APPLIED NEUROPSYCHOLOGY: CHILD
https://doi.org/10.1080/21622965.2021.1967154

Symbol relations training improves cognitive functioning in students with neurodevelopmental disorders

Negin Motamed Yeganeh[a], Rachel King[b], Lara A. Boyd[c], Gregory M. Rose[d], and Rachel C. Weber[e]

[a]Djavad Mowafaghian Centre for Brain Health, The University of British Columbia, Vancouver, Canada; [b]Department of Educational & Counselling Psychology & Special Education, The University of British Columbia, Vancouver, Canada; [c]Department of Physical Therapy, The University of British Columbia, Vancouver, Canada; [d]Departments of Anatomy and Physiology, Southern Illinois University School of Medicine, Springfield, Missouri, United States; [e]The University of British Columbia, Vancouver, Canada

ABSTRACT

Students with neurodevelopmental disorders [Specific Learning Disorders (SLD), Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD)] often experience learning challenges due to underlying weaknesses in cognitive processes. As these are some of the most common conditions to impact functioning, the development of effective treatments is a priority for neuropsychologists. However, the task of designing effective cognitive interventions has proven one of the most difficult challenges for our field. The Arrowsmith Program uses a novel approach compared to other cognitive intervention programs. We hypothesized that intensive practice of one aspect of this program would lead to improved cognitive functions in students with neurodevelopmental disorders. Twenty-seven students with neurodevelopmental disorders (ages 9.4–18.4 years) were recruited from Arrowsmith schools. Cognitive baseline and post-intervention data were gathered using components of the Woodcock–Johnson IV Tests of Cognitive Abilities. The intervention consisted of 6 weeks of intensive practice of the Symbol Relations Task. W-scores were used in a paired sample *t*-test analysis to determine if cognitive skill improvement occurred. Significant improvements were found in several measures of neuropsychological assessment, in particular in the Cattell–Horn–Carroll broad abilities These results provide a foundation for further work examining the utility of this novel approach to cognitive intervention.

KEYWORDS

Cognitive intervention; executive functioning; intervention outcomes; neurodevelopmental disorders; symbol relations training

Introduction

Neurodevelopmental disorders (NDs) are normative differences in brain growth and functioning that can affect multiple domains. NDs typically manifests in early childhood and are characterized by lifelong impairments in personal, social, academic, or occupational functioning (American Psychiatric Association, 2013). Children and youth can exhibit a variety of neurodevelopmental disorders. Most common among these appear to be Attention Deficit Hyperactivity Disorder (ADHD—a persistent pattern of inattention and/or hyperactivity and impulsivity that interferes with functioning), Autism Spectrum Disorder (ASD—a persistent pattern of difficulty with social interaction, communication, and rigid or repetitive behavior), and an umbrella category of Specific Learning Disorders (SLDs—a persistent pattern of problems with the acquisition of reading, writing or math skills) (Cleaton & Kirby, 2018). Individuals with neurodevelopmental disorders often have cognitive difficulties, compared to their typically developing peers, which are thought to contribute to their impairments in overall functioning (Spratt et al., 2012).

A considerable amount of research has been conducted to develop an understanding of the cognitive correlates of NDs. Executive functions (EFs) deficits are commonly identified across NDs (Riccio et al., 2010). Executive functions are defined as a set of cognitive control processes, largely supported by the prefrontal cortex, that regulate perceptual and motor responses, enabling self-regulation and goal-directed behavior (Miyake & Friedman, 2012). Three core interrelated EF skills, inhibitory control, working memory, and cognitive flexibility, give rise to higher-order skills such as reasoning, problem-solving, and planning (Dajani & Uddin, 2015; Diamond & Ling, 2016). Working memory, particularly verbal working memory and verbal short-term memory, are impaired in many NDs (Gathercole & Alloway, 2006). While challenges with EFs broadly, and working memory specifically, are common across NDs, research has focused on defining the cognitive profiles of specific NDs.

For example, children with SLD can have intact comprehension-knowledge and fluid reasoning, but deficiencies in working memory, processing speed, temporal processing, and attention (Peng & Fuchs, 2016; Toffalini et al., 2017). However, specific cognitive skills have been identified as having influence over certain academic competencies, and therefore subtypes, of SLD. For example, SLD-related challenges with fluid reasoning are associated with impairments

CONTACT Negin Motamed Yeganeh negin.yeganeh@ubc.ca Brain Behaviour Laboratory, University of British Columbia, 2211 Wesbrook Mall, Vancouver, British Columbia T142A, Canada.

in essay writing and math skills. Reduced comprehension-knowledge is associated with SLD in all aspects of reading and most writing skills. Diminished auditory processing is associated with SLD in foundational reading skills, and impaired processing speed is associated with SLD in reading fluency, math fluency and math calculation skills. Those with SLD have also been shown to have challenges with EFs including inhibition, cognitive flexibility, short-term verbal memory, and verbal working memory (Faedda et al., 2019). The cognitive deficits found within the SLD population are commonly thought to lead to observed challenges in academic performance in this group (Sahoo et al., 2015).

The cognitive profile that has emerged for those with ADHD has some similarities to that of SLD. Those with ADHD have a similar pattern of EF deficits (with inhibition, cognitive flexibility, short-term verbal memory, and verbal working memory) but these are more profound than is seen in SLD (Faedda et al., 2019). ADHD also has a pattern of deficits in working memory and processing speed (Fenollar-Cortés et al., 2015). These cognitive challenges are associated with a variety of functional challenges, including difficulties with social skills, adaptive skills, classroom learning, and completion of academic tasks (Storebø et al., 2019).

