



The integration of the neurosciences, child public health, and education practice: hemisphere-specific remediation strategies as a discipline partnered rehabilitation tool in ADD/ADHD

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ADD/ADHD is the most common and most studied neurodevelopmental problem. Recent statistics from the U.S. Center for Disease Control state that 11% or approximately one out of every nine children in the US and one in five high school boys are diagnosed with ADD/ADHD. This number is thought to be increasing at around 15–20% per year. The US National Institute of Mental Health's Multi-modal Treatment Study has shown that medication has no long-term benefit for those with ADHD. To effectively address ADD/ADHD from within the framework of child public health, an interdisciplinary strategy is necessary that is based on a neuroeducational model that can be readily implemented on a large-scale within the educational system. This study is based on previous findings that ADD/ADHD children possess underactivity between sub-cortical and cortical regions. An imbalance of activity or arousal in one area can result in functional disconnections similar to that seen in split-brain patients. Since ADD/ADHD children exhibit deficient performance on tests developed to measure perceptual laterality, evidence of weak laterality or failure to develop laterality has been found across various modalities (auditory, visual, tactile). This has reportedly resulted in abnormal cerebral organization and ineffective cortical specialization necessary for the development of language and non-language function. This pilot study examines groups of ADD/ADHD and control elementary school children all of whom were administered all of the subtests of the Wechsler Individual Achievement Tests, the Brown Parent Questionnaire, and given objective performance measures on tests of motor and sensory coordinative abilities. Results measured after a 12-week remediation program aimed at increasing the activity of the hypothesized underactive right hemisphere function, yielded significant improvement of greater than 2 years in grade level in all domains except in mathematical reasoning. The treated group also displayed a significant improvement in behavior with a reduction in Brown scale behavioral scores. Non-treated control participants did not exhibit significant differences during the same 12 week period in academic measurements. Controls were significantly different from treatment participants in all domains after a 12-week period. The non-treatment group also demonstrated an increase in behavioral scores and increased symptoms of ADD/ADHD over the same time period when compared to the treated group. Results are discussed in the context of the concept of functional disconnectivity in ADD/ADHD children.

Keywords: attention deficit hyperactivity disorder, hemispheric function, rehabilitation, synchronized metronome, hemisphere-specific training

INTRODUCTION

Public health issues surrounding Attention Deficit/Hyperactivity Disorders (ADD/ADHD) have not been thoroughly studied but for a few major published works on the subject (1, 2). Of consequence for public health is that while ADHD is the most

common and the most studied neurodevelopmental problem, each discipline working with the problem has its own approach to remediation ranging from behavioral management, medication, behavior modification, and/or resource-room management within the educational system. We had earlier (3) noted that with

the integration of the substance of all disciplines we could be able to create interventions that would no longer be physiologically, medically, or educationally based but rather be knowledge-based.

Since 1902 when George Still described the “lack of moral control among children without noted physical impairments,” (4) no single cause of the disorder has been found. Numerous researchers have reported specific impairment in executive functioning as part of the core deficits of ADHD (5, 6). Barkley (5) postulated a primary deficit in response inhibition broadly affecting executive functions. Tannock (6) had suggested three areas as potential core deficits: executive functions including deficits in working memory, visual-spatial orienting, and energetic state, particularly activation. To date, there is no experimental evidence implicating a single set of deficits shared by all individuals with ADD/ADHD. From a classification perspective, it would simplify our understanding of the disorder if a measurable core deficit were identified. Nevertheless, because ADD/ADHD is so heterogeneous, it seems unlikely that a single unifying “deficit” would emerge. This may well be why the medical model may be an inappropriate way to both view the problem and also to address its remediation (7). The current trend in the mental health system is toward understanding psychological issues according to a medical model in which behavioral symptoms are viewed as organic diseases that should be treated with medical interventions (8). The medical model presents attention deficit hyperactivity disorder (ADHD) as a brain dysfunction to be treated with medication that changes the biology of the brain. More comprehensive programs that would effect neuroplasticity may be better suited to effect change in ADD/ADHD on a large scale.

