The Effects of a Consumer-Oriented Multimedia Game on the Reading Disorders of Children with ADHD

Tammy M. McGraw, Ed.D.

Krista Burdette, M.A.

Kristine Chadwick, Ph.D.

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Post Office Box 1348
Charleston, West Virginia 25325-1348
304-347-0400
800-624-9120
304-347-0487 fax
aelinfo@ael.org
www.ael.org

This publication is based on work sponsored wholly or in part by the Institute of Education Sciences (IES), U.S. Department of Education, under contract number ED-01-CO-0016. Its contents do not necessarily reflect the views of IES, the Department, or any other agency of the U.S. government.

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It is impossible to overstate the importance of effective interventions for addressing two highly prevalent and potentially devastating disorders affecting school-age children—dyslexia and Attention-Deficit/Hyperactivity Disorder (ADHD). Both have been found to increase children's risk for underachievement, school failure, delinquency, and dropping out. Furthermore, there is evidence that the disorders often coexist, though the nature of this overlap is still not fully understood. While more and more children with learning deficits are being educated in regular classrooms, many of those teachers lack sufficient training to help them succeed. Moreover, the pressures high-stakes testing and accountability place on schools make it imperative to identify interventions that address learning deficits and maximize academic achievement.

Certain interventions such as computer programs that ameliorate impairments in reading and attention disorders operate on the physiological level and, therefore, lend themselves to technology-based applications. This study builds on an exploratory study (McGraw, Burdette, Seale, & Gregg, 2002) in which investigators sought to determine if consistently playing a popular, interactive multimedia game called *Dance Dance Revolution (DDR)* could improve performance on reading and writing assessments of students with ADHD and demonstrated reading impairment. It was hypothesized that by matching movements to visual and rhythmic auditory cues, *DDR* may strengthen neural networks involved in reading and attention and thereby improve student outcomes. The results of the exploratory study were encouraging: The treatment group demonstrated significant improvement in three subtests of the Process

Assessment of the Learner (PAL) (Berninger, 2001). Those results supported the continuation of research and led to the refinement of procedures and methodologies used in the present study.

Review of the Literature

Because of their potentially devastating effects on learning and behavior, dyslexia and ADHD pose a particular challenge to educators who must help struggling students meet performance goals. Dyslexia is “the most prevalent . . . learning disorder in childhood,” affecting up to one in five students (Pennington, 1991, p. 45; Shaywitz, 1996). Similarly, ADHD is the “most common neurobehavioral disorder” and “one of the most prevalent chronic health conditions affecting school-aged children”—as many as 10% (American Academy of Pediatrics, 2000, p. 1159). Both disorders have been found to increase children’s risk for underachievement, school failure, dropping out, suspension, expulsion, and delinquency (Crawford, 1996; Dickman, 1996; Gregg, 1995a, 1995b, 1996; Lyon, 1996).

Dyslexia comprises a cluster of language processing deficits that can seriously impact a person’s ability to deal with the printed word. If the language processing deficits go undetected, those who are afflicted can suffer far-reaching consequences (Tallal et al., 1996). The long-term effects of dyslexia have been shown to be related to permanent psychological, sociological, and emotional scars; diminished motivation; lack of confidence; and poor self-esteem. Such deficits are particularly problematic in the classroom, where a student with dyslexia, who is typically of average or above-average intelligence, underachieves and persistently faces poor evaluations and inadequate performance on even the simplest of activities requiring normal reading skills.

ADHD is a mainly heritable disorder of inhibition, self-control, and executive function, affecting a child's ability to sit still, pay attention, follow rules, and complete cognitive tasks crucial to school success (e.g., organizing, prioritizing, sequencing, planning, problem solving, concentrating, self-motivating, inhibiting impulses, memorizing verbal information, and working toward future goals) (Barkley, 1997, 1998; Castellanos, 1997; Lyon, 1996; Pennington, 1991; Tannock & Martinussen, 2001).

Despite high prevalence of both disorders, many teachers lack the necessary training to help students with special needs succeed. In response, states and districts are providing professional development opportunities to help teachers acquire the knowledge, skills, and repertoire of interventions and strategies needed to assist students with dyslexia, ADHD, and other disorders. Yet training large numbers of teachers at sufficient depth and intensity to affect pedagogy can be costly, time-consuming, and slow to show results in improved student performance.

Dyslexia

According to the *MEDLINEplus Medical Encyclopedia,* dyslexia, also known as developmental reading disorder, is "a reading disability resulting from a defect in the ability to process graphic symbols" (A.D.A.M., Inc., 2002). Impairments associated with dyslexia diminish children's ability to distinguish the sounds in words, link letters and sounds, retrieve and name words, and become automatic, fluent readers (Denckla, 1998a, 1998b; Lyon, 1996; Pennington, 1991; Shaywitz, 1996; Wolf, 1998; Wood, 1998; Zeffiro & Eden, 2000). Because reading skills are prerequisite to learning in all academic areas and to participation in large-scale assessments, poor readers are likely to underachieve in all subjects and perform poorly on assessments unless they are provided testing accommodations or modifications.

