



# Persistent Childhood Primitive Reflex Reduction Effects on Cognitive, Sensorimotor, and Academic Performance in ADHD

Robert Melillo<sup>1</sup>, Gerry Leisman<sup>1,2\*</sup>, Raed Mualem<sup>3</sup>, Alon Ornai<sup>3</sup> and Eli Carmeli<sup>1</sup>

<sup>1</sup> Department of Physiotherapy, Faculty of Social Welfare and Health Sciences, University of Haifa, Haifa, Israel,

<sup>2</sup> Neurofisiología Clínica, Instituto de Neurología y Neurocirugía Neurofisiología Clínica, Universidad de Ciencias Médicas, Havana, Cuba, <sup>3</sup> Oranim Academic College, Qiriat Tivon, Israel

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### \*Correspondence:

Gerry Leisman  
g.leisman@alumni.manchester.ac.uk

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A study was performed on 2,175 individuals between the ages of 3.2 and 22.04 years diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) and drawn from 89 separate locations across the United States in satellite clinics with common practices and common staff training and equipment. The objective was to determine the efficacy of a hemispheric-based training program to reduce extant retained primitive reflexes (RPRs) and examine the relationship to motor function by metronome-based motor, DL, and cognitive tasks measured by subtests of the Wechsler Wide Range Achievement Test. After a 12-week program, RPR's were significantly reduced, as well as performance on all motor and cognitive measures significantly increased. Listening comprehension demonstrated significant increases between pre- and post-testing of 7% ( $W = 1213000$ ;  $df = 2094$ ;  $p < 0.0001$ ) and mathematical problem solving revealed a significant increase of 5% ( $W = 1331500$ ;  $df = 2091$ ;  $p < 0.0001$ ) associated with a significant reduction in primitive reflexes. The study concluded that the incorporation of relatively simple hemispheric-based programming within the educational system worldwide could relatively inexpensively increase academic, cognitive, and motor performance.

**Keywords:** retained primitive reflexes, academic achievement, cognition development, ADHD, hemisphere-specific training

## INTRODUCTION

Much has been written to caution health care providers, educators, and parents of the inherent difficulties associated with the use of methods and methodologies that are not empirically validated in managing children with disabilities [e.g., (1–3)]. Many established practices in the fields of Clinical Psychology, Occupational and Physical Therapies, as well as in primary education have not been effectively studied and their effectiveness has not been determined under controlled conditions. One difficulty in endeavoring to foment an unbiased understanding of intervention strategies in rehabilitation sciences is the notion that physical modification of the body is the purview of Medicine and the Health Care professions when we well know that both Rehabilitation Sciences and Education are inescapably involved in neuroplasticity [cf. (4, 5)]. What all professions concerned with education, rehabilitation, and neuroconnectivity require are both well-designed clinical trials and study of the human connectome.

## Retained Primitive Reflexes and Attention Deficit Hyperactivity Disorder

Primitive reflexes are adaptive reactions in the neonate and diminish as the brain and nervous system mature. Most of these reflexes can be present in normal individuals, even in young adults. The snouting reflex has been found in 13% of those between 40 and 57 years and between 22 and 33% in those above 60 years and above; the palmomental reflex between 6 and 27% of those between 20 and 50 years of age and in those above 60 years, between 28 and 60% (6, 7). Even the sucking reflex, which for some investigators (7) “invariably indicates frontal lobe disease,” has been reported to be found in more than 6% of normal individuals aged between 73 and 93 years (7).

Therefore, the frequency of these retained primitive reflexes (RPRs) is varied, and there exists disagreement about their pathological impact and significance, and even on their increased incidence related to the aging process. The only RPRs consistently recognized as being markers of neurological disease or disorders are the grasp reflex and extensor plantar responses (Babinski sign). These differences may be explained by methodological and theoretical disagreements between investigators. For example, some investigators think that a positive sucking reflex involves only the muscles associated with lip contraction, while other investigators think that a sucking reflex necessitates supplementary pharyngeal and lingual sucking movements.

Differences between investigators may also exist in associating variables influencing the prevalence of RPRs such as the lack of quantified and standardized protocols, heterogeneity of diseases of the patient groups studied, or stimulation strength and subject's emotional state (8), which can impact on the extent and persistence of responses.