Another ND that has a well-studied cognitive profile is ASD. Some of the established challenges for those with ASD include flexibility, planning, and theory of mind or social cognition (Craig et al., 2016; González-Pardo & Álvarez, 2013). There is more variability in the level of social cognition in ASD than is seen in the typically developing population. Other cognitive challenges that have been identified in ASD include executive dysfunctions regarding attention, planning, and set-shifting (Torske et al., 2017). The combination of these challenges means that many young people with ASD have difficulty learning in a typical classroom environment but can also have difficulty completing academic work independently (Lecavalier et al., 2006).

Researchers are increasingly examining whether cognitive training platforms can improve functioning in children and youth with NDs (Robinson et al., 2014), as well as in adults with cognitive deficits (e.g., Ball et al., 2002; Zhang et al., 2019). Much of the latter research has involved older adults and those with mild cognitive impairment (MCI). In their review, Stott and Spector (2011) found that cognitive training (with a focus on memory skills) resulted in improvements in memory skills in those with MCI. Similarly, individuals with MCI can improve global cognitive function, EFs, processing speed, memory, and attention following a cognitive intervention (Yang et al., 2020). In studies with older adult populations, cognitive interventions were sometimes, but not always, shown to improve working memory, processing speed, and reasoning skills when they were intervention targets (reviewed in Acevedo & Loewenstein, 2007). In general, there has been a lack of well-designed randomized controlled trials to evaluate the effectiveness of these interventions; further, the gains seen in the cognitive exercises usually do not translate into functional improvements (Acevedo & Loewenstein, 2007; Stott & Spector, 2011).

A meta-analysis of studies evaluating cognitive interventions in ND populations found significant gains in all intervention targets, aside from inhibitory control. Large effect sizes were seen for attention, working memory, memory tasks, and small effect sizes for academic achievement and behavior rating scales (Robinson et al., 2014). However, the authors cautioned against making strong conclusions about the efficacy of cognitive interventions due to the heterogeneity of results across studies and the quality of the evidence. In SLD populations, Azizi et al. (2018) noted that a tripartite model of cognitive interventions (Butler & Copeland, 2002) can improve attention, and that cognitive intervention was more effective than neurofeedback training. Several other studies also show modestly positive results (reviewed in Titz & Karbach, 2014). However, there is little evidence that the cognitive performance gains seen in those with SLD transfer to academic skills (Diamond & Ling, 2016).

There is a growing general interest in the potential utility of EF training. A significant proportion of the research evaluating EF interventions focuses on the typically developing rather than ND populations, but the results have been promising. Diamond and Ling (2016) concluded that EFs can be improved at any age. Melby-Lervåg et al. (2016) found improvements in EFs following a computerized cognitive intervention, as did Blakey and Carroll (2015) in an EF intervention with preschoolers. However, in both of these studies, the results did not appear to transfer to improvements in academic areas. While it has been reported that EF training transfers to improvements in untrained areas, such as enhanced language skills and a reduction in achievement gaps (Wang et al., 2019), others have concluded that training in EF generally does not appear to transfer to other skills and lead to other improvements in cognitive or academic functioning (Diamond & Ling, 2016; Sala & Gobet, 2017). Research that has been conducted in the ND population has produced similar findings. The few clinical trials that have been conducted in ND populations are generally supportive of the use of EF training (Kassai et al., 2019; Riccio & Gomes, 2013); however, neither group found a reliable generalization of these gains to other skill areas.

Designing effective interventions to enhance cognition in individuals with NDs has been challenging (Cioni et al., 2016). A number of cognitive training regimens have been evaluated in ND populations (see de Vries et al., 2021 for a recent review). Among the many cognitive and EF interventions being studied today is the Arrowsmith Program (2012). The Arrowsmith Program claims to be different from other cognitive training programs in that it is capacity-based, rather than compensatory-based, such that the program's goal is to change the student's capacity to learn, rather than compensate for or work around their weaknesses (Arrowsmith-Young, 2012). The Arrowsmith Program also differs from others in that each student is evaluated upon entrance to the program in order to develop their Initial Learning Profile (ILP). The ILP outlines areas of strength and weakness for each student, classifying their weaknesses as Learning Dysfunctions. A student may exhibit all, or only some, of the Learning Dysfunctions defined by the program.

After the classification, the Arrowsmith Program then administers cognitive exercises to address the identified weaknesses.

In an initial study of this program with children who had, or were likely to have, SLD, both cognitive and academic growth was evaluated (Weber et al., 2019). Significant improvements in learning, long-term memory, verbal fluency, inductive reasoning, processing speed, and attention were seen after one year in the program. Additionally, significant improvements were seen for overall academic performance, specifically for single-word reading, reading fluency, math fluency, computation, and spelling (Weber et al., 2019). These results indicate that the Arrowsmith Program may be a cognitive intervention with a positive effect on academic outcomes, at least for some individuals in the SLD population.

Purpose of the present study

The goal of the current study was to examine the effect of training in one of the Arrowsmith exercises, the Symbol Relations task, on cognitive performance using components of the Woodcock-Johnson IV Tests of Cognitive Abilities (WJ IV COG; Schrank et al., 2014). In contrast to the individualized multi-task training given to students enrolled in the academic year program, Symbol Relations training is the sole exercise for individuals enrolled in the Arrowsmith summer Cognitive Intensive Program (CIP). Symbol Relations is a critical part of higher-order reasoning and is involved in processing concepts across all academic disciplines. Symbol relations involve understanding and quickly grasping what is read and heard, insight, logical reasoning, seeing connections between ideas, cause and effect processing, and mathematical reasoning. Strengthening the area(s) of the brain responsible for logical reasoning may help students to improve their understanding and performance across the board in academic subjects. We hypothesized that training in the Symbol Relations task would lead to improved cognitive functioning in students with NDs.

