention training than others. This study therefore aimed to explore whether attention outcomes following attention training differed for primary school children according to age, general cognitive ability, and ADHD symptoms. We expected that younger age, higher general cognitive ability, and fewer ADHD symptoms would result in greater improvements in attention following training. The outcomes of this exploratory analysis will contribute to understanding whether attention training is differentially beneficial for subgroups of children, and will highlight the potential role of baseline capacities on subsequent training outcomes.

Method

This study used data from our previous parallel condition cluster-randomized controlled trial which investigated the impact of attention training on cognitive attention processes, inattention, hyperactivity, working memory, and numeracy (Kirk et al., 2021). The trial was approved by the Monash University Human Ethics Research Committee, Catholic Education and prospectively registered with the Australian Clinical Trials Registry (ACTRN12616001111460; registered 17 August 2016).

Participants

Children were recruited from eight classrooms across three participating mainstream primary schools (Catholic and Independent) in Victoria, Australia. Children in Preparatory, Grade 1 and Grade 2 classes (aged 5 to 9 years) were invited to participate in the trial and parents provided written informed consent. Inclusion criteria included general cognitive ability > 70 on Kaufman Brief Intelligence Test at pre-intervention (KBIT-2; Kaufman & Kaufman, 2004). Children were not included in the study if they had a severe visual, auditory and/or motor impairments, or significant difficulties in the use or comprehension of the English language. Children with parent-reported developmental disorders and children on medication were not excluded. Randomization occurred at the class level, with classes allocated to one of three conditions: attention training ($n = 38$), placebo ($n = 31$), or usual school activities ($n = 29$).

Procedures

Teachers delivered the allocated activities in class. The attention training and placebo programs were delivered via 7-in. touchscreen tablets, with all children participating in the sessions concurrently. The programs consisted of 25 sessions, each 20 min in duration. Children used the programs 5 times a week for a 5-week period. Children completed cognitive assessments, and parents and teachers completed behavioral rating scales pre-, post-, and 6-month post-intervention. Teacher questionnaires were completed by the child's class teacher at the time of assessment. As the trial spanned two school years, the 6-month follow-up questionnaires were completed by a different teacher to the baseline and post-training questionnaires. Data collectors, parents, and the data analyst for the trial outcomes paper were blind to condition assignment. Children and teachers in the attention training and placebo conditions were blinded to the program they received; however, this was not possible for the usual school activities condition.

Attention Training

The digital game-based attention training program (Tali Train; Kirk et al., 2016) designed for children 4–8 years old with intellectual and developmental disorders involves training on four exercises. Each exercise lasts 4 min and targets one of three core cognitive attention processes described by Posner and Petersen (1990): selective attention/orienting, sustained attention/alerting, and executive attention. The difficulty level of the exercises automatically adapts to the performance of each child on a level-by-level basis. The selective attention/orienting exercise is based on a visual search task and requires children to locate predefined targets (e.g., orange fish) among a series of distractors (e.g., blue fish). The sustained attention/alerting exercise involves a vigilance task where the child is instructed to monitor a moving target (e.g., a treasure chest), and to make a response by touching the target when it momentarily stops moving. Due to the complexity of executive attention, two exercises were designed to target this process. The first focuses on response inhibition and requires the child to press a target (e.g., elephant) when it appears, but to withhold responses when a nontarget (e.g., lion) appears. The second executive attention exercise focuses on conflict resolution and requires the child to make a response (left or right) depending on the direction a predefined target is facing. Exercise difficulty increases by introducing flanking nontargets that provide either congruent (e.g., facing the same direction as the target) or incongruent (e.g., facing the opposite direction) cues. A reward system encourages motivation, where children obtain tokens for each level completed and virtual toys at the end of each activity which they can interact with at the end of each session.

Placebo

The digital placebo program was designed to control for the experience of using a touchscreen tablet, and to maintain blinding. As with the attention training program, the placebo consisted of four exercises and the same reward system. However, the exercises were designed to involve minimal attentional skills, requiring children to touch, drag, rotate, and pinch shapes on the screen. The exercises were non-adaptive and therefore did not increase in difficulty level during the intervention period.

Usual School Activities

Children assigned to this condition continued with their normal classroom activities and did not use any digital cognitive training program in the classroom during the study period.

Outcome Measures

Cognitive Attention

Subtests from the Test of Everyday Attention for Children Second Edition, (TEACh-2; Manly et al., 2017), designed for children 5–15 years, were used to measure aspects of cognitive attention; (1) selective attention was measured by *Balloon Hunt*, which involves four trials where the child must mark by hand as many balloons as they can on a piece of paper in 15 s. The mean number of balloons located across trials is the variable of interest, with higher scores reflecting better performance (maximum 48); (2) sustained attention was measured by the computerized *Simple Reaction Time* (SRT) subtest, which requires the child to press the keyboard spacebar as quickly as possible when a visual stimulus (blue blob) appears on the screen. The stimulus is presented at random intervals and the task spans for approximately 5 min. The mean response time in milliseconds was the variable of interest with lower scores reflecting better performance; and (3) response inhibition was measured by the *Sustained*

Attention to Response Task (SART). The SART involved the random presentation of shapes on the screen at a regular pace. The child presses the spacebar as quickly as possible when a shape appears on the screen (go trial) but is instructed to withhold a response if the shape is a triangle (no-go trial). The total number of responses to no-go trials was recorded (commission errors) with lower scores indicating better performance. Although this subscale is described as a sustained attention task in the TEACh-2 J (which does not have any specific subtests to assess executive attention), the SART is commonly used to assess response inhibition, particularly when the presentation order of go and no-go trials is randomized (Johnson et al., 2007). In addition, commission errors which are recorded by the TEACh-2 are commonly used to assess response inhibition, whereas omission errors are typically used to assess sustained attention. Raw scores for each subtest were used in analyses.