In summary, the fact that the constellation of behaviors labeled ADHD is considered a medical disorder conveys the expectation to parents, children, and teachers that behavior should be unchanging, constant, and made better only by medicine. In many ways, the diagnosis creates an expectation that manifests in the very symptoms it sets out to describe.

Since Orton (9) in the 1920s, it has been generally assumed that persons with ADD and ADHD have abnormal cerebral organization including atypical or weak patterns of hemisphere specialization (10, 11). The developmental lag hypothesis proposed by Lenneberg (12) suggested that such children are slower to develop basic language skills and demonstrate weak hemispheric specialization for language tasks, including reading. In a reformulation of the progressive lateralization hypothesis (13), it may be that sub-cortical and antero-posterior progressions have a differential developmental course with ADD/ADHD children and adults compared with control subjects or those with acquired syndromes. Because ADD/ADHD children exhibit deficient performance on a variety of tests thought to be a measure of perceptual laterality, evidence of weak laterality or failure to develop laterality has been found across various modalities (audio, visual, tactile) (14). These children are thought to have abnormal cerebral organization, as suggested by Corballis (11). The basic assumption is that dysfunction in the central nervous system, either prenatally or during early postnatal development, results in abnormal cerebral organization and dysfunctional specialization needed for lateralized processing of language and non-language skills. It is thought that cortical and sub-cortical dysfunction resulting from aberrant patterns of

activation or arousal (14), inter- and intra-hemispheric transmission deficits, inadequate resource allocation (15), or any combination of these may compromise the effectiveness of hemispheric specialization in ADD/ADHD individuals (16).

Rabiner and Malone (17) have indicated that children with learning problems associated with ADD/ADHD can acquire at least grade-level reading skills if such children receive early intensive intervention to correct their deficiencies (18, 19). The comorbidity of ADD/ADHD, reading difficulties, and dysfunction in hemispheric specialization justifies the examination and evaluation of remedial strategies for cognitive tasks in ADD/ADHD children that are hemisphere specific.

To examine this notion further, we conducted a pilot study evaluating ADD/ADHD elementary school children from first through sixth grade. All participants were administered tests of academic performance evaluating relevant cognitive abilities, motor and coordinative, and rudimentary literacy skills. ADD/ADHD children were tested both before and after participation in a hemisphere-specific remediation program. Significant improvement was noted with hemisphere-specific interventions as opposed to educational remediation techniques not tailored to the neurocognitive strengths and weaknesses of the child (20).

The literature supports the notion that interventions for ADD/ADHD can be both individualized and administered on a large scale through hemisphere-specific regimens administered through the educational system that would produce a significant public health effect.

This study examines an intervention that involves neurophysiologically specific treatment that is integrated with educational interventions that address the heterogeneity of symptoms of ADD/ADHD.

METHODS

PARTICIPANTS

The pool of participants for this study consisted of 122 children between 6 and 12.11 years of age diagnosed with Attention Deficit Disorder (ADD) or ADHD (ADD/ADHD) who had undergone an intervention program described below and a control group of ADD/ADHD children not having undergone such a program whose characteristics are described below. Informed consent was obtained from each parent/guardian and the project underwent IRB review and approval.

The 122 participant children were randomly selected from a larger group of 181 children undergoing the treatment program; 59 were excluded for not meeting the criteria specified below. At the conclusion of the 12-week intervention program, all children were tested again using the same instruments. All the obtained percentile scores were converted to grade equivalent.