Dyslexia has been linked to impairments of phonological, motor, and sensory processing systems (Denckla, 1998a, 1998b; Kujala et al., 2000; Liden, 1995; Lyon, 1996; Lyon & Chhabra, 1996; Merzenich et al., 1996; Nagarajan et al., 1999; Pennington, 1991; Rumsey, 1998; Rumsey & Eden, 1998; Shaywitz, 1996; Shaywitz & Shaywitz, 1996; Shaywitz et al., 1998; Wolf, 1998; Wood, 1998; Zeffiro & Eden, 2000). Brain-imaging and neuroanatomical studies have revealed structural and functional differences in the brains of individuals with dyslexia as compared to controls. These include the volume and activation of certain brain regions and the size, number, and distribution of particular neurons—especially in the brain's left hemisphere (Fiedorowicz et al., 2000). For example, researchers have found atypical activation of brain regions—specifically the angular gyrus—during phonological tasks (Horwitz, Rumsey, & Donohue, 1998; Shaywitz et al., 1998). This area is thought to assist in the integration of orthographic and phonological information necessary to connect the letters in words to their corresponding sounds. Others have found functional deficits and cellular abnormalities in sensory processing systems, particularly in those pathways central to rapid auditory and visual processing, which could affect entry-level tasks critical to reading, such as discriminating the individual sounds that compose words (Demb, Boynton, & Heeger, 1997; Eden et al., 1996; Galaburda, Menard, & Rosen, 1994; Livingstone, Rosen, Drislane, & Galaburda, 1991; Manis et al., 1997; Nagarajan et al., 1999).

Individuals with dyslexia may also exhibit developmental writing disorder and/or developmental arithmetic disorder, as “all these processes involve the manipulation of symbols and the conveyance of information by their manipulation” (A.D.A.M., Inc., 2002).

ADHD

Brain-imaging studies also have revealed structural and functional differences in subjects with ADHD, particularly in the right hemisphere. These findings support the likelihood of a neurobiological basis for the disorder (Castellanos et al., 1996; Sieg, Gaffney, Preston, & Hellings, 1995; Swanson, Castellanos, Murias, LaHoste, & Kennedy, 1998; Vaidya et al., 1998). For example, in two seminal studies, Zametkin et al. (1990) found reduced metabolic activity in regions linked to motor control and attention, while Castellanos et al. (1996) found decreased cerebral volume in regions associated with inhibition and executive function. Schweitzer et al. (2000) noted underactivation of an area thought to be involved in working memory—an area also impaired in ADHD—during cognitive tasks. Other research has focused on the functions and genetics of neurotransmitter systems that modulate the activity of these same circuits (Biederman & Spencer, 1999; Cook et al., 1995; LaHoste et al., 1996; Madras et al., 2000; Swanson, Sunohara et al., 1998).

Similarities, Comorbidity, and Brain Research

Dyslexia and ADHD frequently coexist (Lyon, 1996; Willcutt & Pennington, 2000). Studies have found that from 25 to 40% of children with ADHD have a reading disorder; likewise, 15 to 26% of those with reading disorders and 30 to 50% of those with learning disabilities meet criteria for ADHD (Fletcher & Shaywitz, 1996; Willcutt & Pennington, 2000). Based on parent and teacher ratings, one study found that 60% of reading-disabled boys met criteria for ADHD, Inattentive Type (Willcutt & Pennington, 2000). Although these disorders frequently coexist, Clark, Barry, McCarthy, and Selikowitz (2002) found EEG differences between children with ADHD and children with ADHD and reading disability—suggesting that reading disability has some elements that differ from those found in children with ADHD.

Both disorders can impair higher order cognition and memory, possibly because language plays a key role in the development of executive functions and working memory (Denckla, 1998a; Pennington, 1991). In addition, both are characterized by social skills deficits, coexisting psychiatric disorders, and motor difficulties (Bagwell, Molina, Pelham, & Hoza, 2001; Barkley, 1997; Crawford, 1996; Dickman, 1996; Lyon, 1996; San Miguel, Forness, & Kavale, 1996; Schumaker & Deshler, 1995; Willcutt & Pennington, 2000).

Clumsiness and motor skills deficits have long been observed in children with ADHD, learning disabilities, and dyslexia (Barkley, 1981; Denckla & Rudel, 1978; Dulcan et al., 1997; Dykman, Ackerman, & Raney, 1993; Gladstone, Best, & Davidson, 1989; Ingersoll, 1988; Kadesjo & Gillberg, 1998; Pennington, 1991; Piek, Pitcher, & Hay, 1999). Likewise, children with developmental coordination disorder have been found to have an increased incidence of nonmotor impairment, especially language disorders (American Psychiatric Association, 1994).

Some researchers propose that underperformance on tests of rapid naming—associated with both dyslexia and ADHD—may be indicative of global motor and temporal processing deficits as well as impairment of executive functions (Denckla, 1996, 1998b; Denckla & Rudel, 1978; Liden, 1995; Wolf, 1998; Wolf & O'Brien, 2002). In children with dyslexia, specific deficits in motor timing have been found (Wolff, 1999), while studies of children with ADHD have shown deficits of motor timing and time perception (Barkley, Koplowitz, Anderson, & McMurray, 1997; Paule et al., 2000). Semrud-Clikeman, Guy, & Griffen (2000) suggest that all aspects of reading skill development are adversely affected by deficits in automaticity.

New thinking about the role of the cerebellum may help to explain the apparent connection between cognitive and motor impairment in dyslexia and ADHD. At one time connected only to functions of motor control and coordination, recent thinking posits that the cerebellum also plays important roles in perception, cognition, and behavior (Gao et al., 1996; Paradiso, Andreasen, O'Leary, Arndt, & Robinson, 1997; Rapoport, van Reekum, & Mayberg, 2000; Schmahmann & Sherman, 1998).

Patients with cerebellar disease have been found to have associated deficits in executive functioning (e.g., planning, verbal fluency, working memory, and reasoning), language, and emotional and behavioral control—impairments also characteristic of reading and attention disorders (Schmahmann & Sherman, 1998). Studies also have suggested the cerebellum contributes to linguistic skills and to sensory discrimination and processing—functions known to be impaired in dyslexia (Ackermann, Wildgruber, Daum, & Grodd, 1998; Gao et al., 1996; Leiner, Leiner, & Dow, 1991; Nagarajan et al., 1999; Ramus, 2001; Shaywitz et al., 1998; Zeffiro & Eden, 2000). In fact, brain-imaging studies have found, in the cerebella of subjects with dyslexia, both structural abnormalities and low levels of activation during speech and learning tasks (Nicolson et al., 1999; Rae et al., 1998).