Inattentive/Hyperactive Behavior

The strengths and weaknesses of ADHD symptoms and normal behavior scale (SWAN; Swanson et al., 2012) parent and teacher versions, suitable for children 4–18 years, were used to assess inattention and hyperactivity at home and in the classroom. The SWAN consists of 18 items and respondents rated children's behavior on each item over the last week on a seven-point scale, ranging from 3 "far below average" and – 3 "far above average." A total raw score was generated for each respondent (parents, teachers) by totalling their own responses, with higher scores indicating more symptoms of inattention and hyperactivity (maximum 54).

Predictors/Moderators

Chronological Age

Children's date of birth was reported by parents in a demographic questionnaire, which was used to calculate chronological age at pre-intervention. Age in months was used in analyses.

General Cognitive Ability

The Kaufman Brief Intelligence Test—Second Edition (KBIT-2; Kaufman & Kaufman, 2004) was conducted at pre-intervention to assess general cognitive functioning. The KBIT-2 is suitable for individuals 4–90 years and has three subscales: *Verbal Knowledge*, *Matrices*, and *Riddles*. The full-scale intelligence composite score was used in analyses ($M = 100$; $SD = 15$; range 40–160).

ADHD Symptoms

The Conner's 3 Parent Rating Scale—Long Form (Conners, 2008), a standardized screening instrument of ADHD symptomology for children 6–18 years, was used. Parents rated their child's behavior over the past month on a four-point scale on subscales relating to inattentive and hyperactive symptoms (32 items). The total standardized score was used in the analysis ($M = 50$; $SD = 10$; range 40–90), with scores > 70 indicating very elevated ADHD symptoms.

Data Analysis

Linear mixed models, with random effects by child, were used to examine change in cognitive attention performance (selective attention, sustained attention, response inhibition) and inattentive/hyperactive behavior (teacher- and parent-rated) over time (pre- to post-intervention; post-intervention to follow-up) and across conditions (training, placebo, usual school activities). Two slopes were estimated to capture change from (a) pre- to post-intervention (time 1) and (b) from post-intervention to follow-up (time 2). These slopes incorporated pre-intervention scores (cognitive attention performances and inattentive/hyperactive behavior) so that any baseline differences on the outcome measures between conditions were accounted for by the model. Age at baseline was included as a covariate in all models. The data had three levels: observations over time, nested within children, and nested within classrooms. With only eight classrooms, a third level, of random effects by classroom, was assumed to be unstable and was not included in the models. Models with a third level of clustering with fewer than 10 level three clusters routinely do not converge (McNeish & Wentzel, 2017). Each of the child characteristics was examined as a predictor (child age, general cognitive ability, and ADHD symptoms) and was mean centered and entered as a fixed effect into the models. A significant predictive effect (time × predictor interaction) suggested that the child characteristic was associated with different changes in that outcome over time. A significant moderating effect (time × condition × moderator interaction) suggested that the child characteristic was associated with condition-specific changes in that outcome over time. Significant interactions were investigated using simple slopes analysis with continuous predictors/moderators plotted at 1 SD above and below the mean (Aiken & West, 1991). Five models were created, one for each outcome measure (selective attention, sustained attention, response inhibition, and inattentive/hyperactive behavior rated by parents and rated by teachers), and each model contained the three conditions: training, placebo, usual school activities to enable comparisons between groups. Confidence intervals were used to evaluate model parameters. Outliers were adjusted to the second highest value if they had a z score of < − 3.29 or > 3.29 (Tabachnick & Fidell, 2013). Models were estimated using maximum likelihood using the "nlme" package (linear and non-linear mixed effect models, version 3.1–137; (Pinheiro et al., 2012) with R version 3.5.2 (R Core Team, 2019). Best fitting random effects structure and changes in model fit were evaluated using the maximum likelihood-ratio test; using − 2 times the change in log-likelihood (− 2LL), distributed as chi-square (χ^2) with degrees of freedom equal to the number of parameters added (Singer & Willett, 2003). Effect sizes were estimated using marginal and conditional r^2 for linear mixed models (Nakagawa & Schielzeth, 2013). Multiple comparisons were accommodated for in the multilevel models, which provide better estimates than classic multiple comparison corrections by more accurately modelling the within-group correlation structure of errors (based on partial pooling; Gelman et al., 2012).

This double-blind cluster-randomized controlled trial of the Tali Train attention training program had adequate power to detect changes in the primary outcome measures from baseline to post-intervention. The estimation of moderation in the current study is exploratory and the sample size is limited with regard to power for these comparisons.

Results

A total of 98 children aged between 5 year 6 months and 9 years 1 month ($M = 91.90$, $SD = 10.12$ months; range = 66–109 months) were included in the analysis. Three children had a parent-reported Autism Spectrum Disorder (ASD): attention training ($n = 1$), placebo ($n = 1$), and usual school activities ($n = 1$). The child in the attention training condition was prescribed medication for sleep disturbance (melatonin, 4 mg), mood problems (Endep, 75 mg), and irritability (risperidone, 0.5 mg). At pre-intervention, the conditions did not differ in general cognitive ability or ADHD symptoms. However, conditions differed in child age, with the training condition being younger than the placebo and usual school activities conditions (Tables 1 & 2). General cognitive ability, ADHD symptoms, and child age were included as predictors and moderators in the following models of attention training outcomes.