Method

Participants

For this study, we recruited a sample of 27 students (18 males, nine females; ages 9.4–18.4 years, $M_{\text{age}} = 12.72$ years, $\text{SD}_{\text{age}} = 2.34$ years; Brief Intellectual Ability (BIA) range 55–118, $M = 91.51$, SD $= 20.39$) who had enrolled in Arrowsmith Cognitive Intensive Program on the recommendation of parents, teachers, or pediatricians. Our study individuals were students from the larger group of CIP participants at the Arrowsmith schools in Toronto, ON, Canada, and Eaton Arrowsmith schools in Vancouver, BC, Canada, and Redmond, Washington, USA during the summer of 2019. Participation in this study was voluntary and participants were completely free to refuse to participate or to withdraw from this study at any time. All of the students had been evaluated by a psychologist or physician and were diagnosed as having a form of SLD ($n = 16$), ADHD ($n = 8$) or ASD ($n = 3$).

Procedures

Recruitment took place through flyers posted at the Arrowsmith Schools. Initial contact was made by the interested party or their family. The research team then followed up to explain the study, discuss the inclusion and exclusion criteria, and provided the consent and assent forms for the participant and their family to consider. The letter of informed consent was used as a template to describe what was being asked of the participant and the risks and benefits associated with participation. Among interested individuals, those who were between the ages of nine and 19 years and right-hand dominant were invited to participate in this project.

The study design was approved by the Clinical Research Ethics Board (CREB) at the University of British Columbia under certificate number H17-01258. In their initial assessment, a battery of Woodcock-Johnson cognitive tests and a pretraining assessment on the Symbol Relations task Arrowsmith 12–point rating scale (1 = very severe to 12 = above average) were completed over one appointment. Following their initial assessment, students trained in the Symbol Relations task (see below) for six weeks. Post-testing on Symbol Relations and the Woodcock-Johnson battery was performed over one appointment immediately after the participants completed their training sessions.

Measures

Cognitive functioning was assessed using the Woodcock-Johnson Tests of Cognitive Abilities–Fourth Edition (WJ IV COG; Schrank et al., 2014). WJ IV COG is a battery designed to measure broad and narrow cognitive abilities that cover all aspects required for a comprehensive neuropsychological evaluation and serves as baseline testing for a more comprehensive neuropsychological assessment (Miller, 2013). Compared to all of the other major tests of cognitive abilities, the WJ IV provides the most coverage across the classifications defined by contemporary Cattell–Horn–Carroll (CHC) theory. It also provides more coverage for the assessment and description of deficits and preserved neurocognitive functions than any other single source (Schrank et al., 2014). Normative data are based on a large, nationally representative sample of 7,416 individuals ranging in age from 2 to 90 years and older (Schrank & Wendling, 2018). Across the clusters of interest, all demonstrate excellent reliability (coefficients of 0.92 or higher). Individual test reliability estimates are above 0.80 where available (See McGrew et al., 2007, for a comprehensive review).

The WJ IV COG provides transformations of raw scores data into test-specific W-scores that allow for tracking of student growth over time. In addition, the test provides a Relative Proficiency Index (RPI). This score describes a student's level of proficiency on tasks that typical age- or

Table 1. RPI Scores for WJ IV cognitive performance data.

	Mean		
Cluster	Pretest	Post-test	*p*-value
Comprehension-knowledge	66.53	73.11	0.01*
Fluid reasoning	68.66	73.18	0.01*
Stwm	62.22	66.14	0.04*
Cps	47.92	68.46	0.00*
Long-term retrieval	76.00	85.92	0.00*
Number facility	54.14	54.55	0.21
Perceptual speed	48.84	60.65	0.00*
Cognitive efficiency	53.48	59.37	0.01*
Ext. cognitive efficiency	54.81	61.96	0.01*

Abbreviations: STWM: short-term working memory; CPS: cognitive processing speed.
*Wilcoxon signed-ranks test.

grade-level peers would perform with 90% proficiency. The RPI score at or below 82/90 is an indication of lower than average performance compared to a typical age-or grade-peer and is a strong predictor of significant difficulty in the skill area (Schrank et al., 2014).

For the purposes of this study, measures of broad and narrow CHC abilities were generated from components of the WJ IV COG standard and extended batteries. Broad abilities measured included Comprehension-Knowledge, Fluid Reasoning, Short-Term Working Memory, Cognitive Processing Speed, and Long-Term Retrieval. Narrow abilities measured included Number Facility, Perceptual Speed, and Cognitive Efficiency and Extended Cognitive Efficiency. We used the WJIV Brief Intellectual Ability (BIA) score to assess participants' intelligence. The BIA is based on an equal weighting of the WJIV three tests (Oral Vocabulary, Number Series, and Verbal Attention) in the cluster. The BIA has median reliability of 0.94 in the 5 to 19 age range (Mather & Wendling, 2016).

Symbol relations training

The Arrowsmith Symbol Relations Task is a computer-based exercise consisting of a sustained visual-spatial processing task of progressively increasing difficulty. It requires students to use relational reasoning to conceptually and automatically process the relationships between an increasing number of hands-on an analog clock face. Participants were presented with an analog clock face, initially showing only one hand. They used a keyboard to enter a value for the hour shown. Feedback on the computer screen indicated whether the response is correct or incorrect. If the response was incorrect, the participant continued to respond until the correct answer was entered. After this, a new clock face was shown. Once a participant reached a criterion of 90% accuracy over a series of consecutive responses, an additional hand was added to the clock face (e.g., hours and minutes). This process continued until up to 10 hands had been added to the clock, differentiated by a combination of thickness, length, and color.