Cerebellar dysfunction also may contribute to the core symptoms of ADHD. Research suggests that the cerebellum plays a role in motor control, behavioral inhibition, and attention (Allen, Buxton, Wong, & Courchesne, 1997; Schmahmann & Sherman, 1998). In addition, brain-imaging studies have found structural and functional differences in the cerebella of subjects with ADHD as compared to controls (Anderson et al., 1999; Berquin et al., 1998).

Research Implications for Interventions

Knowledge of the brain's plasticity, or its ability to adapt to the environment (Gopnik, Meltzoff, & Kuhl, 1999; Kotulak, 1996; Pinker, 1997; Ratey, 2001), has raised the possibility that interventions can directly target neural impairments underlying certain disorders (Merzenich, 2001). Studies show certain interventions based on this principle—such as *Fast ForWord,* discussed below—to be promising for ameliorating the impairment in reading and attention disorders. Because these interventions are intended to work on a physiological level, they lend themselves to technology-based applications.

Technology-Based Games and Applications

Fast ForWord, an interactive computer game developed by neuroscientists Merzenich and Tallal, was designed to remedy rapid temporal processing deficits by artificially stretching or slowing the sounds in speech (Merzenich, n.d.). It has been shown to improve the reading achievement of children with language impairment and dyslexia by promoting the development of auditory discrimination and phonological awareness (Merzenich et al., 1996; Tallal et al., 1996).

Similarly, students with dyslexia who received audiovisual training with a computer game developed by Kujala et al. (2001) improved their reading skills, even though the game was nonlinguistic. By matching sound patterns to graphic representations, the children improved auditory perception—a finding confirmed by electroencephalogram readings.

Attention Trainer and *Interactive Metronome* are computer programs that aim to ameliorate the symptoms of ADHD by strengthening pathways involved in attention, motor planning, and sequencing. *Attention Trainer* uses neurofeedback to evoke and reinforce a type of brainwave purportedly linked to attention, although rigorous research as to the program's effectiveness is lacking. Preliminary studies of *Interactive Metronome,* on the other hand, found that the program significantly improved attention and motor control, as well as language and reading skills (Shaffer et al., 2001).

The preceding examples are indicative of efforts to develop specialized, interactive, multimedia computer games to address disorders such as ADHD and dyslexia. *Dance Dance Revolution (DDR),* on the other hand, is a pervasive, interactive, multimedia game designed solely for entertainment. As such, it has massive appeal to young people. The investigators contend that *DDR* may provide similar physiological benefits to those afforded by the previously discussed interventions.

Described as a high-tech combination of the children's games Twister and Simon Says, *DDR* made its first appearance in Japanese arcades in 1998 and quickly became enormously popular. It appeared in the United States in March 1999 in California and exceeded initial projections for play. For example, owners of a San Francisco-based arcade expected 30 to 35 plays a day but reported 4,000 plays in the first 30 days (Libaw, 2000). Tournaments are routinely held in major cities across the United States. The popularity of the arcade game quickly led to the release of a home version.

Konami and Sony PlayStation introduced the home version of *DDR* in March 2001. The popularity of the original game led to the production of *DDR Disney Mix* (released in September 2001) and *DDR Konamix* (released in April 2002). All the versions hold an "E" rating (suitable for everyone) by the Entertainment Software Rating Board (ESRB). The PlayStation One console sells for approximately $50, the games sell for $30 (*DDR* and *DDR Konamix*) to $40 (*DDR Disney Mix*), and the peripheral dance pads range in price from $20 to $50, making the game relatively inexpensive and widely available. The games also are compatible with the PlayStation 2 (PS2) console, which sells for approximately $180. This study used the *DDR Disney Mix,* which features popular Disney songs with "kid-friendly" lyrics and visual imagery, on the PS2 console.

Method

Participants

The pool of potential participants included 74 sixth-grade students who were identified by their parents or guardians as having been diagnosed with ADHD by a medical or psychological professional. Students attended four middle schools (described in Table 1) during three distinct project periods: Spring 2002, Spring/Summer 2004, and Fall/Winter 2004.

Table 1

Description of Participating Schools

School	State	Locale	Schoolwide Race/Ethnicity	Schoolwide Free or Reduced-Price Meals
1	Virginia	Urban Fringe of Mid-Size City	Asian: 0.4% Black: 15.4% Hispanic: 1.8% White: 82.5%	Eligible: 99.5%
2	West Virginia	Rural	Black: 5.2% White: 94.8%	Eligible: 71.6%
3	West Virginia	Small Town	Asian: 0.9% Black: 0.2% Hispanic: 0.5% White: 98.4%	Eligible: 50.0%
4	West Virginia	Small Town	Asian:0.3% Black: 0.1% Hispanic: 0.1% White: 99.5%	Eligible: 39.9%

(National Center for Education Statistics, 2004)

Because diagnoses of dyslexia and ADHD are protected within confidential student records with limited access or, in some cases, unknown to the school (i.e., some parents choose to withhold the diagnostic information and seek private treatment), letters explaining the study and informed consent forms were distributed to every sixth-grade student's household. Parents nominated their children by returning the forms, thereby verifying the diagnosis of ADHD by a medical or psychological professional. For the purposes of the study, the presence of reading impairment in potential participants was determined by a pretest.