Konicarova and Bob (9) examined the notion that RPRs may be related to indicators of Attention Deficit Hyperactivity Disorder (ADHD) and found that the persisting reflexes were linked to the condition. They hypothesized that the symptoms of ADHD in children between 8 and 11 years. may reflect a compensatory strategy for delayed neurological maturation. They went on to conclude (10, 11) that the symptoms found in those with ADHD are the result of functional integrative deficiencies between brain regions that result in developmental balance and coordination deficits.

Bilbilaj et al. (12) supported the earlier findings of (9) when they measured eight primitive reflexes that included: sucking, asymmetric tonic, rooting, Moro handheld, Galant, tonic lateral and symmetrical tonic reflexes. Reflexes were measured by methods earlier described by Blythe (13). Bilbilaj et al. found that children with difficulties in learning, including those with ADHD, demonstrated a significantly higher level of RPRs compared with controls. The investigators suggested research to find mechanisms to better suppress these retained reflexes earlier in the developmental cycle when these reflexes persisted beyond a child's biological age.

Niklasson et al. (14) offered support for the notion that developmental delays are highly associated with RPRs. These investigators compared healthy children's sensorimotor maturity

to those with developmental coordination disorder (DCD), including those with ADHD, who had completed treatment with sensorimotor therapy. The children in the DCD group completed a therapeutic regimen consisting of stereotypical fetal and infant movements, vestibular, tactile, and auditory stimulation, and assorted gross motor skill exercises. The results showed that normals fared significantly better on all sensorimotor tests as compared to the untreated children in the DCD group. Results demonstrated, no significant differences between normal and treated DCD participants, indicating that RPRs relate to developmental delays that are amenable to relatively simple and easily implemented intervention perceptual-motor remedial strategies.

## Intervention Strategies for the Reduction of RPRs and Increasing Cognitive Skills

Approaches having received some traction recently are nominally based on perceptual-motor theories that attribute learning difficulties in childhood to the persistence of primitive reflexes post-infancy, that could impair normal growth and development and the ability to attain skills such as reading and writing effectively (15–17).

Essentially, perceptual-motor programs suggest that comparatively simple exercises can essentially modify the brain's structure and facilitate learning (4, 18). Most of the programs extant at this time have not undergone rigorous evaluation and scrutiny, however. Perceptual-motor intervention programs (PMPs) typically advocate the employment of specific motor activities and exercises. Some of the advocated tasks are tailored and adjusted to the individual's needs (19), while others may be generic (14, 20, 21). These programs frequently integrate actions, such as throwing and catching, ostensibly improving vestibular function, fine and gross motor skills, and academic accomplishment. The requisite tasks may comprise performing the simultaneous performance of multiple tasks.

While some programs have promoted exercises mimicking activities of fetuses and infants, it has been purported that replaying early stages of development can inhibit the perseverance of these RPRs. This has oftentimes been used as a justification for programs that advocate exercises that simulate fetal and infant activity and infants (16, 17, 22, 23). Claims have been made that movements following primitive reflex patterns will inhibit those reflexes and improve cognitive function and the ability to acquire academic skills (17).

Kavale and Mattson (24) performed a meta-analysis of 180 studies of PMPs and found a minor effect size of 0.08. Effect sizes were described for outcome measures that included intelligence, school achievement, reading, and perceptual and motor skills. Specific training programs, different groups of children, and different grade levels demonstrated no significant positive effects. The effect size for perceptual-motor skill improvement was reported to be 0.17 suggesting that the programs examined had little impact even on perceptual-motor skills themselves. On the other hand, Grzywniak (25) examined the utility of an integrative program of exercises aimed at encouraging development in

children with learning difficulties who have preserved vestigial reflexes. Their symptoms included motor and visual-motor coordination difficulties, lowered visual and auditory analysis and synthesis, attention deficits, and hyperactivity. Almost all the obtained results were statistically significant, especially with ADHD children.

