Article: Training the Brain to Learn: Beyond Vision Therapy

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According to The Nation's Report Card in 2013, only 38% of students could read at or above the level of "proficient," and less than 40% of graduating high school seniors were predicted to be academically prepared for college.[1] Although only 5% of students in the United States are officially diagnosed with learning disabilities,[2] these numbers indicate that many more students struggle in school. Practitioners in the field of visual therapy are continually challenged with finding effective interventions to minimize the impact of learning problems among their patients.[3]

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Like conducting an orchestra, learning is a complex act requiring the execution of simultaneous cognitive processes, each of which contributes to various aspects of learning. For example, *visual processing* is the ability to perceive, analyze, and think in images. If a student struggles with visual imagery, tasks like math word problems and reading comprehension are difficult. *Auditory processing* is the ability to perceive, analyze, and conceptualize what is heard. If a student struggles with blending, segmenting, or analyzing sounds, reading and spelling skills will be affected. *Attention* includes the ability to stay on task, to ignore distractions, and to handle multiple tasks simultaneously — all which contribute to academic success. *Working memory* is the ability to capture and retain information for short periods of time while simultaneously using it, and *long-term retrieval* is the ability to recall information learned in the past, including associations between visual and auditory stimuli. A student's ability to produce correct responses or draw accurate conclusions is affected if his ability to store or retrieve information is weak.

Together, these and other cognitive processes, such as *processing speed* and *fluid reasoning,* enable us to analyze, evaluate, retain information, recall experiences, make comparisons, and determine action. For example, in order to read, a child must visually process the letters and words as well as simultaneously recall and associate those visual images with sounds. At the same time, the child must mentally associate the words with meaning. A deficit in just one cognitive

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skill may limit the efficiency of the child's brain to process information on the page.

Several cognitive skill deficits have been identified as contributors to reading and learning difficulty. Although deficits in auditory processing are frequently associated with poor reading ability,[4] deficits in visual attention,[5] visual memory,[6] and visual motor integration[7,8] have also been identified. Further, research on both children and adults with reading disabilities has revealed deficits in working memory[9] and processing speed,[10] the ability to perform automatic cognitive tasks.

Research also suggests that visual processing interventions have successfully improved targeted cognitive skills necessary for learning. For example, visual attention therapy improved reading comprehension scores among a group of 6th grade students with moderate reading disabilities.[11] In addition, studies by Center[12] and Brown[13] reported statistically significant correlations between visualization training and reading comprehension scores of students when used as part of a multiple-strategy instruction intervention.

Working memory interventions have also been successful in enhancing the skills needed for learning. Working memory is responsible for managing the process of extracting information from text and integrating it with prior knowledge to create meaning.[14] In a study of both skilled readers (n = 50) and dyslexic readers (n = 41), improvements were noted in decoding, fluency rate, and comprehension for both groups following direct training of working memory.[15] In a recent article in Optometry and Visual Performance, Groffman[16] also noted the importance of integrating working memory training techniques in optometric vision therapy practices.

Targeted training in logic and reasoning may also help students process information more effectively. Logic and reasoning is the ability to solve problems using unfamiliar information or novel procedures. The process of inferential reasoning requires both short-term and long-term memory and acting on retrieval of background knowledge combined with the text to arrive at implicit information.[17] In one study, children trained in reasoning skills increased their IQ by an average of 10 points.[18]

Given the success of such targeted interventions at remediating individual cognitive skills, is it easy to see the impetus to develop a therapeutic model to address remediation of multiple cognitive skills. This study addresses the effectiveness of such a model that can be used as part of a visual therapy practice. Pediatric optometrist Ken Gibson (first author) developed a comprehensive cognitive training intervention called ThinkRx,[19] a revised version of the Processing and Cognitive Enhancement (PACE) program used by more than 600 clinicians to augment their visual therapy, occupational therapy, audiology, speech therapy, and psychology practices. The program is based on Gibson's *Learning Model* (Figure 1), a schematic of how information is processed.