Table 1 Characteristics of the study sample at pre-intervention

	Attention training ($n = 38$)		Placebo ($n = 31$)		Usual school activities ($n = 29$)		Condition comparison
	N	%	*N*	%	*N*	%	χ^2
Gender (male)	21	55.3	23	74.2	17	58.6	.242
ADHD symptom range[a]							.534
Very elevated (≥ 70)	2	6.1	6	20.7	2	6.9	
Elevated (65–69)	5	15.2	4	13.8	4	13.8	
High average (60–64)	5	15.2	2	6.9	5	17.2	
Average (40–59)	21	63.6	17	58.6	18	62.1	
Responder relationship[b]							.771
Mother	28	87.5	25	86.2	23	79.3	
Father	3	9.4	4	13.8	5	17.2	
Other	1	3.1	0	0.0	1	3.4	
Responder highest education							.782
Secondary education or below	3	9.4	2	6.8	4	13.6	
Partial university/TAFE	3	9.4	1	3.4	2	6.9	
University degree	18	56.3	15	51.7	18	62.1	
Postgraduate degree	8	25.0	11	37.9	5	17.2	
Responder work status							.344
Full-time	13	40.6	12	41.4	9	31.0	
Part-time or casual	13	40.6	13	44.8	13	44.8	
Carer	4	12.5	4	13.8	6	20.7	
Unemployed	2	6.3	0	0.0	1	3.4	

IQ Intelligence Quotient as measured by the Kaufman Brief Intelligence Test (KBIT-2). [a]Seven parents/guardians did not complete the Conner-3 questionnaire at pre-intervention (attention training: $n = 5$; placebo: $n = 2$; usual school activities: $n = 0$). [b]Eight parents/guardians did not complete the child characteristic questionnaire at pre-intervention (attention training: $n = 6$; placebo: $n = 2$; usual school activities: $n = 0$)

Table 2 Characteristics of the study sample at pre-intervention

	Attention Training ($n=38$)			Placebo ($n=31$)			Usual school activities ($n=29$)			Condition comparison
	N	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*p*
Age in months	38	87.47	13.04	31	93.65	6.73	29	95.83	5.99	.001
General cognitive ability (IQ)	38	104.97	13.44	31	107.39	12.14	29	109.03	13.02	.435
ADHD symptoms[c]	33	55.55	9.08	29	58.69	12.71	29	55.02	11.86	.403
Selective attention	37	15.08	3.61	31	16.79	3.86	29	16.32	2.61	.109
Sustained attention	35	676.31	218.62	29	596.74	156.91	29	502.10	123.96	.001
Response inhibition	37	10.87	5.91	30	10.77	5.82	29	8.69	4.89	.235
Inattentive/hyperactive behavior										
Teacher-rated	37	0.65	22.70	29	5.03	17.06	26	−7.15	22.43	.101
Parent-rated	33	−9.88	15.67	24	−3.42	16.29	29	−13.83	20.24	.102

[c]Total *t* score of the two scales on inattentive and hyperactive behavior from the Conners-3 questionnaire

Intervention Effects

As previously reported (Kirk et al., 2021), effects of time were found for cognitive attention outcome measures at post-intervention (selective attention: $est=3.33$, $SE=0.59$, 95% CI [2.24, 4.43]; sustained attention: $est=97.56$, $SE=35.13$, 95% CI [32.51, 162.62]; response inhibition: $est=-2.17$, $SE=1.05$, 95% CI [−4.12, −0.21]); and teacher-rated inattentive/hyperactive behavior ($est=-13.32$, $SE=3.77$, 95% CI [−20.26, −6.36]). At follow-up, effects of time were found for sustained attention ($est=-105.20$, $SE=41.83$, 95% CI [−180.62, −27.73]) and teacher-rated inattentive/hyperactive behavior ($est=7.84$, $SE=3.77$, 95% CI [0.88, 14.80]). Significant training effects were observed for teacher-rated inattentive/hyperactive behavior, with children in the attention training condition showing greater reductions in teacher-rated inattentive/hyperactive behavior from pre- to post-intervention, than children in the placebo ($est=14.33$, $SE=5.13$, 95% CI [4.86, 23.79]) or usual school activities conditions ($est=15.25$, $SE=6.20$, 95% CI [3.83, 26.67]; Table 4). From post-intervention to follow-up, children in the attention training condition showed greater increases in teacher-rated inattentive/hyperactive behavior than children in the placebo ($est=-13.05$, $SE=5.19$, 95% CI [−24.31, −4.16]) and the usual school activities condition ($est=-13.92$, $SE=6.33$, 95% CI [−21.54, −4.40]; Table 4).

Predictors and Moderators of Attention Training

Child Age

At pre-intervention, age was positively associated with aspects of cognitive attention, specifically selective attention ($r=0.41$) and sustained attention performance ($r=0.47$), with older age associated with better selective and sustained attention. Age was not a significant predictor of any of attention outcome measures studied.

Age was a significant moderator of training outcomes from pre- to post-intervention for select cognitive attention outcomes, specifically (a) sustained attention, between the training and usual school activities condition; and (b) response inhibition, between the training and placebo condition (Table 3). Older children who received training showed fewer gains in sustained attention from pre- to post-intervention (i.e. increase in response time), than children in the usual school activities condition (simple slopes analysis training condition $t(133)=2.62$, $p=0.010$; Fig. 1). Younger children who received training showed more improvements in response inhibition (i.e., decrease in errors) from pre- to post-intervention than children in the placebo condition (simple slopes analysis training condition $t\ (139)=-3.13$, $p=0.014$; Fig. 1).

Age was also a significant moderator of training outcomes from post-intervention to follow-up for select attention outcomes, specifically (a) sustained attention between the training and usual school activities condition; and (b) parent-rated inattentive/hyperactive behavior between the training and usual school activities condition (Tables 3 and 4). Older children who received training showed greater gains from post-intervention to follow-up (i.e., decrease in response time) than children in the usual school activities condition (simple slopes analysis training condition $t\ (133)=-2.05$, $p=0.042$; Fig. 2). Younger children who received training showed less change in parent-rated inattentive/hyperactive behavior from post-intervention to follow-up than children in the usual school activities condition who showed a decrease in these behaviors (simple slopes analysis training condition $t\ (98)=0.33$, $p>0.05$; see Fig. 2).