The participants worked for 30 to 40 min per session on the task, with breaks in between, up to five hours per day, five days per week, for six weeks in the Arrowsmith schools. They were assigned a level of proficiency (1–12) at baseline and the end of the intervention based upon an assessment of their accuracy for the various levels of the task.

Statistical analyses

IQ scores were examined with ANOVA with age as a grouping variable and with independent samples *t*-tests with gender as a grouping variable. Paired-samples *t*-tests were used to evaluate the effects of Symbol Relations training on WJ IV cognitive assessments. W-scores were used to track participants' performance before and after Symbol Relations training (Riccio et al., 2010). RPI scores were used to provide an estimate of the participants' level of academic proficiency compared to others of their age and to track participants' performance growth after the training. Nonparametric analysis (Wilcoxon signed-ranks test) was used when a normal distribution of the data was not indicated. Additional analysis indicated that there were no statistical outliers, so no data were excluded. The significance level was defined as $p \leq 0.05$. The scores on the 12–point rating scale was used to measure student's growth on the Symbol Relations task. In order to identify potential associations between Brief Intellectual Ability (BIA) and cognitive measures, Pearson's correlation analyses were run using all participants. Also, correlational analyses were used to examine for potential relationships between Symbol Relations and WJ IV subscale improvements.

Results

There was no effect of age ($F(22, 4) = 0.701$, $p = 0.742$) on BIA scores, as well as no significant difference in the BIA scores between boys ($M = 93.88$, SD = 18.83) and girls ($M = 87.44$, SD = 24.67); $t(25) = 0.756$, $p = 0.457$. The overall mean BIA of our study population ($M = 91.51$, SD = 20.39) was within the average range of performance (McGrew et al., 2007). However, the subjects' mean level of proficiency using the RPI measure ($M = 59.1$, range 49.8–76.0) for a composite of all the WJ IV measures at the baseline indicated that most of the subjects are not performing at an average or appropriate level of performance (RPI ≥ 82/90) compared to typical age- or grade-level peers (Schrank et al., 2014). See Table 1 for details.

The average Symbol Relations score at pretest and post-test is depicted in Figure 1. As might be expected, a paired-samples *t*-test indicated that training resulted in significant improvement in Symbol Relations task performance ($p < 0.0001$; Figure 1 and Table 2). A paired samples t-test analysis was conducted to evaluate the effectiveness of Symbol Relations training on all cognitive measures. The sample's mean changes in cognitive W-scores over time ranged from +5.11 (Short-term Working Memory; SD = 13.17) to +14.00 (Cognitive Processing Speed; SD = 11.91) W-score points (Figure 1 and Table 2). Our analysis revealed that the training resulted in statistically significant improvements ($p < 0.05$; range: $p = 0.005$–<0.001) in all areas evaluated except for Short-Term Working Memory ($p = 0.054$) and Number Facility ($p = 0.086$). Effect size

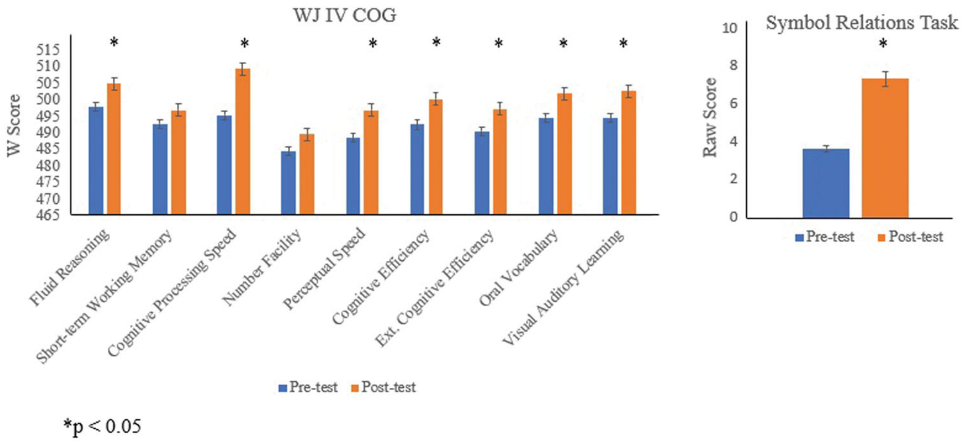

Figure 1. Change in WJ IV Cog scores and symbol relations performance after intensive training. Significant improvements were seen in all WJ IV subtests except for the short-term working memory and number facility. Data shown are W scores (left) and symbol relations scores (right) for group means ± S.E.M. Paired-*t*-tests were used to determine statistical significance. *$p < 0.05$; further details are presented in Table 2.

Table 2. WJ IV COG (W-scores) and symbol relations task performance data.

	Mean (SD)							
Cluster	Pretest	Post-test	Mean difference	SD	*t*	df	Sig.	Cohen's d
Comprehension-knowledge	494.62 (23.70)	501.96 (20.53)	7.33	10.26	3.71	26	0.001*	0.71
Fluid reasoning	497.96 (24.42)	504.88 (24.36)	6.92	8.83	4.07	26	0.000*	0.78
STWM	492.81 (21.67)	497.02 (21.10)	5.11	13.17	2.01	26	0.054	0.38
CPS	495.40 (50.14)	509.40 (47.95)	14.00	11.91	6.10	26	0.000*	1.17
Long-term retrieval	494.55 (11.66)	502.77 (12.35)	8.22	8.61	4.95	26	0.000*	0.95
Number facility	484.44 (42.99)	489.58 (41.94)	5.40	15.75	1.78	26	0.086	0.34
Perceptual speed	488.51 (58.52)	496.88 (53.81)	8.37	13.08	3.32	26	0.003*	0.63
Cognitive efficiency	492.59 (38.62)	500.33 (35.54)	7.74	13.11	3.06	26	0.005*	0.59
Ext. cognitive efficiency	490.62 (37.94)	497.37 (35.63)	6.74	8.83	3.96	26	0.001*	0.76
Symbol relations task	3.58 (2.53)	7.00 (3.09)	3.41	2.68	6.27	23	0.000*	1.41

Abbreviations: STWM: short-term working memory; CPS: cognitive processing speed.
*Paired-samples *t*-test.