The participants presented with inattention, hyperactivity, impulsivity, academic under-achievement, and/or behavior problems, and each met the criteria of the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, (21) and clearly demonstrated the absence of coexisting conditions as evaluated by non-participating licensed Psychologists or Psychiatrists. The participating children came from centers located in school districts in middle- to upper-middle-class school districts in Nassau and Suffolk Counties, New York, NY, USA. Of the total participants,

94 (77%) were male and 28 (23%) female. For both control, and treatment group participating children, all were in the average range of intellectual ability as measured by standardized tests of intelligence (data not herein reported). Parental informed consent was obtained. The exclusionary criteria included (a) severe vision or hearing problems, (b) frequent ear infections, (c) severe emotional problems, (d) limited intellectual ability, (f) English as a second language, and (g) diagnosed with Pervasive Developmental Disorder. All children in the study's treatment group were taking stimulant medication before, during, and at the conclusion of the study. No changes in pharmacological management occurred during the course of the study for any of the participants. Formal testing employing the BADD (22), was 100% concordant with the diagnosis of ADD/ADHD that each participant had received elsewhere before entry into the study. Each of the participants of the treatment group underwent a 12-week interventional program employing resources described below.

A second group of children between the ages of 4–13 (SD = 8.94) were also studied. While all went through the same initial evaluation process, none underwent any of the interventions that the treatment group did, but were likewise re-tested after 12 weeks. Of the participants in the control group, 22 were male (59%) and 15 (41%) female. Each was diagnosed with ADD or ADHD (ADD/ADHD) and met the identical criteria specified above. The participating children came from clinics located in school districts in middle- to upper-middle-class school districts in various regions of the United States that included, St Louis, Missouri, Los Angeles, and San Francisco California, Tampa and Miami, Florida, Carey Indiana, Wake Forest, Illinois, Atlanta Georgia, and Minneapolis, Minnesota.

Twenty-two of the children in the control group in the study were taking stimulant medication before, during, and at the conclusion of the study.

PROCEDURE

Treatment-intervention

Initial pre-treatment evaluations included the functional assessment of sensory and motor function and on a separate day, academic testing as described below. The combined testing allowed the clinicians to formulate a remediation program for participants in the treatment group. The program was designed to selectively stimulate skills that were significantly below age-or functional level for a given participant. Additionally, tasks were designed to stimulate the less efficiently performing hemisphere (23). Each participant participated in this multi-modal program three times per week for 1 h each time over a 12-week period. Each treatment group participant underwent specific interdisciplinary supervised activities during that time that included: sensory stimulation, motor training, aerobic strength and conditioning, and academic training. Compliance with the regimen was achieved with most but not all participants. Also employed in the regimen were primitive reflex inhibition exercises, as well as academic home training exercises, hemispheric music stimulation, dietary changes and lifestyle management. After 36 sessions over a 12-week period, participants were again tested on the same battery of tests of sensory, motor, and academic performance, including the completion of the parent behavioral checklist. The same individual performed the academic testing during both the pre- and post-treatment sessions.

The program attempted to achieve physiologic balance, temporal coherence, and evenness of skills that would be at or above the child's actual age and or grade level.

Synchronized metronome training (SMT) was employed. Participants in the treatment group wore a headphone and listened to a reoccurring metronomic beat. As they listened to the beat, they engaged in physical movements such as clapping hand-to-hand with a sensor on one palm as they matched their physical movement to the presentation of the beat (e.g., clap at the beat). The training attempted to reduce the mean negative synchronization error during normal tracking of the regularly occurring metronome beat (clapping before or past the beat). During training, participants received feedback through an auditory guidance system as they progressed through the simple, interactive physical movements. Although feedback was also provided through visual stimuli, the auditory feedback guidance system was the primary feedback method. The auditory feedback system provided tonal stimuli that indicated whether the participant responded before, at, or past the regularly occurring auditory metronomic beat. The accuracy of participants' expectancy response to the metronome beat was provided in milliseconds (ms), with different tones indicating far from, close to, or at the metronome beat. A visual reading of millisecond latency was also presented to the participants on a computer screen. These interventional procedures have been elsewhere reported to be effective in effective change in psychophysical signal detection capabilities (24, 25).

The purpose of the training was to improve participants' timing/rhythmicity by reducing the latency between the onset of the metronome beat and the participant's expectancy response to the beat. At the completion of the treatment program, participants had engaged in approximately 25,000 motoric repetitions. The purpose of the procedure was to examine the relationship between improvements in domain-specific SMT-based intervention and domain general improvements in the areas of academics and ADD/ADHD functioning – more fully explained in (22, 24).