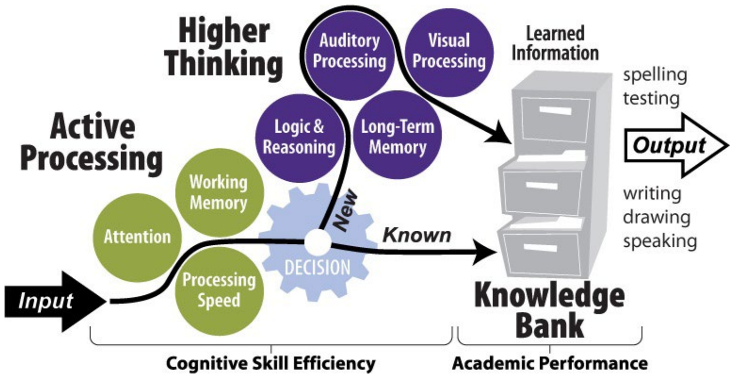

Figure 1

The Learning Model[20] is grounded in the Cattell-Horn-Carrol (CHC) theory of intelligence, which describes thinking as a set of seven broad abilities: comprehension knowledge, long-term retrieval, visual-spatial thinking, auditory processing, fluid reasoning, processing speed, and short-term memory.[21] According to the Learning Model, a child takes information in through the senses (input) that must be recognized and analyzed by the active processing system (working memory, processing speed, attention). This executive control system determines which information is unimportant, easily handled, or requires thinking. Unimportant information is discarded from working memory. If the input contains important information about data that have already been stored in the knowledge bank, it is quickly retrieved and converted to output such as speaking or writing. If the information has not been previously stored, higher thinking processes must then occur. Reasoning, auditory processing, and visual processing must be used to solve the problem or complete the task. If the task is practiced often enough, however, the information is stored in the knowledge bank, which will decrease the time between input to output. This occurs because the higher thinking processes can then be bypassed.

The ThinkRx cognitive training program targets and remediates the seven primary cognitive skills and multiple sub-skills through repeated engagement in game-like mental tasks delivered one-on-one by a clinician or cognitive trainer. The tasks emphasize visual or auditory processes that require attention and reasoning throughout each 60 to 90 minute training period. Using a synergistic "drill for skill" and meta-cognitive approach to developing cognitive skills, the program incorporates varying levels of intensity, hierarchical sequencing of tasks, multiple task loading, and instant feedback from the clinician. Training sessions are focused, demanding, intense, and tightly controlled by the clinician to push students to just above their current cognitive skill levels. Deliberate distractions are built in to the sessions to tax the brain's capacity for sorting and evaluating the importance of incoming information. This ability to correctly handle distracting information and interruptions is the foundation for focus and attention skills.[20]

Consisting of 23 different procedures with more than 1,000 total difficulty levels, the 60-hour ThinkRx program serves as the foundation for the LearningRx cognitive skills training system, and is often used in combination with an additional 60 hours of an intensive sound-to-code reading intervention, called ReadRx.[22] The addition of ReadRx gives clinicians more procedures to deliver that focus on auditory processing, basic code, and complex coding skills necessary to improve reading rate, accuracy, fluency, comprehension, spelling, and writing. The interventions are delivered over the course of twelve to twenty-four weeks. All students are trained with each procedure to mastery; that is, some students may spend more time on one procedure than another depending on the number of repetitions needed to master the task. In the ThinkRx/ReadRx combination of training, the first 60 training hours are divided into 50% ThinkRx procedures and 50% ReadRx procedures. The remaining 60 hours of training focus 75% of the time on ReadRx procedures and 25% of the time on ThinkRx procedures. Student and trainer workbooks include a detailed progression through the levels of each procedure to ensure continuity in treatment implementation across students. The following training procedures are examples of multiple-skill targeting in the cognitive training program.