(Cohen's *d*) for each cluster of paired-samples t-tests was also calculated; these ranged from small (0.38) to large (1.41) (Cohen, 2013). An analysis of RPI scores produced similar results, indicating significant improvement after Symbol Relations training in all tests (*p*-values ranging from 0.05 to less than 0.001) except for Number Facility ($p > 0.20$). Despite seeing significant improvements in most measures, post-test RPI scores did not reach normal values (>82/90) with the exception of Long-Term Retrieval.

Bivariate correlational analyses revealed that, across all participants, there were significant positive correlations (p's < 0.05) between Brief Intellectual Ability (BIA) and measures of cognitive performance at the pre-training baseline (Comprehension-Knowledge, $r = 0.659$; Fluid Reasoning, $r = 0.931$; Short-Term Working Memory, $r = 0.728$; Cognitive Processing Speed, $r = 0.597$; Long-Term Retrieval, $r = 0.596$; Number Facility, $r = 0.744$; Perceptual Speed, $r = 0.584$; Cognitive Efficiency, $r = 0.610$; Ext. Cognitive Efficiency, $r = 0.718$). However, none of the improvements seen in cognitive performance were found to be associated with the BIA (p's > 0.05). Correlational analyses were also conducted to assess the relationship between Symbol Relations improvement and individual cognitive measures. While significant improvements were seen in most WJ IV COG measures after Symbol Relations training, as reported above, individual improvement in the Symbol Relations task was not found to be associated with the degree of individual cognitive skill growth (p's > 0.05).

Discussion

This pilot study examined the effect of a six-week period of Arrowsmith Symbol Relations training on neuropsychological measures of cognition using tests from the Woodcock–Johnson IV cognitive battery. While the study was exploratory in nature, we anticipated that students would demonstrate improvements in cognitive functioning after they participated in the program. Improvement was, in fact, observed in a wide range of cognitive measures. Specifically, participants showed significant improvements in the broad abilities of Comprehension-Knowledge, Fluid Reasoning, Cognitive Processing Speed, Long-Term Retrieval, and the narrow abilities of Perceptual Speed, Cognitive Efficiency, and Extended Cognitive Efficiency. These results provide evidence of possible near transfer for the effects of Symbol Relations training.

As was briefly reviewed in the Introduction, NDs have been associated with impairments in many cognitive functions. The alignment of the cognitive challenges seen in NDs with the improvements in cognitive measures demonstrated after Symbol Relations training indicates that this may be part of an effective intervention to support those with NDs. Although the study group's IQ scores fell in the normal range, analysis of participants' level of proficiency (RPI) scores at baseline showed that the performance of most participants was below normal. Thus, the subject group could be defined as an ND population. Although most RPI scores significantly improved after Symbol Relations training, they did not reach an average performance level. It is unclear whether this is the consequence of the relatively brief training period or reflects a limitation of training in this single task. W-scores on most cognitive measures also improved following Symbol Relations training. The finding that not all scores were significantly improved at the post-test suggests that the positively changed scores were likely the result of training, though caution is warranted based on the fact that not all skills develop at the same rate. However, if improvements were simply a result of practice effects, we would have predicted similar improvements on all scales.

Our work extends the existing body of research on cognitive training effects on children with neurodevelopmental disorders and is generally in alignment with the literature (Diamond & Ling, 2016; Robinson et al., 2014). Our results have shown that Symbol Relations training led to improvements in cognitive measures in individuals with SLD, and may imply potential benefits for those with NDs more broadly. Other cognitive intervention studies in SLD populations have also had success (Titz & Karbach, 2014). In the NDs population, more broadly, there is evidence in favor of the use of cognitive training programs (Cortese et al., 2015; Diamond & Ling, 2016; Farias et al., 2018; Kassai et al., 2019; Kirk et al., 2015; Rapport et al., 2013; Riccio & Gomes, 2013; Robinson et al., 2014). Longer training in the full Arrowsmith Program appears to lead to expanded improvements in learning, long-term memory, verbal fluency, inductive reasoning, and processing speed in those with SLD (Weber et al., 2019) overlapping with many of the improvements seen in the current study that examined selective training in Symbol Relations task.

A difference between our results and others' work is the lack of significant improvement in short-term working memory (e.g. Robinson et al., 2014; Shah et al., 2012). However, the present results are consistent with previous research showing no significant improvement in short-term working memory after more extensive Arrowsmith training (Weber et al., 2019). It is possible that the lack of positive effects of the Cognitive Intensive Program on short-term working memory and number facility may be due to our relatively small sample size or the short duration of the program. Meta-analyses and literature reviews of cognitive intervention programs generally describe a positive relationship between the duration of the training and cognitive gains (Diamond & Ling, 2016). Future studies with a larger sample, longer training duration, and alternative assessments of working memory could further evaluate these differences.