Assessment of treatment effects

All participating children in both treatment and control groups were given the Wechsler Individual Achievement Tests [WIAT-II] (26), including Word Reading, Reading Comprehension, Mathematical Reasoning, Spelling, Written Expression, Listening Comprehension, and Oral subtests. All subtests were given immediately before the participants' start in the program and again at the conclusion of the 12-week hemisphere-specific intervention program. Additionally, all participants' parents were given the Brown Attention Deficit Disorder Scales (BADD), (22) appropriate for each participant's age, both before and after the 12-week intervention program.

The WIAT reading tasks were chosen because they require the ability of the participant to correctly read a series of printed words, sentences, and paragraphs and to answer questions about what was read and to correctly apply phonetic decoding rules when reading a series of nonsense words.

The Mathematical Reasoning Subtest of the WIAT was chosen because it assesses the ability of the participants to add, subtract, multiply, and divide one- to three-digit numbers and to understand number, consumer math concepts, geometric measurement, basic graphs, and solve one-step word problems.

The Spelling (Written Language) subtest was chosen because it requires the participants to correctly spell verbally presented words and to generate words within a category, generate sentences to describe visual cues, combine sentences, and compose an organized paragraph. This subtest likely measures skills less related to attentional concerns and more to a direct measure of achievement.

The WIAT Oral Language subtest was chosen as the tasks require the participants to identify a picture best representing an orally presented descriptor or to generate a word that matches the picture and to generate words within a category, to describe scenes and give directions. Whereas IQ subtests are largely tests of thinking and reasoning skills, the WIAT-II is a test of academic achievement. We were interested in examining whether hemisphere specific training would have an effect on unmasking the actual level of achievement with reduced attentional effects and whether we could conclude that the evidence is enough to warrant a clinical trial on the notion of hemisphere-specific training.

STATISTICAL ANALYSES

Pre-Post treatment differences were examined by using correlated *t* tests.

RESULTS

The results indicated significant differences ($t = 5.25$, $df = 60$, $p < 0.000005$) between pre- and post-treatment responses by parents of the ADD/ADHD children in the treatment group as reported on the parent completed BADD, 79% of the participants demonstrated a significant improvement on pre- as compared with post-testing and a 67% difference between the treatment and control group parental responses on the Brown scale (see **Tables 1A,C**).

Pre-post sensory-motor measured performance changes were likewise significant for the treatment group. Rhythmic integrated eye-hand and eye-foot coordination revealed that in excess of 54% of those ADD/ADHD children tested demonstrated statistically significant improvement ($t = 74.71$, $df = 97$, $p < 0.000001$). The non-treatment control group, however, demonstrated a significant 94% difference with the experimental treatment group ($t = 77.3$, $df = 96$, $p < 0.0005$).

In the measurement of academic performance on subtests of the WIAT, the results indicated significant changes in all domains measured that required a strong attentional component to test performance in the treatment but not in the non-treatment control group. Tasks like Mathematical Reasoning, which require greater academic skill and less attentional focus, were more resistant to change. For example, on the WIAT Word Reading subtest, 62% of participants demonstrated a significant improvement, defined for this study as greater than 2 years improvement in grade level ($t = 2.94$, $df = 38$, $p < 0.01$) but no significant differences between pre- and post-testing were observed with WIAT Mathematical Reasoning in the treatment group ($t = 0.55$, $df = 122$, NS). Even so, significant differences were still reported in Mathematical Reasoning associated with hemisphere-specific training when comparing controls with the treatment group ($df = 122$, $t = 2.96$, $p < 0.001$).