Figure 2

Procedure 1: Memory Match

Memory Match (Figure 2) engages and develops visual memory, visual discrimination, and visual span, as well as processing speed and sustained attention. Using matching workboards with six squares each, the clinician randomly arranges cards containing cones, rings, or boxes into a pattern that the student may study for three seconds. After the clinician covers his workboard, the student must reproduce the same pattern on his own workboard while simultaneously counting aloud to the beat of a metronome. There are nine progressively more difficult levels for this procedure with 34 total variations.

Figure 3

Procedure 2: Reasoning Brain Cards

The Reasoning Brain Cards (Figure 3) cognitive training task targets logic and reasoning, visual discrimination, processing speed, working memory, selective and sustained attention, and comprehension. The clinician randomly arranges a set of 9 or 12 cards, each with four characteristics: shape, color, size, and orientation. The student must identify a group of three cards that shares one of the characteristics. For example, a group of three cards may all contain a medium-sized shape. There are 10 progressively more difficult levels with 40 variations of the task.

Procedure 3: Attention Speed

Attention Speed targets working memory, processing speed, attention, saccadic fixation, visual discrimination, visual span, and sensory-motor integration (Figure 4). On a grid of 144 similarly-shaped letters (p, d, b, q), the student may be asked to circle every p, cross out every d, draw a triangle around every b, and draw a square around every q while counting to every beat on the metronome and racing the stopwatch. There are 11 levels and 44 variations of this procedure, including visual discrimination of numbers.

Figure 4

Procedure 4: Reading Pictures

The Reading Pictures task targets learning of complex code. It is used once the students have improved the underlying reading and spelling skills of blending, segmenting, and auditory analysis as well as learned basic codes for 42 sounds. Early and struggling readers are trained in the use of visual images to help them remember the alternative spellings for the same sounds. In the example (Figure 5), the sound /o/ uses the code 'o' like in octopus and 'a' like in watch. The larger of the images indicates the more common spelling of the sound.

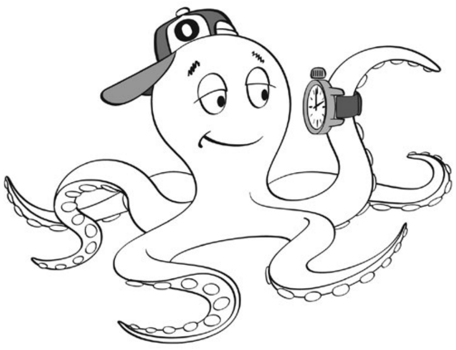

Figure 5

The purpose of the current study was to evaluate the effectiveness of ThinkRx/ReadRx cognitive training by examining the change in cognitive skills of students who completed the training program compared to students who did not. Given the pretest to post-test changes documented in unpublished clinical results reports for more than 7,000 students prior to the study,[23] we hypothesized that children who received cognitive training would achieve greater cognitive skills improvements than children who did not receive cognitive training.

METHODS

Participants

Sixty-one students (ages 6-18) were selected for inclusion in the study. The treatment group (n = 31) included students who had completed 120 hours of ThinkRx/ReadRx cognitive training at a brain training center in Colorado Springs. The mean duration of training was 23.6 weeks. There were 20 males and 11 females with a mean age of 11.2. In the treatment group, 14 participants entered the program with a diagnosed learning disability. All members of the treatment group entered the program with general learning problems, however. Intake forms completed by parents indicated 71% of the treatment group struggled with reading or writing, 10% struggled with math, and 19% experienced other classroom difficulties such as poor attention and memory, slow to finish work, and work avoidance. The control group (n = 30) was a cohort of propensity-matched children who had pretested but did not enroll in the cognitive training program. There were 21 males and 9 females with a mean age of 10.1, and eleven participants had been previously diagnosed with a learning disability. All members of the control group were experiencing learning problems. Intake forms completed by parents indicated 80% of the treatment group struggled with reading or writing, 7% struggled with math, and 13% experienced other classroom difficulties such as poor attention and memory, slow to finish work, and work avoidance. The mean duration between pre-testing and post-testing was 26.1 weeks, meaning treatment and control participants completed both rounds of testing within the same general time periods. Permission to conduct the study was granted by the LearningRx Scientific Advisory Board. Informed consent and assent were obtained from parents and children, respectively. Participants in the control group received a gift card to a local store as compensation for returning for post-testing.