There are two reported studies of the Dyslexia Dyspraxia Attention Treatment (DDAT) exercise-based approach (19, 26) but research methodology inadequacies and analysis and interpretation of the results offered weak evidence in support of the efficacy of the approach (27–29). Jordan-Black (16) and McPhillips et al. (17) did report significant results on reading and math but not for spelling after the use of a perceptual-motor program developed by McPhillips. These studies, however, possess limitations and have not been adequately replicated. Evaluation of the perseverance of primitive reflexes was accomplished using inspection of movement of the arms in reaction to the turning of the head (Schilder test) and the results scored on a four-point scale. Neither McPhillips and colleagues nor Jordan-Black offered data on the reliability and the validity of these procedures as well as the fact that no inter-rater agreement measures were provided. Both reports also indicate that the decreases in primitive reflexes are only associated with a concomitant increase in the “readiness” to learn.

The aim was to study the relationship between brain-based perceptual-motor interventions and cognitive and academic performance and the relationship to the RPRs from data obtained from a multi-center database. In particular, we wanted to examine (a) whether relationships exist between RPRs in children with ADHD and academic/cognitive and motor performance, (b) whether brain-based training regimens can reduce the RPRs, and (c) thereby have an affect cognitive/academic and motor performance?

## METHODS

### Participants

The pool of participants for this study consisted of 2,175 children between and 3.2 and 22.04 years ( $M = 8.4$ ;  $SD = 3.2$ ) years of age of whom 1,541 were male and 634 female diagnosed with ADHD drawn from 89 separate locations across the United States in satellite clinics with centralized staff training in assessment and treatment procedures with reliability having been previously examined (30). While much debate has existed in the literature over gender differences in ADHD and that females have been underrepresented in studies, a worldwide meta-regression analysis of 11 studies of adults with ADHD found that a similar pattern of psychiatric disorders and impaired psychosocial/school functioning between males and females with ADHD indicate that etiologic factors for ADHD do not differentiate between gender (31).

All those with Autism Spectrum Disorder other than ADHD including Asperger's were not included in this study. Of the total participants 70.8% were male and 28 (29.2%) female. Inclusion criteria required all participants to have had a WISC Full Scale IQs of 90 or better and each received the diagnosis of ADHD by either a licensed psychologist or psychiatrist.

Each participant was functioning at least 2 years below grade level as evaluated by the Wechsler Individualized Achievement Tests (WIAT). All participants in the *post-hoc* study presented with reports of inattention, hyperactivity, impulsivity, academic underachievement, and behavior problems each of whom met the criteria of the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, and who clearly demonstrated the absence of coexisting conditions including learning disabilities, as reported by the referring psychologist or psychiatrist.

The exclusion criteria included: (a) recurrent ear infections (b) severe hearing or vision difficulties, (c) significant emotional problems, (d) intellectual impairment, (f) English as a second language, and (g) all participants with reported co-morbidities of obsessive-compulsive disorder, Tourette's syndrome, dyslexia, and Autistic Spectrum Disorder (h) all participants who were non-compliant with the treatment protocol (i.e., who did not attend the intervention sessions as scheduled or who did not complete all of the assessments) were excluded. All children in the study's intervention 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 (32), was 100% concordant with the diagnosis of ADHD that each participant had received elsewhere before entry into the study.

Written informed consent was obtained from each parent/guardian and the project underwent IRB review and approval through Oranim Academic College. The approval by this institution's review board is required for all research emanating or involving members of their faculty or students including analyses only. The data employed in the study was obtained from a depository of de-identified data. The dataset was stripped of all identifying information and there was no way that it could be linked back to the participants from whom it was originally collected (through a key to a coding system or by any other means). The subsequent use of the data by the lead researcher or others did not constitute human participants research, since the data was no longer identifiable as there were no identifiable means, the identity of each participant was unknown and could not be readily ascertained by the investigator or associated with the information. In general, information is considered to be identifiable when it can be linked to specific individuals by the investigator(s) either directly or indirectly through coding systems, or when characteristics of the information obtained are such that by their nature a reasonably knowledgeable person could ascertain the identities of individuals. Therefore, even though the dataset may have been stripped of direct identifiers (names, addresses, student ID numbers, etc.), it may still be possible to identify an individual through a combination of other characteristics (e.g., age, gender, ethnicity, and place of employment). These possibilities had been removed and the data existed as part of a database of over 67,000 data sets. The use of the data therefore did not constitute research with human participants because there was no interaction with any individual and no identifiable private information used. The project did not, therefore, require IRB review. The project was then submitted to an independent