General cognitive ability was not significantly associated with any of the pre-intervention attention measures. There

Table 3 Child characteristics as predictors and moderators of cognitive attention outcomes following training

	Outcome measures					
	Selective attention[a]		Sustained attention[b]		Response inhibition[b]	
	Estimate (SE)	95% CI	Estimate (SE)	95% CI	Estimate (SE)	95% CI
Marginal/conditional r^2	0.29/0.90		0.23/0.87		0.13/0.86	
Pre- to post-intervention predictors						
Child age	−0.07 (0.05)	−0.16, 0.02	2.67 (2.70)	−2.31, 7.66	0.01 (0.09)	−0.07, 0.26
General cognitive ability (IQ)	0.06 (0.04)	−0.02, 0.13	−1.10 (2.13)	−5.04, 32.84	−0.03 (0.07)	−0.16, 0.10
ADHD symptoms (CPRS)	−0.02 (0.06)	−0.14, 0.10	−5.27 (3.15)	−11.10, 0.57	−0.00 (0.11)	−0.20, 0.20
Training vs placebo	0.19 (0.86)	−1.40, 1.78	−29.07 (50.39)	−122.37, 64.24	1.06 (1.54)	−1.79, 3.91
Training vs usual teaching	−0.72 (1.01)	−2.60, 1.16	14.84 (58.14)	−92.83, 122.50	−0.08 (1.80)	−3.41, 3.26
Pre- to post-intervention moderators						
Age × training vs placebo	0.13 (0.09)	−0.05, 0.30	−3.13 (4.32)	−11.13, 4.87	−0.32 (0.16)*	−0.61, -0.02
Age × training vs usual teaching	0.12 (0.11)	−0.08, 0.32	−10.48 (4.85)*	−19.45, −1.51	−0.09 (0.18)	−0.43, 0.24
IQ × training vs placebo	−0.07 (0.06)	−0.18, 0.03	1.15 (2.65)	−3.75, 6.06	−0.13 (0.10)	−0.31, 0.05
IQ × training vs usual teaching	−0.11 (0.06)	−0.22, 0.00[c]	−0.83 (2.64)	−5.72, 4.06	0.07 (0.10)	−0.12, 0.25
ADHD × training vs placebo	0.03 (0.07)	−0.11, 0.17	7.98 (3.41)*	1.66, 14.29	0.00 (0.12)	−0.23, 0.23
ADHD × training vs usual teaching	−0.02 (0.08)	−0.16, 0.12	5.79 (3.51)	−0.71, 12.29	−0.05 (0.13)	−0.29, 0.18
Post-intervention to follow-up predictors						
Child age	0.06 (0.05)	−0.03, 0.15	−0.47 (3.20)	−6.39, 5.44	0.04 (0.09)	−0.13, 0.21
General cognitive ability (IQ)	0.01 (0.04)	−0.06, 0.09	−0.46 (2.44)	−4.98, 4.07	0.01 (0.07)	−0.12, 0.14
ADHD symptoms (CPRS)	0.02 (0.06)	−0.09, 0.14	−0.31 (3.67)	−7.11, 6.48	0.07 (0.11)	−0.13, 0.27
Training vs placebo	−0.79 (0.87)	−2.41, 0.83	3.27 (60.69)	−109.12, 115.65	−1.33 (1.62)	−4.34, 1.68
Training vs usual teaching	0.78 (1.02)	−1.13, 2.69	36.89(67.58)	−88.25, 162.03	−0.05 (1.86)	−3.41, 3.50
Post-intervention to follow-up moderators						
Age × training vs placebo	0.05 (0.10)	−0.15, 0.24	−1.73 (5.69)	−12.27, 8.80	−0.01 (0.17)	−0.33, 0.31
Age × training vs usual teaching	−0.11 (0.11)	−0.31, 0.10	11.38 (5.58)*	1.05, 21.71	−0.26 (0.18)	−0.59, 0.07
IQ × training vs placebo	0.00 (0.06)	−0.11, 0.12	−0.91 (3.30)	−7.02, 5.21	−0.02 (0.10)	−0.21, 0.17
IQ × training vs usual teaching	0.00 (0.06)	−0.11, 0.11	−1.44 (3.02)	−7.03, 4.15	−0.07 (0.10)	−0.25, 0.11
ADHD × training vs placebo	−0.02 (0.07)	−0.16, 0.11	1.38 (3.99)	−6.01, 8.76	−0.09 (0.12)	−0.32, 0.14
ADHD × training vs usual teaching	−0.07 (0.08)	−0.21, 0.07	1.40 (4.07)	−6.13, 8.94	−0.09 (0.12)	−0.32, 0.14

IQ, Intelligence Quotient; *CPRS*, Conners 3 Parent-Rated Scale

[a]Random intercept model; [b]random intercept and random slope model; [c]the p value for this model estimate was greater than 0.05; model main effects are not reported for simplicity

$p < .05$; $^{**}p < .01$; $^{***}p < .001$

was no evidence that general cognitive ability was a significant predictor or moderator of attention training on any of the study outcome measures (Tables 3 and 4).

ADHD Symptoms

At pre-intervention, ADHD symptoms were positively associated with inattentive/hyperactive behavior (parent-rated: $r = 0.71$; teacher-rated: $r = 0.48$), with fewer ADHD symptoms associated with fewer inattentive/hyperactive behaviors. ADHD symptoms were a significant predictor of parent-rated inattentive/hyperactive behavior from post-intervention to follow-up (Table 4), with more ADHD symptoms predictive of greater improvements in parent-rated inattention/hyperactivity (i.e., decrease in scores).