Measures

The Process Assessment of the Learner: Test Battery for Reading and Writing (PAL–RW) is used to identify students at risk for reading/writing problems, monitor students' progress as they participate in intervention programs, and aid in diagnosis by evaluating the nature of reading/writing-related problems (Berninger, 2001). It is designed to provide assessment of specific reading and writing component skills of students from kindergarten through Grade 6. The test contains 24 subtests relevant for students in Grade 6: (1) Alphabet Writing, (2) Receptive Coding, (3) Expressive Coding, (4) Rapid Automatized Naming—Letters, (5) Rapid Automatized Naming—Words, (6) Rapid Automatized Naming—Digits, (7) Rapid Automatized Naming—Words and Digits, (8) Note-Taking (Task A), (9) Syllables, (10) Phonemes, (11) Rimes, (12) Word Choice, (13) Pseudoword Decoding, (14) Finger Sense—Repetition—Dominant Hand, (15) Finger Sense—Repetition—Nondominant Hand, (16) Finger Sense—Succession—Dominant Hand, (17) Finger Sense—Succession—Nondominant Hand, (18) Finger Sense—Localization, (19) Finger Sense—Recognition, (20) Finger Sense—Fingertip Writing, (21) Sentence Sense, (22) Copying (Task A), (23) Copying (Task B), and (24) Note-Taking (Task B).

According to Berninger (2001), the subtests target the neurodevelopmental processes most relevant to learning to read and write: phonological processing; orthographic coding; rapid automatized naming; finger-function skills; word-specific representations; and integration of listening, note taking, and summary writing skills. The test exhibits adequate validity and reliability and was standardized according to 1998 U.S. census data for grade level, sex, race/ethnicity, geographic region, and parent/guardian education. "The independent criteria used for the validity studies of the PAL-RW include scores from other tests measuring constructs typically used in psychoeducational assessment: the WIAT-II (The Psychological Corporation, 2001), *Peabody Picture Vocabulary Test—Third Edition* (PPVT-III; Dunn & Dunn, 1997), *Beery Visual Motor Integration Test* (VMI; Beery, 1997), and *Clinical Evaluation of Language Fundamentals—Third Edition* (CLEF—III; Semel, Wiig, & Secord, 1995)" (Berninger, 2001, p. 116). Subtest raw scores are converted to decile scores, which the test manual divides into five classifications (see Table 2).

Table 2

Classification by Decile Score of Reading-Related Neurodevelopmental Processes According to the PAL-RW Manual

DECILE SCORE	CLASSIFICATION
10 & 20	Deficient
30 & 40	At-Risk
50	Emerging Adequate
60, 70, & 80	Adequate
90 & 100	Proficient

Materials

In addition to the PAL-RW test, the study used *DDR Disney Mix,* Sony PlayStation game consoles, external dance pads, and large-screen televisions.

Procedure

Subsequent to acquiring parent approval, the 74 students diagnosed with ADHD were tested individually using the PAL-RW to reveal the presence of reading impairment and to provide baseline data. For the purpose of this study, reading impairment was defined by the percentage of subtest scores in the Deficient and At-Risk categories compared to the percentage of subtest scores in the Proficient category. That is, students with greater than or equal to 40% of subtests scored in the Deficient (10-20 decile score) and At-Risk (30-40 decile score) categories, *and* less than or equal to 40% of subtests scored in the Proficient (90-100 decile score) range, were considered eligible for the study.

The pretest yielded 62 students in four locations eligible to participate in the study. However, the choice to limit participation in the treatment group to only elective class periods had a negative impact on the sample size, requiring the exclusion of 9 eligible students in one location. Students were sorted by class period availability and assigned to treatment, control, or exclusion groups using a table of random numbers. In three locations, no eligible students were excluded, and students were assigned to treatment and control groups using a table of random numbers.

After assignment, 1 student in the treatment group and 4 students in the control group withdrew from the study, leaving 25 in the treatment group and 23 in the control group. Ineligible students were used as fillers to ensure pairs during each treatment session, but no additional data were collected about them or their performance.

Although demographic variables were not included in the study, Table 3 reveals the gender and ethnic representation within the treatment and control groups.

Table 3

Gender and Ethnic Representation Within Treatment and Control Groups

GROUP	**GENDER**		**ETHNICITY**	
	Female	Male	Black	White
Treatment	11	14	6	19
Control	5	20	4	21

Students assigned to the control group did not participate in the intervention activity. They attended elective courses as normal, and completed the posttest at the end of the treatment period.

DDR Disney Mix was the intervention used with the treatment group of this study. Game settings were adjusted to minimize background visual stimuli (i.e., background effects "off" and background brightness set to the lowest setting, "25%"). Participants followed onscreen cues to match rhythm and choreography. They stepped on arrows on the dance pad when corresponding arrows on the television screen indicated forward, back, left, and right. Students participated in pairs (matched randomly within their available class period), attending two 25-minute sessions each week for varying treatment periods (i.e., 4 weeks, 8 weeks, and 12 weeks). Sessions were monitored by a trained researcher or research assistant. Figure 1 depicts students using the DDR game and equipment.