Measures

All participants were pretested and post-tested by a clinician or certified cognitive trainer using the Woodcock Johnson III – Tests of Cognitive Abilities and Tests of Achievement24. Because testing is conducted prior to enrollment in any LearningRx program, the test administrators were not aware if the students were going to be included in the treatment or control groups at the time of pretesting. At post-testing, test administrators were unaware of the students' pretest scores or training program status. To further avoid potential bias, students in the treatment group were not post-tested by their own cognitive trainers. Test administrators reported the raw scores to the program director but did not participate in the calculation or interpretation of results.

The psychometric properties of the Woodcock Johnson III (WJ-III) have been extensively researched, and it is considered an accurate assessment of cognitive skill development. The test was normed on 8,818 subjects, with reliability coefficients of .80 and above and concurrent validity correlations of .67 to .7625. For this study, the specific WJ III test batteries used to measure five primary cognitive skills and two key learning skills included Visual-Auditory Learning, Spatial Relations, Concept Formation, Numbers Reversed, Pair Cancellation, Word Attack, and Sound Awareness (Table 1). The Visual-Auditory Learning test measures associative and semantic memory, which require both encoding and retrieval of auditory and

Table 1: Woodcock Johnson III Test Descriptions

Test No.	Test Name	Skill Measured	Description
COG 2	Visual-Auditory Learning	Associative Memory	Learn and recall the meaning of rebuses
COG 3	Spatial Relations	Visual Processing	Identify individual pieces that form a completed shape
COG 5	Concept Formation	Logic & Reasoning	Derive a rule from a presented stimulus set
COG 7	Numbers Reversed	Working Memory	Perform an operation on numbers held in working memory
COG 20	Pair Cancellation	Processing Speed	Locate and mark a repeated pattern quickly
ACH 13	Word Attack	Word Attack	Produce letter sounds and read nonsense words aloud
ACH 21	Sound Awareness	Auditory Processing	Rhyme, delete, substitute, and reverse words or word parts

Table 2: Mean Difference from Pretest to Post-test by Treatment Group

Test	Group	n	Pretest (SD)	Post-test (SD)	Difference (SD)
WJ III COG 2: Visual-Auditory Learning	Control	30	99.17 (10.72)	103.90 (11.51)	4.73 (11.03)
	LearningRx	31	92.07 (8.54)	111.75 (11.41)	19.70 (10.17)
WJ III COG 3: Spatial Relations\	Control	30	105.07 (9.38)	108.40 (10.53)	3.33 (8.62)
	LearningRx	31	100.68 (11.20)	109.68 (7.75)	8.77 (11.35)
WJ III COG 5: Concept Formation	Control	30	107.73 (14.05)	109.97 (10.73)	2.23 (10.56)
	LearningRx	31	104.71 (12.62)	115.64 (12.93)	11.87 (8.62)
WJ III COG 7: Numbers Reversed	Control	30	98.07 (12.09)	96.83 (10.81)	-1.23 (12.01)
	LearningRx	31	96.00 (17.31)	108.36 (15.83)	13.48 (14.25)
WJ III COG 20: Pair Cancellation	Control	30	98.67 (11.66)	104.57 (11.72)	5.90 (8.64)
	LearningRx	31	96.59 (13.74)	113.71 (15.55)	17.90 (10.33)
WJ III ACH 13: Word Attack	Control	30	104.50 (9.83)	102.47 (11.83)	-2.03 (9.32)
	LearningRx	31	99.86 (13.32)	110.96 (9.25)	10.84 (9.57)
WJ III ACH 21: Sound Awareness	Control	30	105.17 (11.37)	105.37 (13.30)	.20 (14.12)
	LearningRx	31	103.29 (15.20)	119.29 (12.75)	16.87 (9.89)