ADHD symptoms were a significant moderator of select attention outcomes from pre- to post-intervention, specifically for (a) sustained attention between the training and placebo condition (Table 3) and (b) teacher-rated inattentive/hyperactive behavior between the training and usual school activities condition (Table 4). Children with fewer pre-intervention ADHD symptoms who received training showed poorer sustained attention performance (i.e., increase in response time) from pre- to post-intervention than children in the placebo condition (simple slopes analysis training condition $t\,(133) = 3.31$, $p = 0.001$; Fig. 3). Children with more ADHD symptoms who received training showed greater improvements in teacher-rated inattentive/hyperactive behavior (i.e., decrease in scores) from pre-intervention to post-intervention than children in the usual

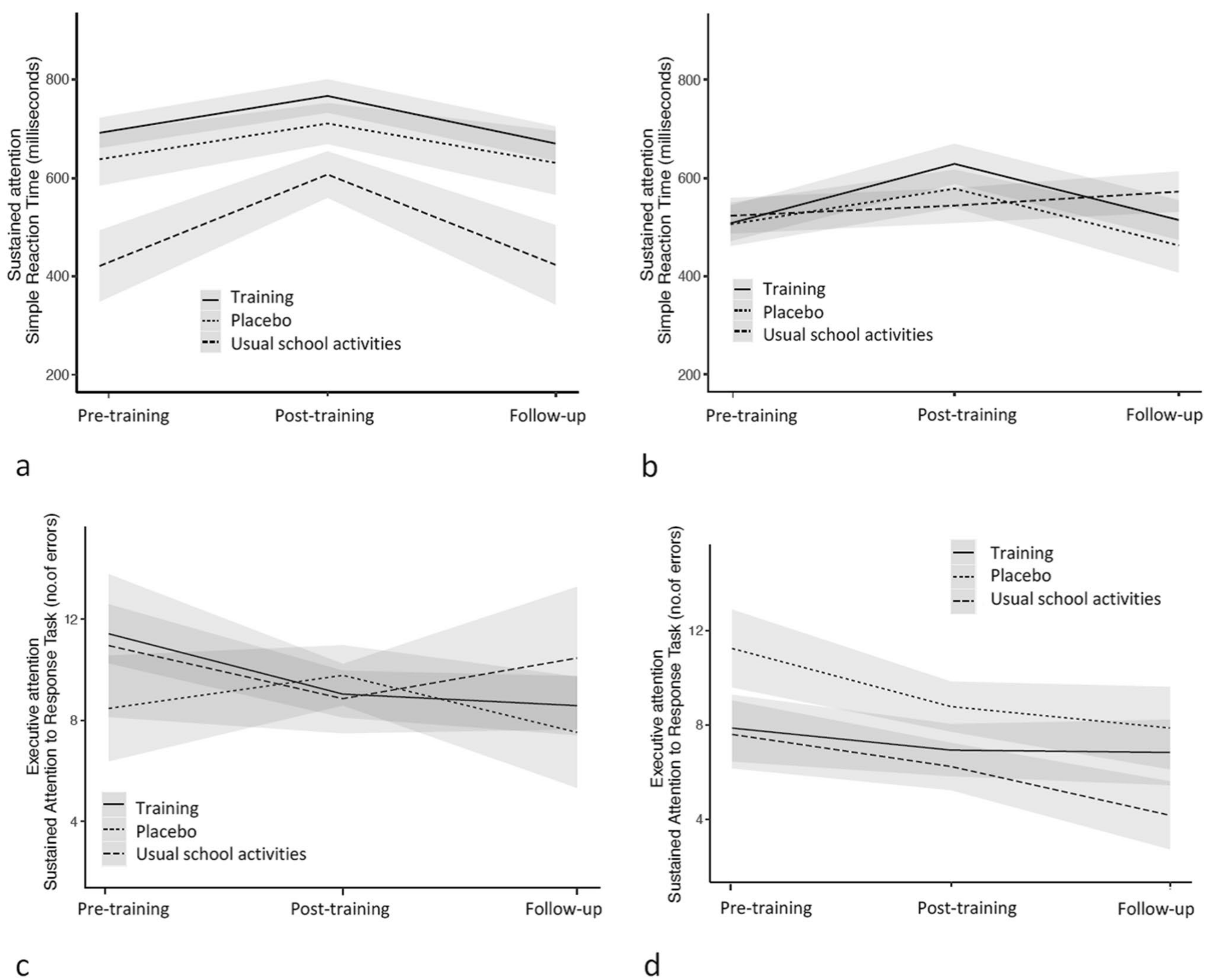

Fig. 1 Interaction of intervention group and time for **a** sustained attention for younger children (−1 SD, 6.8 years) and **b** sustained attention for older children (+1 SD, 8.5 years), as well as **c** executive attention for younger children (−1 SD, 6.8 years; **d** and executive attention for older children (+1 SD, 8.5 years). Shading represents standard error

school activities condition (simple slopes analysis training condition t (133) = −3.85, $p < 0.001$; Fig. 3).

Discussion

This is the first study to explore the potential influence of child age, general cognitive ability and ADHD symptoms on attention training outcomes in children attending mainstream primary schools. We found evidence for select moderating effects of these child characteristics on aspects of attention immediately and 6-months following training. Specifically, younger children who received attention training showed greater improvements in response inhibition (compared to placebo) and older children who received training showed fewer improvements in sustained attention from pre- to post-intervention (compared to usual teaching). In contrast, from post-intervention to follow-up, older children who received training showed greater improvements in sustained attention, and younger children showed fewer reductions in parent-rated inattention and hyperactivity (compared to usual teaching). Furthermore, children with more ADHD symptoms who received training showed greater reductions in teacher-rated inattention and hyperactivity (compared to usual teaching), and children with fewer ADHD symptoms who received training showed less improvements in sustained attention from pre-intervention to post-intervention (compared to placebo). Collectively the findings suggest that age and ADHD symptoms (but not general cognitive ability) may help to understand the effects of attention training in primary school children. These findings would have been more robust if they were observed consistently across both