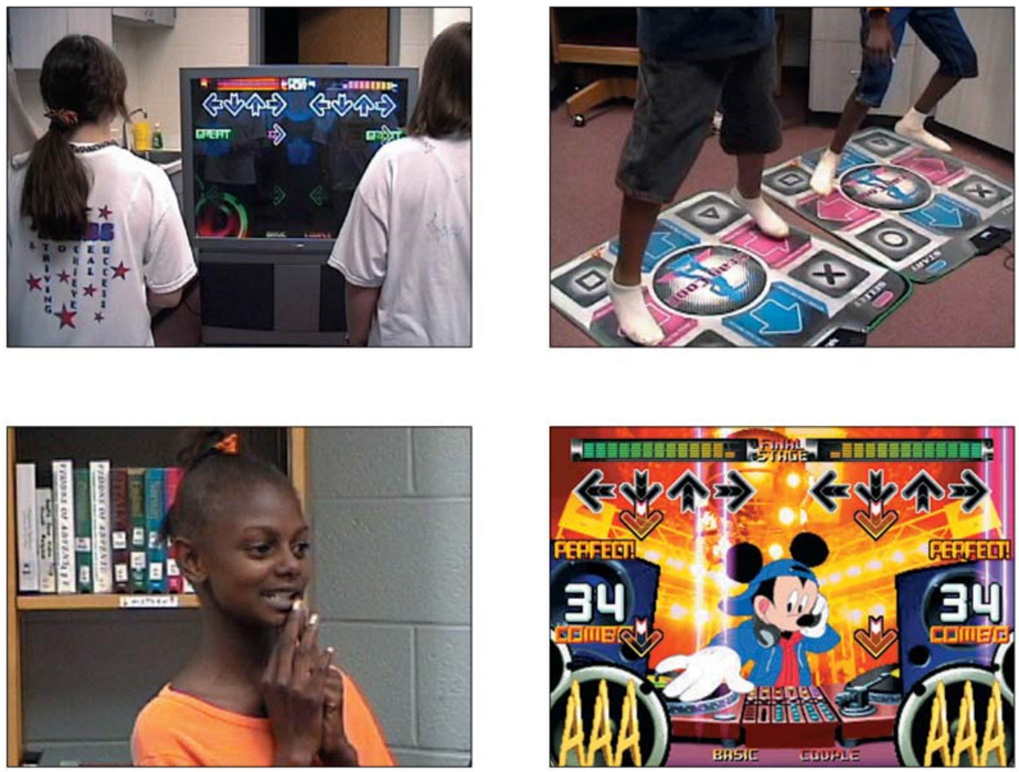

Figure 1. Students use the *Dance Dance Revolution* game and equipment. A standard large-screen television (upper left) and external dance pads (upper right) connect to a Sony PlayStation. The *DDR Disney Mix* is shown (lower right) with contrast and background effects adjusted to minimize visual stimuli.

As researchers anticipated, the number of completed treatment sessions varied by participant within the treatment group due to illness, weather-related school closings, schoolwide events, and the like.

Following the treatment period, the PAL-RW was readministered. Posttest subtest raw scores were compared to pretest subtest raw scores.

Results

The experiment was designed to test the hypothesis that students with ADHD who were involved in the intervention would exhibit less reading impairment (as measured by the PAL-RW), and would improve to a greater extent than would comparable students who were not exposed to the intervention. The pretest and posttest scores on the 24 subtests of the PAL-RW were used for comparison.

Table 4 displays the means and standard deviations for each group (treatment and control) on each of the 24 subtests. Notably, there are large differences in the variances associated with the subtests. Most of this observed variation may be due to the different scales composing the subtests. However, there are also some large differences in standard deviations within a subtest, either across the treatment versus control conditions and/or across the pretest and posttest measurements.

Table 4

Pretest and Posttest Raw Scores for the Treatment and Control Conditions for 24 Subtests

Subtest	**Treatment (N=25)**				**Control (N=23)**			
	Pre		***Post***		***Pre***		***Post***	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Alphabet Writing	3.28	2.98	4.80	3.71	3.92	2.98	4.91	2.78
Receptive Coding	30.40	3.00	32.64	2.25	29.54	4.41	30.17	3.73
Expressive Coding	10.80	3.19	12.68	3.63	11.79	4.31	12.65	4.77
RAN Letters	51.56	9.31	46.60	9.06	49.29	10.18	45.87	11.03
RAN Words	29.08	6.09	26.44	4.92	28.42	4.57	25.86	6.09
RAN Digits	40.32	8.07	42.25	8.74	44.88	12.34	44.96	12.32
RAN Words & Digits	40.32	8.07	36.68	8.40	39.30	10.74	39.43	17.66
Note-Taking (Task A)	21.08	9.01	24.92	8.67	21.00	11.08	24.70	9.79
Syllables	3.68	1.38	3.88	1.45	3.92	1.50	4.22	1.20
Phonemes	2.40	1.68	3.20	1.83	2.92	1.89	3.48	1.68
Rimes	3.00	1.61	3.24	1.67	3.29	1.83	3.30	1.66
Word Choice	26.72	2.59	27.32	2.88	25.92	4.19	26.09	4.50
Pseudoword Decoding	31.68	13.05	34.40	12.55	33.87	12.18	33.78	10.68
Finger Sense Repetition 1	6.96	1.84	6.84	2.56	6.79	1.72	6.52	2.15
Finger Sense Repetition 2	6.71	1.63	6.84	2.39	6.79	1.32	7.00	1.86
Finger Sense Succession 1	9.20	1.94	10.84	8.73	9.38	4.16	8.35	3.02
Finger Sense Succession 2	10.21	2.87	11.40	9.25	9.04	3.61	8.70	2.72
Finger Sense Localization	9.88	0.60	9.72	0.74	9.71	0.75	9.70	1.06
Finger Sense Recognition	9.44	1.19	9.60	0.71	9.58	0.72	9.74	0.62
Finger Sense Fingertip Writing	4.76	2.24	5.36	1.75	5.08	2.08	4.91	2.09
Sentence Sense	6.72	1.82	7.80	2.38	7.38	2.02	7.70	2.12
Copying (Task A)	9.33	5.30	14.08	4.92	9.86	4.73	14.00	6.11
Copying (Task B)	36.54	18.26	72.84	26.28	37.75	23.40	64.87	28.79
Note-Taking (Task B)	16.71	8.64	23.80	8.36	15.96	11.11	20.78	9.78

The pretest scores for the treatment and control conditions were examined to ensure that there were no significant differences found. *T*-tests on the pretest scores for each of the 24 subtests confirmed there were no pre-existing significant differences between the treatment and control conditions.

Participants in the treatment condition received between 5 and 23 treatment sessions. Treatment condition participants averaged 9.92 sessions each, with a standard deviation of 5.06 sessions. Nearly half of the treatment group participants received 7 or 8 treatment sessions. Figure 2 displays the number of participants receiving each number of treatment sessions.