There were strong positive correlations between BIA and pretraining assessments of the WJ IV cognitive functions used in our study. However, we did not find a relationship between BIA and the changes in WJ IV scores seen after Symbol Relations training. Intellectual function and neuropsychological test performance are related, but are separate constructs, as the degree of neuropsychological test variance explained by IQ is significant but not complete (Ackerman et al., 2005). The association of BIA scores to the scores on WJ IV COG subtests has not been reported in previous studies. However, it is important to explore this association and establish how BIA is related to performance on the WJ IV as a whole, in the same individuals, and large samples across relevant demographic variables.

Study limitations and future directions

Although we attributed the improvements experienced by children with neurodevelopmental to the neuropsychological intervention performed, these findings of this pilot study should be evaluated in light of some potential limitations, most importantly the limited sample size ($N = 27$) and the absence of a control group that did not receive Symbol Relations training. However, the design of our study was such that each subject served as their own control, making it highly likely that the performance improvements we observed were due to the training intervention. The heterogeneity within the sample, including a large age range and the range of neurodevelopmental diagnoses, is another challenge to interpreting the results. This study included a wide range of ages and IQ. While these limit the specificity of our results, our ANOVA analysis of BIA and included age as a control variable, attenuate the potential confound of age on the current findings. Since this was an exploratory study, we also did not implement the strictest statistical controls but rather elected to try to capture a variety of effects that could be more stringently followed up later. Finally, compared to other measures of IQ, the BIA may underestimate IQ level since the IQ score obtained by the BIA is based just on the administration of Oral Vocabulary, Numbers Series, and Verbal Attention subtests of the WJ IV COG. Therefore, our results probably reflect a valid relationship between IQ and cognitive performances in ND populations, but may not necessarily generalize to other populations.

We plan to address these limitations in future research by continuing this research to add subjects, expand and stratify the range of ages examined, group participants by neurodevelopmental diagnosis, assess the effect of training in typically developing control groups, and examine the consequences of repeated neuropsychological testing in both NDs and typically developing control groups that do not receive Symbol Relations training. One particular focus during further exploration and validation of the current results should be to ensure that changes in W-scores after a particular training program are not a function of normal fluctuation, attributable to normal growth, or a result of measurement error. We plan to use all the subtests of the WJ IV for the cognitive assessments, as well as to examine increasing the time between assessments, both to further guard against practice effects on the neuropsychological tests and to determine whether the effects of Symbol Relations training that we observed are long-lasting. In this vein, we will also include follow-up sessions to examine the etiological processes involved in the development and the stability of the outcomes of this study.

Conclusions

This exploratory study examined the effect of a relatively brief, but intense, period of training in the Arrowsmith Symbol Relations task on neuropsychological measures from the Woodcock–Johnson IV cognitive assessment battery. Our results indicate potential beneficial effects of Symbol Relations training on a variety of cognitive functions in subjects with neurodevelopmental disorders. Additional studies will be needed to replicate our initial results, measure their stability, and examine for possible far transfer of practice effects on the neuropsychological assessments (Calamia et al., 2012). This will enable us to isolate and specify the underlying cognitive mechanisms involved and facilitate the translation of our findings into practice.

Acknowledgments

The authors acknowledge the Arrowsmith schools in Toronto, ON, Canada, and Eaton Arrowsmith schools in Vancouver, BC, Canada, and Redmond, Washington, USA, where we recruited the sample for this study, as well as the children and adolescents who participated in this study and their parents.

Disclosure statement

The authors declare that they have no conflicts of interest with respect to their authorship or the publication of this article.

Funding

This work was funded by private donations to the Brain-Behaviour Lab at the University of British Columbia, the Southern Illinois University Neuroscience Research Center, and the Arrowsmith School in Toronto, Canada.

ORCID

Negin Motamed Yeganeh http://orcid.org/0000-0003-0647-6934
Rachel C. Weber http://orcid.org/0000-0002-3787-0179

References

Acevedo, A., & Loewenstein, D. A. (2007). Nonpharmacological cognitive interventions in aging and dementia. *Journal of Geriatric Psychiatry and Neurology*, *20*(4), 239–249. https://doi.org/10.1177/0891988707308808

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin*, *131*(1), 30–60. https://doi.org/10.1037/0033-2909.131.1.30

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub. https://doi.org/10.1176/appi.books.9780890425596

Arrowsmith-Young, B. (2012). *The woman who changed her brain and other inspiring stories of pioneering brain transformation*. Free Press.

Azizi, A., Drikvand, F. M., & Sepahvandi, M. A. (2018). Comparison of the effect of cognitive rehabilitation and neurofeedback on sustained attention among elementary school students with specific learning disorder: A preliminary randomized controlled clinical trial. *Applied Psychophysiology and Biofeedback*, *43*(4), 301–307. https://doi.org/10.1007/s10484-018-9410-8

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., Morris, J. N., Rebok, G. W., Smith, D. M., Tennstedt, S. L., Unverzagt, F. W., & Willis, S. L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *The Journal of the American Medical Association*, *288*(18), 2271–2281. https://doi.org/10.1001/jama.288.18.2271

Blakey, E., & Carroll, D. J. (2015). A short executive function training program improves preschoolers' working memory. *Frontiers in Psychology*, *6*, 1827. https://doi.org/10.3389/fpsyg.2015.01827

Butler, R. W., & Copeland, D. R. (2002). Attentional processes and their remediation in children treated for cancer: A literature review and the development of a therapeutic approach. *Journal of the International Neuropsychological Society*, *8*(1), 115–124. https://doi.org/10.1017/S1355617701020112

Calamia, M., Markon, K., & Tranel, D. (2012). Scoring higher the second time around: meta-analyses of practice effects in neuropsychological assessment. *The Clinical Neuropsychologist*, *26*(4), 543–570. https://doi.org/10.1080/13854046.2012.680913

Cioni, G., Inguaggiato, E., & Sgandurra, G. (2016). Early intervention in neurodevelopmental disorders: Underlying neural mechanisms. *Developmental Medicine and Child Neurology*, *58 Suppl 4*, 61–66. https://doi.org/10.1111/dmcn.13050

Cleaton, M. A. M., & Kirby, A. (2018). Why do we find it so hard to calculate the burden of neurodevelopmental disorders. *Journal of Childhood & Developmental Disorders*, *04*(03), 1–20. https://doi.org/10.4172/2472-1786.100073

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences* (2nd ed.). Erlbaum.