Table 4 Child characteristics as predictors and moderators of behavioral attention outcomes following training

	Outcome measures			
	Hyperactivity/inattention parent[a]		Hyperactivity/inattention teacher[a]	
	Estimate (SE)	95% CI	Estimate (SE)	95% CI
Marginal/conditional r^2	0.04/0.93		0.08/0.94	
Pre- to post-intervention predictors				
Child age	−0.01 (0.20)	−0.36, 0.35	0.52 (0.41)	−0.23, 1.27
General cognitive ability (IQ)	−0.10 (0.15)	−0.37, 0.17	−0.19 (0.22)	−0.59, 0.21
ADHD symptoms (CPRS)	−0.06 (0.23)	−0.49, 0.36	−0.57 (0.32)	−1.16, 0.03
Training vs placebo	−4.29 (3.74)	−11.15, 2.58	14.33 (5.13)**	4.86, 23.79
Training vs usual teaching	2.48 (3.83)	−4.55, 9.52	15.25 (6.20)*	3.83, 26.67
Pre- to post-intervention moderators				
Age × training vs placebo	−0.06 (0.41)	−0.81, 0.69	0.31 (0.55)	−0.69, 1.32
Age × training vs usual teaching	−0.08 (0.41)	−0.83, 0.67	−1.25 (0.68)	−2.51, 0.01
IQ × training vs placebo	0.17 (0.25)	−0.29, 0.62	0.36 (0.32)	−0.23, 0.96
IQ × training vs usual teaching	0.17 (0.23)	−0.24, 0.59	0.17 (0.33)	−0.43, 0.77
ADHD × training vs placebo	0.19 (0.29)	−0.36, 0.74	0.51 (0.39)	−0.21, 1.22
ADHD × training vs usual teaching	−0.04 (0.28)	−056, 0.49	0.87 (0.40)*	0.13, 1.61
Post-intervention to follow-up predictors				
Child age	−0.23 (0.23)	−0.65, 0.19	−0.06 (0.41)	−0.82, 0.69
General cognitive ability (IQ)	−0.23 (0.17)	−0.55, 0.09	−0.06 (0.22)	−0.46, 0.35
ADHD symptoms (CPRS)	−0.64 (0.27)*	−1.13, −0.13	0.27 (0.32)	−0.33, 0.87
Training vs placebo	2.39 (4.14)	−5.21, 9.98	−13.05 (5.19)*	−24.31, −4.16
Training vs usual teaching	−9.82 (5.18)[b]	−19.32, −0.32	−13.92 (6.33)*	−21.54, −4.40
Post-intervention to follow-up moderators				
Age × training vs placebo	0.06 (0.51)	−0.87, 0.99	0.41 (0.61)	−0.72, 1.55
Age × training vs usual teaching	1.51 (0.55)**	0.51, 2.52	1.16 (0.69)	−0.12, 2.43
IQ × training vs placebo	−0.24 (0.31)	−0.80, 0.33	−0.35 (0.35)	−1.04, 0.27
IQ × training vs usual teaching	0.24 (0.29)	−0.30, 0.77	−0.23 (0.33)	−0.87, 0.35
ADHD × training vs placebo	0.53 (0.34)	−0.10, 1.15	−0.33 (0.39)	−1.04, 0.41
ADHD × training vs usual teaching	0.28 (0.34)	−0.35, 0.90	−0.80 (0.41)[b]	−1.54, −0.05

IQ, Intelligence Quotient; *CPRS*, Conners 3 Parent-Rated Scale; *EAI*, Everyday Attention Index; *SE*, standard error; *CI*, confidence interval

[a]Random intercept model; [b]the *p* value for this model estimate was greater than 0.05; model main effects are not reported for simplicity

*$p < .05$; **$p < .01$; ***$p < .001$

control groups. Further research in large samples of children examining the role of child characteristics in training effects is required before such findings should be used in clinical decision making.

Of the child characteristics we studied, ADHD symptoms were the only characteristic that moderated differential change in teacher-rated inattention and hyperactivity directly after training. This is of particular interest, given that attention training effects were only identified for this outcome measure (Kirk et al., 2021). Specifically, children who received attention training showed a greater reduction in teacher-rated inattention and hyperactivity than children in both the placebo and usual school activities conditions directly after training. The current findings indicate that children with more ADHD symptoms who received attention training experienced greater reductions in inattentive and hyperactive behavior in the classroom in the short-term when compared to children who received usual teaching. This finding is inconsistent with past training studies in clinical samples, which indicate that fewer clinical symptoms (i.e., fewer ASD symptoms; de Vries et al., 2018) are associated with greater improvements following training. We speculate that in our sample of predominantly typically developing children, greater level of ADHD symptoms (Table 1) may be similar to lower levels of symptoms in clinical samples. Therefore, a specific threshold of clinical symptoms may influence training outcomes in children. Although the current sample consisted of three children with parent reported ASD, with one child in each of the intervention conditions, this small number was not sufficient to examine differential