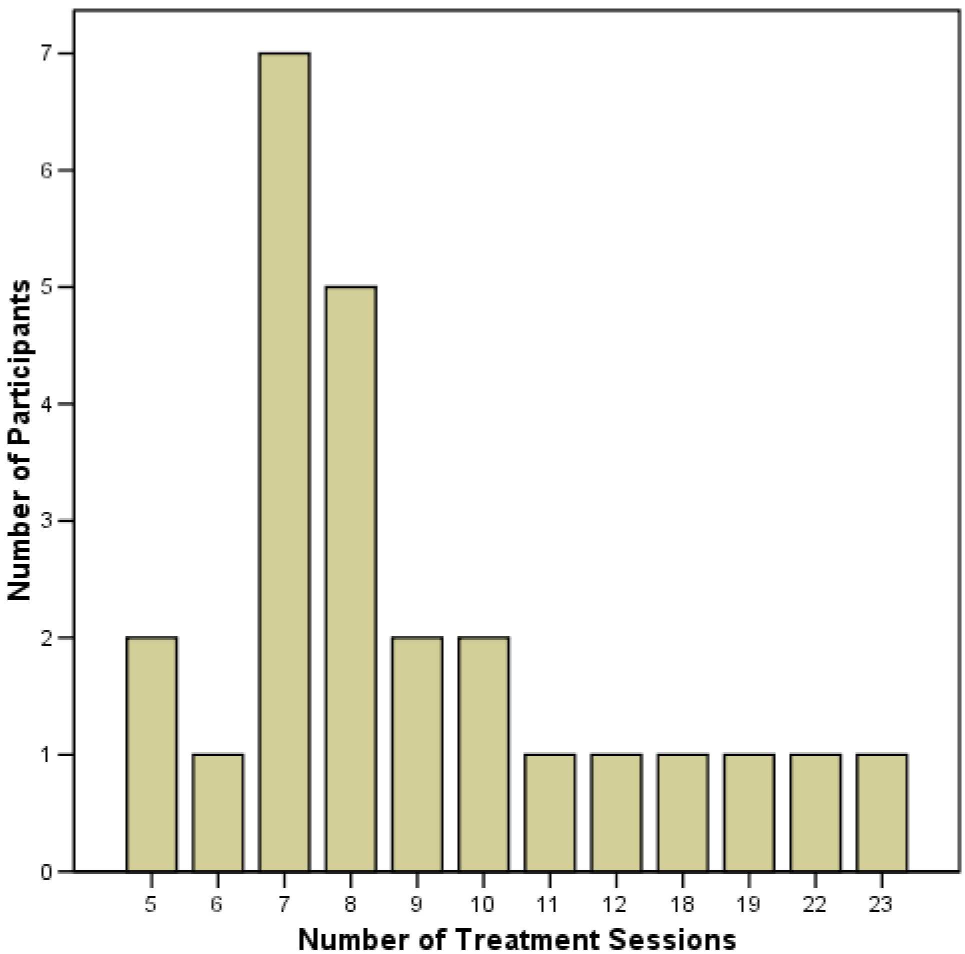

Figure 2. Number of treatment sessions completed by each participant in the treatment condition.

In order to test for differences between the treatment and control groups, the general linear model for repeated measures was employed with treatment condition as the between-subjects factor, pretest/posttest as the within-subjects factor, and then each of the 24 subtests as the dependent variables. The main focus of these analyses was determining whether there was a significant difference between the treatment and control groups, or an interaction between treatment assignment and pretest/posttest score.

Of the 24 repeated measures analyses, two will be discussed because the results support possible effects of the intervention. The participants who underwent the intervention gained approximately 2 points more from pretest to posttest on the RAN Digit subtest than did those students in the control group. Table 5 displays the ANOVA results. Although the magnitude of the effect appears to be small, there may be some practical significance to the association between subtest gain (pretest to posttest) and treatment effect.

Table 5

Summary of the Analysis of RAN Digit Subtest

Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**	**Partial Eta Squared**
Treatment Condition	8.168	1	8.168	.033	.856	.001
Error (Treatment)	11063.747	45	245.861			
Pre/Post	147.768	1	147.768	10.269	.002	.186
Pre/Post * Treatment	105.257	1	105.257	7.315	.01	.14
Error (Pre/Post)	647.552	45	14.390			

There is also some evidence that the intervention may have had an effect on participants' ability to perform on the Receptive Coding subtest. Participants in the treatment condition gained approximately two points from pretest to posttest, compared to a gain of less than one point among the controls. In addition, there was less variance among the treated group's scores than among those in the control group. Table 6 presents the ANOVA results. Again, the magnitude of the effect was small.

Table 6

Summary of the Analysis of Receptive Coding Subtest

Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**	**Partial Eta Squared**
Treatment Condition	65.261	1	65.261	3.374	.073	.068
Error (Treatment)	889.697	46	19.341			
Pre/Post	48.606	1	48.606	11.123	.002	.195
Pre/Post * Treatment	15.939	1	15.939	3.647	.062	.073
Error (Pre/Post)	201.019	46	4.370			

Following the repeated measures analyses, a closer examination was made of the effects of differing levels of the intervention. Regression analyses were performed using number of treatment sessions as the predictor variable and the difference score (posttest minus pretest) from each of the 24 subtests as the criterion variable. Again, only the results from those subtests where the number of treatment sessions did have an effect on the difference score are presented.

The number of treatment sessions had a positive effect on the gains made by treatment group participants in two subtest areas. As can be seen in Table 7 and Figures 3 and 4 below, there was a positive relationship between the number of treatment sessions to which a participant was exposed and the gains that participant made on the Receptive Coding and Finger Sense Recognition subtests. In other words, the more sessions of *DDR* a participant completed, the greater gain he or she made from pretest to posttest on these two subtests.