visual associations. The student is first taught a rebus, or a set of pictures that each represents a word. Then, the student must recall the meaning of each picture by reading them as a sentence aloud. The Spatial Relations test measures visual processing skills by asking the student to match individual puzzle pieces to a completed shape. The Concept Formation test measures fluid reasoning and inductive logic by requiring the student to determine and apply rules to a set of shapes that share similarities and differences. For example, a set of four objects might include three large circles and one small circle. The student must indicate which object is different from the others.

The Numbers Reversed test measures short-term and working memory by asking the student to repeat a set of numbers in reverse order from how they were presented. The Pair Cancellation test measures attention and processing speed by asking the student to locate and circle pairs of matching pictures in a limited amount of time. The Word Attack test measures basic reading skills by asking the student to apply knowledge of phonetic structure to the reading of nonsense words.

RESULTS

Prior to analysis, difference scores from pretest to post-test were calculated for each test battery (Table 2). The treatment group achieved large positive gains across all cognitive skills tested, and the control group achieved losses in working memory and word attack scores while making only small positive gains on the remaining tests. Multiple regression (MR) analyses—using difference-in-difference or first differencing—were conducted to examine if membership in the treatment group predicted greater gains in scores for students. The dependent variable in each regression model was the difference score between each cognitive pretest and post-test. Three common predictors of academic differences — age, gender, and learning disability — were also included as covariates. Technically, these covariates would not be included, due to first differencing, but their inclusion helps to improve the estimate of the treatment effect. Results indicated that treatment group membership was a significant predictor of greater gains from pretest to post-test across measures of long-term memory, logic and reasoning, working memory, processing speed, auditory processing,

Table 3: Multiple Regression Results for Predictors of Gains on Tests of Cognitive Skills

Unstandardized Coefficients			Standardized Coefficients		
WJIII COG 2	**β**	**SE**	**β**	**p**	**sr^2**
Group	13.96*	2.62	.543	.000	.280
Age	1.27	.47	.268	.010	--
Gender	-1.01	2.7	-.037	.715	--
LD	-4.06	2.65	-.155	.132	--
WJIII COG 3	**β**	**SE**	**β**	**p**	**sr^2**
Group	4.90	2.50	.238	.055	--
Age	.862	.451	.231	.061	--
Gender	-2.08	2.64	-.09	.433	--
LD	-5.45	2.53	-.260	.036	--
WJIII COG 5	**β**	**SE**	**β**	**p**	**sr^2**
Group	9.33*	2.55	.440	.001	.184
Age	.280	.459	.073	.545	--
Gender	-2.51	2.68	-.111	.352	--
LD	-1.843	2.57	-.085	.477	--
WJIII COG 7	**β**	**SE**	**β**	**p**	**sr^2**
Group	13.94*	3.50	.467	.000	.207
Age	.794	.632	.147	.214	--
Gender	-.234	3.69	-.007	.950	--
LD	-.623	3.54	-.021	.861	--
WJIII COG 20	**β**	**SE**	**β**	**p**	**sr^2**
Group	11.30*	2.36	.508	.000	.245
Age	1.09	.423	.273	.013	--
Gender	3.19	2.48	.135	.203	--
LD	-3.81	2.39	-.168	.116	--
ACH 13	**β**	**SE**	**β**	**p**	**sr^2**
Group	12.29*	2.48	.544	.000	.281
Age	.490	.447	.120	.277	--
Gender	-3.06	2.61	-.127	.247	--
LD	-1.13	2.51	-.049	.652	--
ACH 21	**β**	**SE**	**β**	**p**	**sr^2**
Group	15.94*	3.21	.547	.000	.284
Age	.758	.579	.144	.196	--
Gender	1.95	3.39	.063	.567	--
LD	.650	3.25	.022	.842	--

and Word Attack skills (Table 3). Age, gender, and learning disability did not have significant contributions to the variances in scores.