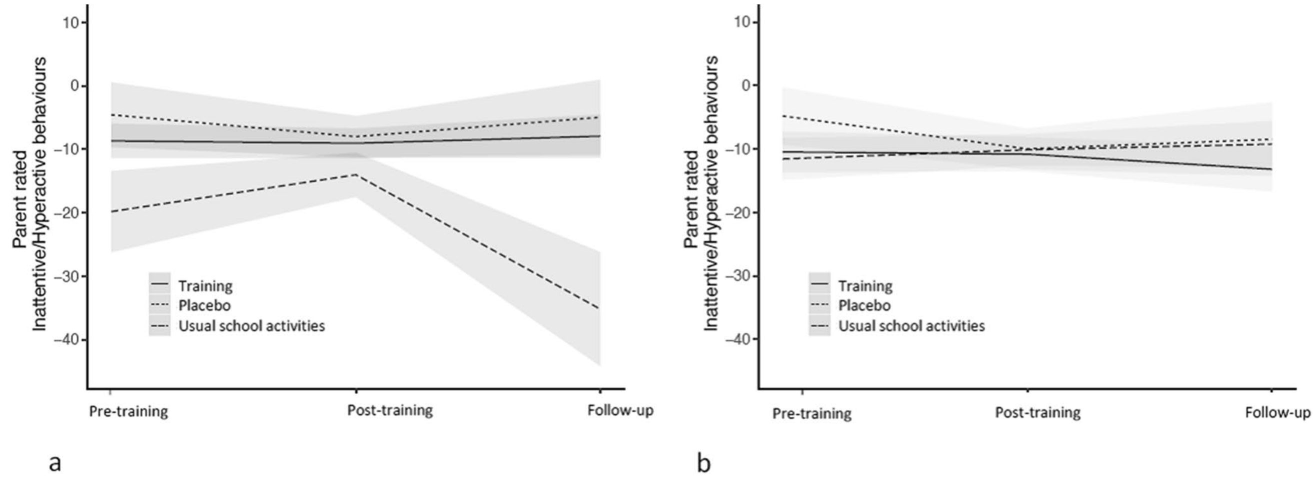

Fig. 2 Interaction of group and time for parent-rated inattentive/hyperactive behaviors for **a** younger children (− 1 *SD*, 6.8 years) and **b** older children (+ 1 *SD*, 8.5 years). Shading represents standard error

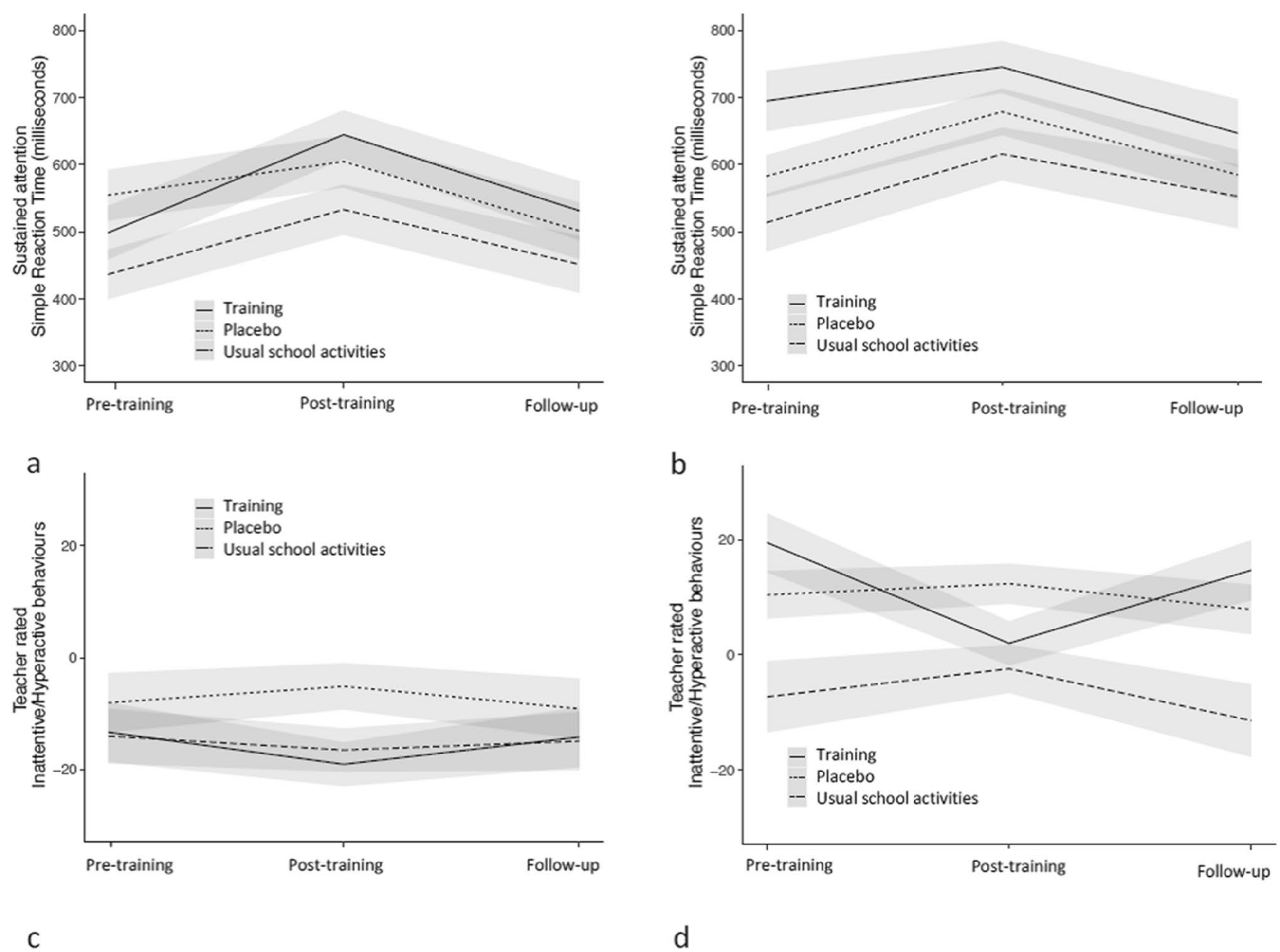

Fig. 3 Interaction of group and time for **a** sustained attention for children with fewer pre-training ADHD symptoms (− 1 *SD*, Conner's total standardized score 45.2) and **b** sustained attention for children with greater pre-training ADHD symptoms (+ 1 *SD*, Conner's total standardized score 67.6), as well as **c** teacher-rated inattentive/hyperactive behaviors for children with fewer pre-training ADHD symptoms (− 1 *SD*, Conner's total standardized score 45.2) and **d** teacher-rated inattentive/hyperactive behaviors for children with greater pre-training ADHD symptoms (+ 1 *SD*, Conner's total standardized score 67.68). Shading represents standard error