Table 7

Regression Analysis Summary for Number of Treatment Sessions Predicting Change in Receptive Coding Scores from Pretest to Posttest

Predictor Variable	**Criterion (Subtest) Variables**	**B**	**$Error_B$**	**β**	**R^2**	**Significance**
Number of Treatment Sessions	Receptive Coding	.252	.100	.464	.215	.02
	Finger Sense Recognition	.111	.054	.392	.154	.05

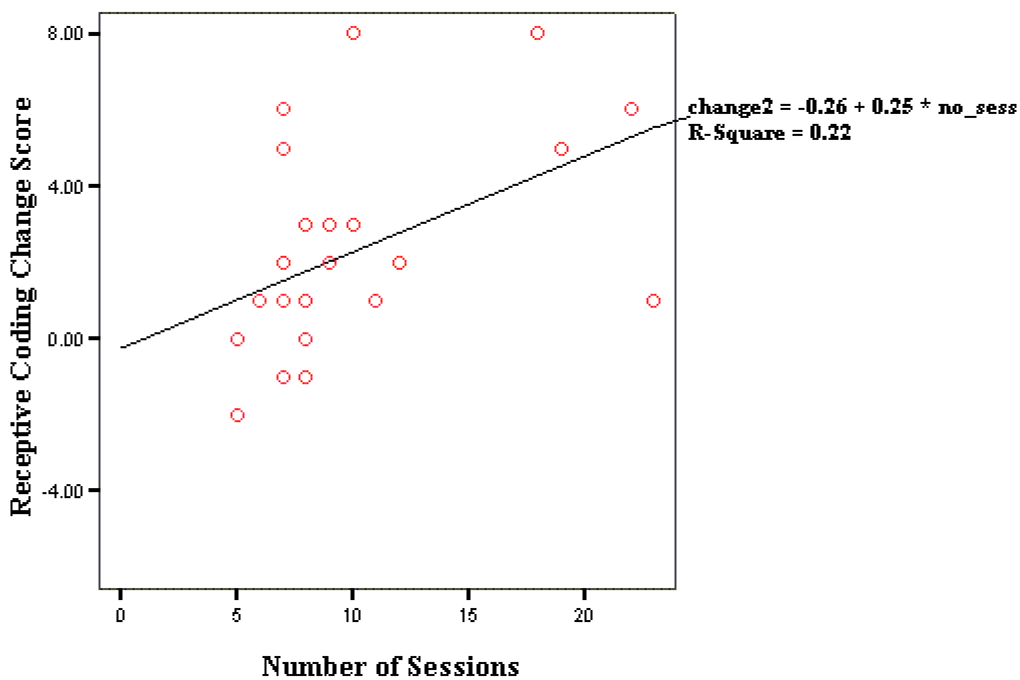

Figure 3. Scatterplot with regression line showing change in Receptive Coding scores by number of treatment sessions.

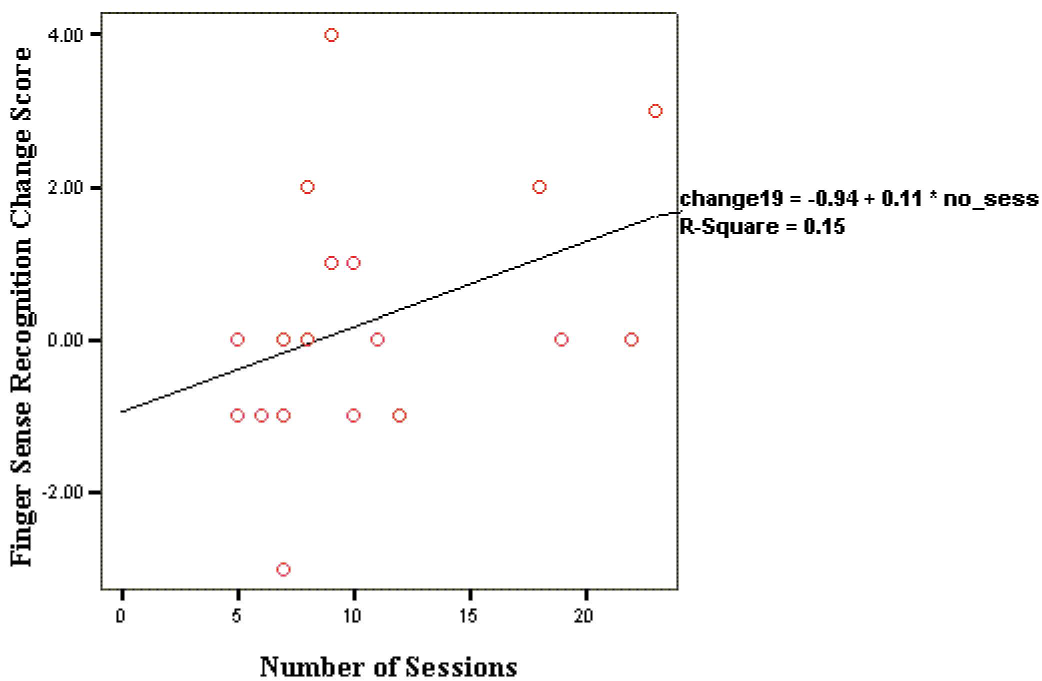

Figure 4. Scatterplot with regression line showing change in Finger Sense Recognition scores by number of treatment sessions.

Discussion

Regression analyses revealed a positive relationship between the number of treatment sessions completed and the gains made on Receptive Coding and Finger Sense Recognition subtests. This supports the need for further research and provides guidance for it (e.g., longer intervention periods, increased treatments during the intervention period, and targeted PAL-RW testing versus full administration).

A perplexing result was that of an apparent decrease in performance by the treatment group on the RAN Digits subtest, according to the repeated measures analyses. One possible explanation is that, with the small sample size, the poorer performance of just a few students unduly swayed the results. Another possible explanation is that the intervention does, in some way, result in poorer performance on this measure. Regardless, the ambiguity of findings points to the need for additional research.