Cortese, S., Ferrin, M., Brandeis, D., Buitelaar, J., Daley, D., Dittmann, R. W., Holtmann, M., Santosh, P., Stevenson, J., Stringaris, A., Zuddas, A., & Sonuga-Barke, E. J. S. (2015). Cognitive training for attention-deficit/hyperactivity disorder: meta-analysis of clinical and neuropsychological outcomes from randomized controlled trials. *Journal of the American Academy of Child and Adolescent Psychiatry*, *54*(3), 164–174. https://doi.org/10.1016/j.jaac.2014.12.010

Craig, F., Margari, F., Legrottaglie, A. R., Palumbi, R., De Giambattista, C., & Margari, L. (2016). A review of executive function deficits in autism spectrum disorder and attention-deficit/hyperactivity disorder. *Neuropsychiatric Disease and Treatment*, *12*, 1191–1202.https://doi.org/10.2147/ndt.s104620

Dajani, D. R., & Uddin, L. Q. (2015). Demystifying cognitive flexibility: Implications for clinical and developmental neuroscience. *Trends in Neurosciences*, *38*(9), 571–578. https://doi.org/10.1016/j.tins.2015.07.003

de Vries, M., Kenworthy, L., Dovis, S., & Geurts, H. M. (2021). Cognitive training in children with neurodevelopmental conditions. In: T. Strobach & J. Karbach (Eds.), *Cognitive training* (pp. 351–356). Springer. . https://doi.org/10.1007/978-3-030-39292-5_24

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Faedda, N., Romani, M., Rossetti, S., Vigliante, M., Pezzuti, L., Cardona, F., & Guidetti, V. (2019). Intellectual functioning and executive functions in children and adolescents with attention deficit hyperactivity disorder (ADHD) and specific learning disorder (SLD). *Scandinavian Journal of Psychology*, *60*(5), 440–446. https://doi.org/10.1111/sjop.12562

Farias, S. T., Giovannetti, T., Payne, B. R., Marsiske, M., Rebok, G. W., Schaie, K. W., Thomas, K., Willis, S., Dzierzewski, J., Unverzagt, F., & Gross, A. L. (2018). Self-perceived difficulties in everyday function precede cognitive decline among older adults in the ACTIVE study. *Journal of the International Neuropsychological Society*, *24*(1), 104–112. https://doi.org/10.1017/S1355617717000546

Fenollar-Cortés, J., Navarro Soria, I., González Gómez, C., & García-Sevilla, J. (2015). Cognitive profile for children with ADHD by using

WISC-IV: Subtype differences?. *Revista de Psicodidáctica*, *20*(1), 157–176. https://doi.org/10.1387/RevPsicodidact.12531

Gathercole, S. E., & Alloway, T. P. (2006). Practitioner review: Short-term and working memory impairments in neurodevelopmental disorders: Diagnosis and remedial support. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *47*(1), 4–15. https://doi.org/10.1111/j.1469-7610.2005.01446.x

González-Pardo, H., & Álvarez, M. P. (2013). Epigenetics and its implications for psychology. *Psicothema*, *25*(1), 3–12. https://doi.org/10.7334/psicothema2012.327

Kassai, R., Futo, J., Demetrovics, Z., & Takacs, Z. K. (2019). A meta-analysis of the experimental evidence on the near-and far-transfer effects among children's executive function skills. *Psychological Bulletin*, *145*(2), 165–188. https://doi.org/10.1037/bul0000180

Kirk, H. E., Gray, K., Riby, D. M., & Cornish, K. M. (2015). Cognitive training as a resolution for early executive function difficulties in children with intellectual disabilities. *Research in Developmental Disabilities*, *38*, 145–160. https://doi.org/10.1016/j.ridd.2014.12.026

Lecavalier, L., Leone, S., & Wiltz, J. (2006). The impact of behaviour problems on caregiver stress in young people with autism spectrum disorders. *Journal of Intellectual Disability Research*, *50*(Pt 3), 172–183. https://doi.org/10.1111/j.1365-2788.2005.00732.x

Mather, N., & Wendling, B. J. (2016). Chapter 6 – Instructional implications from the Woodcock–Johnson IV tests of achievement. In D.P. Flanagan & V.C. Alfonso (Ed.), *WJ IV clinical use and interpretation* (pp. 151–190). Academic Press. https://doi.org/10.1016/B978-0-12-802076-0.00006-2

McGrew, K. S., Schrank, F. A., & Woodcock, R. W. (2007). *Woodcock-Johnson III normative update*. Riverside Publishing.

Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far Transfer": Evidence from a meta-analytic review". *Perspectives on Psychological Science*, *11*(4), 512–534. https://doi.org/10.1177/1745691616635612

Miller, D. C. (2013). *Essentials of school neuropsychological assessment–* (2nd ed.). Wiley.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Peng, P., & Fuchs, D. (2016). A meta-analysis of working memory deficits in children with learning difficulties: Is there a difference between verbal domain and numerical domain? *Journal of Learning Disabilities*, *49*(1), 3–20. https://doi.org/10.1177/0022219414521667

Rapport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*, *33*(8), 1237–1252. https://doi.org/10.1016/j.cpr.2013.08.005

Riccio, C. A., & Gomes, H. (2013). Interventions for executive function deficits in children and adolescents. *Applied Neuropsychology Child*, *2*(2), 133–140. https://doi.org/10.1080/21622965.2013.748383

Riccio, C. A., Sullivan, J. R., & Cohen, M. J. (2010). *Neuropsychological assessment and intervention for childhood and adolescent disorders*. John Wiley & Sons. https://doi.org/10.1002/9781118269954

Robinson, K. E., Kaizar, E., Catroppa, C., Godfrey, C., & Yeates, K. O. (2014). Systematic review and meta-analysis of cognitive interventions for children with central nervous system disorders and neurodevelopmental disorders. *Journal of Pediatric Psychology*, *39*(8), 846–865. https://doi.org/10.1093/jpepsy/jsu031

Sahoo, M. K., Biswas, H., & Padhy, S. K. (2015). Psychological co-morbidity in children with specific learning disorders. *Journal of Family Medicine and Primary Care*, *4*(1), 21–25. https://doi.org/10.4103/2249-4863.152243

Sala, G., & Gobet, F. (2017). Does far transfer exist? Negative evidence from chess, music, and working memory training. *Current Directions in Psychological Science*, *26*(6), 515–520. https://doi.org/10.1177/0963721417712760

Schrank, F. A., Mather, N., & McGrew, K. S. (2014). *Woodcock-Johnson IV Tests of Cognitive Abilities*. Riverside. https://doi.org/10.1177/0734282915571408

Schrank, F. A., & Wendling, B. J. (2018). The Woodcock–Johnson IV: Tests of cognitive abilities, tests of oral language, tests of achievement. In D. P. Flanagan & E. M. McDonough (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 383–451). The Guilford Press.

Shah, P., Buschkuehl, M., Jaeggi, S., & Jonides, J. (2012). Cognitive training for ADHD: The importance of individual differences. *Journal of Applied Research in Memory and Cognition*, *1*(3), 204–205. https://doi.org/10.1016/j.jarmac.2012.07.001

Spratt, E. G., Friedenberg, S. L., Swenson, C. C., Larosa, A., De Bellis, M. D., Macias, M. M., Summer, A. P., Hulsey, T. C., Runyan, D. K., & Brady, K. T. (2012). The effects of early neglect on cognitive, language, and behavioral functioning in childhood. *Psychology*, *3*(2), 175–182. https://doi.org/10.4236/psych.2012.32026

Storebø, O. J., Elmose Andersen, M., Skoog, M., Joost Hansen, S., Simonsen, E., Pedersen, N., Tendal, B., Callesen, H. E., Faltinsen, E., Gluud, C., & Storebø, O. J. (2019). Social skills training for attention deficit hyperactivity disorder (ADHD) in children aged 5 to 18 years. *Cochrane Library*, *2019*(6), CD008223–CD008223. https://doi.org/10.1002/14651858.CD008223.pub3

Stott, J., & Spector, A. (2011). A review of the effectiveness of memory interventions in mild cognitive impairment (MCI). *International Psychogeriatrics*, *23*(4), 526–538. https://doi.org/10.1017/S1041610210001973

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research*, *78*(6), 852–868. https://doi.org/10.1007/s00426-013-0537-1

Toffalini, E., Giofrè, D., & Cornoldi, C. (2017). Strengths and weaknesses in the intellectual profile of different subtypes of specific learning disorder: A study on 1,049 diagnosed children. *Clinical Psychological Science*, *5*(2), 402–409. https://doi.org/10.1177/2167702616672038

Torske, T., Naerland, T., Øie, M. G., Stenberg, N., & Andreassen, O. A. (2017). Metacognitive aspects of executive function are highly associated with social functioning on parent-rated measures in children with autism spectrum disorder. *Frontiers in Behavioral Neuroscience*, *11*, 258. https://doi.org/10.3389/fnbeh.2017.00258

Wang, C., Jaeggi, S. M., Yang, L., Zhang, T., He, X., Buschkuehl, M., & Zhang, Q. (2019). Narrowing the achievement gap in low-achieving children by targeted executive function training. *Journal of Applied Developmental Psychology*, *63*, 87–95. https://doi.org/10.1016/j.appdev.2019.06.002

Weber, R. C., Denyer, R., Motamed Yeganeh, N., Maja, R., Murphy, M., Martin, S., Chiu, L., Nguy, V., White, K., & Boyd, L. (2019). Interpreting the preliminary outcomes of the arrowsmith Programme: a neuroimaging and behavioural study. *Learning: Research and Practice*, *5*(2), 126–148. https://doi.org/10.1080/23735082.2019.1674908

Yang, C., Moore, A., Mpofu, E., Dorstyn, D., Li, Q., & Yin, C. (2020). Effectiveness of combined cognitive and physical interventions to enhance functioning in older adults with mild cognitive impairment: A systematic review of randomized controlled trials. *The Gerontologist*, *60*(8), 633–642. https://doi.org/10.1093/geront/gnz149

Zhang, H., Huntley, J., Bhome, R., Holmes, B., Cahill, J., Gould, R. L., Wang, H., Yu, X., & Howard, R. (2019). Effect of computerised cognitive training on cognitive outcomes in mild cognitive impairment: A systematic review and meta-analysis. *BMJ Open*, *9*(8), e027062. https://doi.org/10.1136/bmjopen-2018-027062