Associative memory. MR analysis to predict associative memory outcomes indicated that pretest to post-test gains on the Visual-Auditory Learning test were 13.4 points higher for the treatment than the gains for the control group. The overall analysis of variance was statistically significant (F (4, 56) = 11.20, p < .001) with a large effect size (R^2 = .445). The overall regression model accounted for 44.5% of variance in scores; and examination of individual predictor variables indicated that almost 28% (sr^2 = .281) of the variance in associative memory was explained by group membership.

Visual processing. MR analysis to predict outcomes in visual processing indicated that pretest to post-test gains on the Spatial Relations test were 4.9 points higher for the treatment group than the gains for the control group. The overall analysis of variance was statistically significant (F (4, 56) = 3.79, p =.008) with a medium effect size (R^2 = .213). The overall regression model accounted for 21.3% of variance in scores; no individual predictor variables were significant.

Logic and reasoning. Training outcomes in logic and reasoning were analyzed with MR analysis of the pretest to post-test difference scores on the Concept Formation test. The overall analysis of variance was statistically significant (F (4, 56) = 4.26, p = .004) with a medium effect size (R^2 = .233). The overall regression model accounted for 23.3% of the variance in scores, and 18.4% (sr^2 = .184) was explained by group membership. The treatment group gains were 9.33 points greater than the control group.

Working memory. MR analysis to predict working memory outcomes indicated that pretest to post-test gains on the Numbers Reversed test were 13.9 points higher for the treatment than the gains for the control group. The overall analysis of variance was statistically significant (F (4, 56) = 5.04, p = .002) with a large effect size (R^2 = .265). The overall regression model accounted for 26.5% of variance in scores, and examination of individual predictor variables indicated that almost 21% (sr^2 = .207) of the variance in working memory gains was explained by group membership.

Processing speed. Training outcomes in processing speed were analyzed with MR analysis of the pretest to post-test difference scores on the Pair Cancellation test. The overall analysis of variance was statistically significant (F (4, 55) = 9.53, p < .001) with a large effect size (R^2 = .409). The overall regression model accounted for 41% of the variance in scores, and 24.5%

(sr^2 = .245) was explained by group membership. The treatment group gains were 11.3 points greater than the control group gains.

Word Attack. MR analysis to predict Word Attack outcomes indicated that pretest to post-test gains on the Word Attack test were 12.3 points higher for the treatment than the gains for the control group. The overall analysis of variance was statistically significant (F (4, 56) = 7.84, $p < .001$) with a large effect size (R^2 = .359). The overall regression model accounted for 36% of variance in scores, and examination of individual predictor variables indicated that 28.1% (sr^2 = .281) of the variance in Word Attack gains was explained by group membership.

Auditory processing. Training outcomes in auditory processing were analyzed with MR analysis of the pretest to post-test difference scores on the Sound Awareness test. The overall analysis of variance was statistically significant (F (4, 56) = 7.59, $p < .001$) with a large effect size (R^2 = .352). The overall regression model accounted for 35.2% of the variance in scores, and 28.4% (sr^2 = .284) was explained by group membership. The treatment group gains were 15.9 points greater than the control group gains.