Results from the general linear model for repeated measures indicate that the treatment may have had an effect on participants' ability to perform on the Receptive Coding subtest. For a sixth-grade student, this subtest requires (a) looking at a target word for only one second before viewing a page with letters and then determining if they were or were not in the previous word in the correct order and (b) looking at a target word for only one second before viewing a page with a letter and determining if it was or was not in the previous word. The student may not look at the word again and must try to remember what was seen. The subtest measures the child's ability to "code whole written words into short-term memory and then to segment each word into units of different size" (Berninger, 2001, p. 32). Furthermore, attention is vital, as the target word is presented only briefly.

DDR requires the ability to attend to a stimulus (moving arrows on a screen) and decode the meaning (direction) of those arrows. It also requires responding to the sequence and timing necessary to progress in the game as well as monitoring reinforcement (rank, combo score, energy level, and per-step visual feedback such as perfect, good, or miss). Because of demonstrated improvement in the Receptive Coding subtests, the known link between ADHD and dyslexia, motor timing deficits (Wolff, 1999), and memory impairments (Denckla, 1998a; Pennington, 1991) and their relevance in this context is of particular interest. Is it that the game has a positive effect on short-term memory—requiring participants to attend to various visual and auditory cues simultaneously while fluidly storing information and accessing it in their short-term memory—or is it a function of learning and replicating a pattern? Is it possible to understand this distinction using this game? While no overall discernable pattern exists in the game play, certain combinations appear in some songs. One option available in the game, though not used in the present study, is training that allows participants to learn entire songs or certain dance steps within a song. This option could possibly facilitate recognizing, learning, and mimicking patterns. The relationship of the auditory cues/rhythmic component is also unclear and might warrant removing the auditory cues in further research to better understand this distinction.

Limitations

During the first project period (Spring 2002), sample size and intervention period were considered to be limitations. Time constraints, in particular, severely limited the sample size. Because students were available for treatment only during elective class periods and a single class period could provide time for only two full sessions, some eligible students were not included in the study. For example, a large number of students were scheduled for their elective class during third period, but the maximum number of students that could be included in the treatment group per class period was eight (2 students x 2 sessions per class period x 2 days per week). Consequently, although more than eight students in the third-period elective class were eligible, some were excluded through random assignment. Furthermore, scheduling conflicts dictated the shortened treatment period (4 weeks) and caused students in the treatment group to miss sessions. For example, class trips, team activities, and school assemblies interfered with scheduled sessions a number of times.

During the second project period (Spring/Summer 2004), sample size was not restricted but was, again, small. The two schools selected for participation were smaller, so the decrease in potential participants was expected. The intervention period was extended to 12 weeks, and as a result students in the treatment group completed 18 to 23 sessions despite the usual scheduling conflicts associated with the school environment (e.g., activities and assemblies) and other factors such as illness and school closings due to bad weather. Additionally, at one location guardians agreed to extend the treatment period beyond the last day of school to make up for a missed week earlier in the project period.

During the third project period (Fall 2004), the sample size was not restricted and improved relatively. Due to project deadlines the intervention period was limited to 8 weeks, allowing students to complete between 9 and 12 sessions.

As demonstrated by the implementation variance described in prior paragraphs, arranging to conduct experimental research in a school setting was difficult. Investigators contacted a total of 15 school systems in four states. In some cases researchers used a top-down approach (i.e., contact initiated with the superintendent); in others, a bottom-up approach (i.e., contact initiated with a teacher or principal). Likewise, multiple modes of contact were used, including telephone, e-mail, postal mail, and face-to-face meetings. An obvious difference in success or failure to secure participation could not be delineated.

Another project-wide challenge was differing procedures for project approval among school systems. Rarely did a superintendent or director-level official exercise the autonomy to accept or reject the project. Typically, central office staff or a research review committee requested a project description for formal review.

Though highly recommended by reading specialists to the investigators, several issues related to the PAL-RW were viewed as limitations. First, the test does not yield a composite score, necessitating analyses on 24 separate subtest scores. Second, raw scores are converted to decile scores, meaning the standard scores yield only the *tenth* of the distribution in which the child's performance falls. Third, the limited number of items in the upper level (as required for students in Grade 6) of certain subtests makes interpretation more difficult. Last, test-retest comparison of subtests produced reliability coefficients ranging from .61 to .92, with 5 of 24 subtests below the acceptable level of .70; however, consultation with experts and a thorough review of test reviews led researchers to conclude that the PAL-RW was, at the time of the study, the best assessment of reading and writing processes.

Future Directions

There may be value in replicating this study and limiting participation to those students who have been identified with only ADHD or dyslexia, not both. Future investigations might also benefit from other measures such as Achenbach's Child Behavior Checklist or Conners' Ratings Scales (Teacher and Parent) to document changes in ADHD/behavior. The Wide Range Assessment of Memory and Learning (WRAML) might also be appropriate in future studies more narrowly focused on memory. The extent to which other tests measuring receptive coding abilities exist will also be explored. It is likely that other video games will be examined as possible treatments to determine if they produce similar results.

These findings may also warrant the inclusion of brain imaging specifically related to the angular gyrus as associated with integration of orthographic information (Horwitz, Rumsey, & Donohue, 1998; Shaywitz et al., 1998) and the cerebellum as related to deficits in working memory (Anderson et al., 1999; Berquin et al., 1998; Schmahmann & Sherman, 1998).

The video game industry has become a powerful influence on young people, representing a market share of approximately $10 billion in 2002 (Foreman, 2003). It is not uncommon for popular games to top $100 million in sales (Hu, 2002), and with Sony PlayStation One consoles being found in more than one of every three U.S. households, video games have indeed developed into a pervasive technology (“Sony sales data for holiday season,” 2004). A golden opportunity lies before us if this technology can be leveraged to address specific education problems such as those considered here.

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