On the other hand, although 52 and 76% of participants in the treatment group exhibited significant change of greater than two or more years increase in performance after the 12-week

treatment program in Spelling ($t = 4.07$, $df = 119$, $p < 0.0005$) and Written Expression ($t = 17.64$, $df = 119$, $p < 0.000001$), respectively, a significant 82% positive change was noted in performance related to Listening Comprehension, a more heavily attentionally loaded task ($t = 8.52$, $df = 121$, $p < 0.000001$). In contrasting the treatment and non-treatment groups a significant 52% difference was noted for both Spelling ($t = 4.40$, $df = 119$, $p < 0.0005$) and Written Expression ($t = 5.97$, $df = 119$, $p < 0.0005$) respectively, both domains likely having a significant attentional load.

To summarize, results demonstrated significant improvement of greater than 2 years in grade level in all domains except in mathematical reasoning. The treated group also displayed a significant improvement in behavior with a reduction in Brown scale behavioral scores. Non-treated control participants did not exhibit significant differences during the same 12 week period in academic measurements, but did so when compared to the treated group (see **Table 1B**). The non-treatment group did show an increase in behavioral scores and increased symptoms of ADD/ADHD over the same time period this difference was significant relative to the treated group.

DISCUSSION

All sensory perception is based on the effectiveness of the arousal level of non-specific, mostly subconscious, activity of the brain. No specific sensory modality perception like vision or hearing can exist without a baseline arousal level. The more stimulation or greater frequency of stimulation, the more aroused an individual will be. Luria (27) postulated that the brain was divided into three functional units: (1) the arousal unit, (2) the sensory receptive and integrative unit, and (3) the planning and organizational unit. He subdivided the last two into three hierarchic zones. The primary zone is responsible for sorting and recording incoming sensory information. The secondary zone organizes and codes information from the primary zone. The tertiary zone is where data are merged from multiple sources of input and collated as the basis for organizing complex behavioral responses (27). Luria's dynamic progression of lateralized function is similar to Hughlings Jackson's Cartesian coordinates with respect to progressive function from brainstem to cortical regions (28).

Accordingly, the goal of clinical intervention is to attempt to develop brain-based intervention strategies for children with dysfunctions of lateralization that would seem to be threefold: first, to isolate cognitive abilities that are especially important for learning and language development, along with deficiencies in these abilities that might distinguish between poor and normally developing learners; second, to isolate experiential and instructional variables that differentially affect achievement in school and other life programs; and third, to isolate the genetic and neurological underpinnings of the cognitive abilities underlying academic abilities in ADD/ADHD children in the interest of distinguishing between genetic and neuropathological causes of deficits in these abilities in childhood.

Brain development and the adequacy of it functioning are dependent in large measure on sensory input. Specific sensory perceptual processes like vision and hearing are dependent on

Table 1 | (A) Experimental group – pre- vs. post-testing. (B) Control group – pre- vs. post-testing. (C) Post-testing control vs. experimental groups.

	Pre-testing			Post-testing			<i>t</i>	<i>p</i>	% Change [†]
	<i>N</i>	<i>M</i>	<i>d</i>	<i>N</i>	<i>M</i>	<i>d</i>			
Brown	60	67.11	16.87	60	53.42	16.02	5.25	0.000005	0.79
IM	97	194.44	1.42	97	89.84	0.96	74.71	0.000001	0.54
WIAT word reading	38	3.34	2.75	38	5.31	3.2	2.94	0.01	0.62
WIAT math reasoning	122	3.2	48.06	122	5.6	5.67	0.55	**	0.56
WIAT spelling	119	3.2	3.36	119	5.6	2.85	4.07	0.0005	0.57
WIAT written expression	119	2.8	3.16	119	5.8	3.3	17.64	0.000001	0.52
WIAT listening comp.	121	3.2	17.31	121	6.1	2.74	8.52	0.000001	0.85
WIAT oral	117	2.7	3.02	117	6.1	4.05	10.62	0.000001	0.56