DISCUSSION

The purpose of this study was to examine the effectiveness of the ThinkRx/ReadRx cognitive training program for students with learning problems. The results of the analyses indicated that students who completed the cognitive training program realized greater gains than the control group across all measures. Statistically-significant differences were noted in six of the seven sets of scores measuring associative memory, fluid reasoning, working memory, executive processing speed, auditory processing, and Word Attack. The results are consistent with previous findings that direct training of individual cognitive skills increases functioning in the trained area.[4,12,13,14,15,18] However, this is the first study to document significant improvements in six cognitive skills following comprehensive, one-on-one cognitive training. This is a critical addition to the literature given the multivariate nature of skills needed for learning and reading.[26]

Further, membership in the treatment group was a significant predictor of pretest to post-test gains on the same six skills. Although a relationship between age and associative memory approached significance, the examination of individual predictors of score gains revealed no significant association with age, gender, or learning disability in any of the measures. That is, there were no differences in scores based on age, gender, and the presence or absence of a learning disability.

It is interesting to note that the only non-significant difference between the treatment and control groups was on the Spatial Relations test, a measure of visual processing. Although gains were higher in the treatment group (M = 8.77) than the control group (M = 3.33), both groups realized statistically equivalent gains from pretest to post-test. Perhaps this is due to the developmental nature of visual processing skills on a continuum of natural progression through adolescence[27] and associated maturation effects during the 24-week period between pretesting and post-testing. An alternative explanation, however, may be that the exercises delivered by clinicians were focused more heavily on the auditory processing, memory, reasoning, and executive processing skills necessary for reading and learning. This focus is a key component of the ReadRx and ThinkRx programs. A clinical implication of this finding is that the cognitive training procedures use in this study may indeed complement an existing visual therapy paradigm to maximize outcomes in all areas for struggling learners.

It is important to note that there were qualitative differences in a majority of the procedures used to train cognitive skills and the tasks that appeared in pre and post-testing. The tests are designed to measure isolated skills, but the training procedures targeted multiple skills. For example, the working memory test required students to repeat a set of numbers in reverse order from which they were given. During cognitive training, memory skills were targeted with complex visual and auditory tasks such as the Memory Match task described earlier (shown in Figure 1) and Memory Digits, a task requiring students to view a card with a 9-space grid while counting aloud to the beat of a metronome, followed by recall and recitation of the digits in the correct order from the grid. This latter procedure trained not only working memory, but also visual span, visualization, and concentration skills. Further, the test for processing speed asked students to identify and circle pairs of identical images. During cognitive training, processing speed was targeted in all procedures using a metronome, which forced students to make decisions more rapidly. Specific tasks to train processing speed gradually increased in complexity, such as the Attention Speed procedure described earlier and shown in Figure 4. This task required the students to perform multiple actions on the stimuli in a limited time period, which trained not only processing speed, but also attention, working memory, visual discrimination, visual span, and sensory motor integration. The tasks to test and train auditory analysis and word attack skills do share some similarities, however. They both required students to decode and read real and nonsense words. Due to the nature of the acquisition of basic reading skills, it is impossible to avoid some overlap between training and testing of simple and complex phonetic code. The combinations of sounds and the method of presentation, however, were dissimilar. Further, testing of specific trained decoding skills is an indicator of mastery over the fundamental skills needed for learning to read.

A limitation of the study was the lack of randomization of participants. Participants in the treatment group self-selected into the cognitive training program. However, the control group participants were selected through propensity matching, a procedure that helps mitigate the effects of non-randomization. Further, the use of difference-in-difference analysis controlled for omitted variable bias that plagues studies with non-random assignment and differences in pre-intervention cognitive skills measured in the pre-test. Future studies should incorporate randomization and a larger sample size, but the findings from the current study are encouraging for the use of comprehensive cognitive training in the remediation of multiple cognitive skills necessary for learning.

Declaration of Conflict of Interest: As the creator of the ThinkRx and ReadRx protocols used in the current study, Dr. Ken Gibson has a financial interest in the study outcomes. Ms. Tanya Mitchell is Dr. Gibson's daughter and also has a financial interest in the company and in the study outcomes.

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