moderating effects across clinical and non-clinical populations. Future studies would benefit from recruiting larger more diverse child samples to fully examine the impact of clinical characteristics on training outcomes. In the current study, children with greater difficulties in attention may have benefitted most from the targeted attention training program due to greater scope for change (Chacko et al., 2013). Thus, our results may provide some support for the compensation account (Lövdén et al., 2012; Titz & Karbach, 2014), suggesting that children with greater attention difficulties (i.e., more ADHD symptoms) who participate in attention training are likely to experience a reduction in inattentive and hyperactive behavior. However, we did not observe these effects for all attention outcome measures. For instance, ADHD symptoms did not moderate training related gains in selective attention or response inhibition. It might be that the moderating effects of ADHD symptoms are limited to sustained attention and inattentive/hyperactive behaviors, due to these measures being more closely aligned with the measure used to assess ADHD symptoms.

Our study suggested that age may contribute to understanding attention training outcomes in children, with younger children who received attention training showing greater improvements in response inhibition and older children who received attention training experiencing fewer improvements in sustained attention at post-intervention. These findings are in line with a previous meta-analysis of attention training (Peng & Miller, 2016) which indicates that younger individuals experience greater benefits from attention training. Recent evidence indicates that training is most effective when it targets skills that are underdeveloped or do not have an established strategy to allow successful completion (Gathercole et al., 2019); therefore, the early primary school years when skills, such as response inhibition, are still undergoing significant growth may be a particularly responsive developmental period for training to be implemented (Rueda et al., 2004, 2005, 2012). Although it is tempting to conclude that attention training may have more benefits for young children, it is important to note that this effect was only observed on select variables. It is possible that these specific measures may simply be more sensitive to the effects of maturation. Further children in the training condition were younger than those in the control groups, and therefore, the observed effect of age on outcome could be related to general developmental changes. Indeed, previous meta-analyses have found limited evidence for an age effect on cognitive outcomes following training in primary school children (Kassai et al., 2019; Scionti et al., 2020; Takacs & Kassai, 2019).

The lack of moderating effects of general cognitive ability on attention outcome measures following attention training is somewhat surprising given recent evidence that higher general cognitive resources are associated with greater improvements following cognitive training (Gathercole et al., 2019; Jaeggi et al., 2014; Minder et al., 2019). This finding may reflect the relatively restricted spread of IQ scores of children in the current study (range 72–139), with our sample comprising of children attending mainstream primary schools who were screened in to the study based on an $IQ > 70$. It is possible, that in a more diverse sample with a wider range of general cognitive abilities, this characteristic may be found to influence attention training outcomes. We note that in our study, general cognitive ability was not associated with cognitive or behavioral attention at pre-intervention, suggesting that this variable may not be as useful for understanding training outcomes in primary school children for programs that target attention. Indeed, previous training studies that have observed a moderating role of general cognitive ability have studied working memory training programs (Gathercole et al., 2019) or executive function training (Minder et al., 2019).

There are some limitations of our exploratory study. Primarily, the relatively small sample size and low statistical power prevent firm conclusions being drawn about which of the investigated child characteristics have potential moderating effects on training outcomes. Future larger studies are therefore essential. Additionally, the current study examined select child characteristics and did not include both predictor and outcome measures of each cognitive skill trained. Therefore, it will be important for future studies to replicate the current findings and examine the potential moderating effects of additional child characteristics of interest such as baseline cognitive attention, medication, autism spectrum disorder symptoms (de Vries et al., 2018), and motivation (Jaeggi et al., 2011) on training outcomes. Despite these limitations, the inclusion of two control conditions, the wide range of attention outcomes, and the statistical analysis approach are important strengths of the study.

This study suggests that both age and ADHD symptoms may influence attention training outcomes for primary school children. These findings contribute to the view that child characteristics may influence outcomes of attention training and may help to understand which children are likely to benefit most from these types of programs. Further larger sample studies should investigate which individuals are most likely to benefit from training interventions, as this knowledge could assist in screening participants in to subsequent clinical trials and aid clinicians in recommending treatment options to their clients.

Acknowledgements The authors thank the families and schools who participated; Catholic Education Melbourne for their support; Richard Meagher, Yan Yang, and Rosemary Yates for their assistance with data collection; and the research interns, Alice MacDonald, Ashley Grigoriadis, Eugenie Edillo, Gabriel Rae, Grace Evans, and Orianne Rais for their dedication to the project.

Author Contribution HK conceived the research idea, created the research design, applied for and received funding, selected the measures to be included, recruited participants, collected data, entered the data, and drafted this manuscript. SR determined the statistical tests, performed the statistical analyses, drafted sections of the manuscript, and provided feedback. KC assisted in the research idea for this project and provided feedback on this manuscript. MSS was involved in the creation of the research design, measure selection, recruitment of participants, and provided extensive feedback on this manuscript.

Funding Funding was provided by the Australian Department of Innovation, Industry, and Science.

Data Availability The datasets generated during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval The methodology for this study was approved by the Monash University Human Research Ethics committee (Ethics approval number: CF12/2779 – 2012001505).

Consent to Participation and Publication Written informed consent was obtained from legal guardians. The authors affirm that research participants provided informed consent for the publication of their de-identified data.

Competing Interests Authors HK and KC are co-inventors on a patent for the attention training program used in this study. All other authors declare no competing interests.

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