	Pre-testing			Post-testing			<i>t</i>	<i>p</i>	% Change [†]
	<i>N</i>	<i>M</i>	<i>d</i>	<i>N</i>	<i>M</i>	<i>d</i>			
Brown	39	75.95	13.01	39	80.03	11.56	18.54	0.0005	0.05
IM	37	4.98	2.55	37	5.58	2.21	2.00	**	0.11
WIAT word reading	28	3.31	3.31	28	3.69	3.47	0.18	**	0.12
WIAT math reasoning	34	3.06	3.26	34	3.38	3.25	0.08	**	0.09
WIAT spelling	32	2.90	3.35	32	2.91	3.13	0.01	**	0.01
WIAT written expression	32	3.11	3.40	32	2.99	3.48	0.16	**	−0.04
WIAT listening comp.	34	2.37	3.29	34	3.05	3.49	0.81	**	0.08
WIAT oral	33	3.03	3.53	33	2.86	3.63	0.21	**	−0.06

	Experimental			Control			<i>t</i>	<i>p</i>	% Diff. [†]
	<i>N</i>	<i>M</i>	<i>d</i>	<i>N</i>	<i>M</i>	<i>d</i>			
Brown	60	53.42	16.02	39	80.03	11.56	14.38	0.0005	0.67
IM	97	89.84	0.96	37	5.58	2.21	77.3	0.0005	0.94
WIAT word reading	38	5.31	3.2	28	3.69	3.47	2.21	0.01	0.69
WIAT math reasoning	122	5.6	5.67	34	3.38	3.25	2.96	0.001	0.60
WIAT spelling	119	5.6	2.85	32	2.91	3.13	4.40	0.0005	0.52
WIAT written expression	119	5.8	3.3	32	2.99	3.48	5.97	0.0005	0.52
WIAT listening comp.	121	6.1	2.74	34	3.05	3.49	7.09	0.0005	0.50
WIAT oral	117	6.1	4.05	33	2.86	3.63	5.22	0.0005	0.47

[†] Change > 2 grade levels within the 12-week program.

**Not significant.

non-specific sensory input. Sensory input in turn is driven by motor activity, which helps to engage the sensory systems as well as motor feedback. This, in turn, creates a baseline arousal and synchronization of brain activity through activation of cerebellar as well as non-specific and specific thalamo-cortical pathways (8). This is a form of constant arousal and is dependent on a constant flow of sensory input from receptors that are found in slowly adapting receptors, which are most prevalent in postural muscles especially the muscles of the spine and neck. These receptors receive the majority of their stimulation from gravity, creating a feedback loop that forms the basis of most if not all of brain

function. Sensory input drives the brain, and motor activity drives the sensory system. Without sensory input the brain cannot perceive or process input adequately. Without motor activity provided by constant action of postural muscles a large proportion of sensory stimuli are lost to further processing (29). This loop is the somatosensory system (30).

Of particular interest in this study was that the Brown Attention Deficit Disorder Scale data, when completed by the parents of the participants of those in the treatment group at the outset of the intervention, revealed that all participants were ADD/ADHD. After the course of the 12-week hemispheric specific intervention,

81% were considered to no longer be demonstrating ADD/ADHD behaviors, based on the Brown Scale. In contrast the control group showed no change in behavior or slight increased symptoms with parents reporting worse performance as rated by the Brown scale in the same 12 week timeframe.

Behavioral measures represented by the Brown parent scale demonstrated that a significant number of children in the treatment group no longer met the diagnostic criteria for ADD/ADHD after the 12-week intervention, while the control group did not demonstrate a significant change and actually demonstrated a decreased performance on the Brown scale (BADD) associated that is reflective of an increase in the reported symptoms of ADD/ADHD relative to the treatment group.

We here examined if treatment that is preferentially aimed at an hypothesized underactive right hemisphere in ADD/ADHD children would have a positive effect on their sensory-motor performance, as well as on cognitive function related to attention focus. The results support further examination by means of a large-scale clinical trial of the notion that hemisphere-specific training will have a significant effect on attentional performance in children with ADD/ADHD.

The approach is potentially useful as a child public health intervention without the use of drugs in the treatment of attentional problems of childhood. The clinical trials will have to examine the differential effects of medication and hemispheric specific treatment, as well as the effects of nutritional interventions on academic and on sensory, motor, attentional, and signal detection performance, not examined in this study.

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