Review Board in the United States that confirmed that the project did, in fact, not involve human participants (Ethical and Independent Review Services Assigned Study ID: 19159-01). The raw data drawn from the database can be found online in a repository at ([https://www.researchgate.net/publication/323801545\\_Persistent\\_Childhood\\_Primitive\\_Reflex\\_Reduction\\_Effects\\_on\\_Cognitive\\_Sensorimotor\\_and\\_Academic\\_Performance\\_in\\_School-Aged\\_Children\\_with\\_ADHD\\_Raw\\_data](https://www.researchgate.net/publication/323801545_Persistent_Childhood_Primitive_Reflex_Reduction_Effects_on_Cognitive_Sensorimotor_and_Academic_Performance_in_School-Aged_Children_with_ADHD_Raw_data)).

## Procedure

### Assessment

At the outset, all participants were tested and additionally, at the conclusion of the 12-week intervention program, all children were retested employing the same evaluations as during the pre-program testing. All of the scores on the cognitive academic testing were converted to standard scores to allow for equilibration of the testing results. The participants presented with inattention, hyperactivity, impulsivity, academic underachievement, and/or behavior problems, and each met the criteria of the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (33) and clearly demonstrated the absence of comorbidities as appraised by licensed Psychologists or Psychiatrists and medical practitioners not participating in the study.

### Intervention Program

Each of the participants of the intervention group underwent a 12-week interventional program. Initial pre-intervention assessments were comprised of the functional assessment of sensory-motor and reflex function and on a separate day, academic-cognitive examination as reported below. The collective examinations permitted the clinicians to devise a program for participants. The program was devised to selectively stimulate abilities that were significantly below functioning or age level for a given participant. Further, tasks were devised to stimulate the less effectively performing hemisphere (5, 34). Each participant participated in this multi-site multi-modal program three times per week for 1h sessions over a 12-week period. Each participant undertook detailed interdisciplinary administered and controlled activities during each session that comprised: motor training, sensory stimulation, aerobic and strength conditioning, and academic-cognitive training. Compliance with the regimen was achieved with all participants.

Also employed in the intervention were primitive reflex inhibition exercises, as well as at-home academic 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 motor and sensory tests and with measurements of academic performance, including the completion of the parent behavioral checklist. Each individual performed the academic testing during both the pre- and post-intervention sessions.

### Synchronized metronome training

Synchronized metronome training (SMT) was employed. SMT is a computer-based system that trains individuals to match varying beats. In the current application, participants wore a

headset and attended to a recurring metronomic beat. As they attended to the beat, they performed bodily movements such as hand-to-hand clapping with a sensor attached to the palm of the hand as they coordinated their bodily movement to the beat (e.g., clap at the beat). The exercise endeavored to decrease the average synchronization error throughout normal tracking of the recurring metronome beat (clapping before or past the beat). Throughout the metronome training, participants were provided feedback by means of an auditory guidance system as they advanced through the interactive physical movements. Feedback was also provided by means of visual stimuli. The auditory feedback system delivered tonal stimuli that denoted whether the participant responded before, at, or after the auditory metronomic beat. The accurateness of participants' expectancy reactions to the metronomic beat was specified in milliseconds (*ms*), with different tones demonstrating 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 reported elsewhere to be effective in examining psychophysical signal detection capabilities (18).

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 intervention 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 ADHD functioning—more fully explained in Slater and Tate (18) and Brown (32).

### Dichotic listening

Dichotic listening (DL) assessments were also performed to examine selective auditory attention. In particular, DL was employed in this study as a test of hemispheric lateralization of speech sound perception (35). In the DL task, the participant is presented with two dissimilar simultaneous auditory speech stimuli with the stimuli administered to different ears by earphones. We thought that DL was one of the best ways of measuring divided attention in children (36). In most of the children studied, we have found function below the norm in their abilities in divided attention that we think is related to this developmental asynchrony. So both SMT and DL are tools that are well-documented, accepted, and standardized that can be correlated to academic achievement tests as well as primitive reflex testing.

## Assessment of Intervention Effects

### Reflex testing

Standard and accepted tests and scoring methods of testing reflexes 4, based on the percentage of RPRs. 0 is a non-retained primitive reflex, 4 is 100% of an RPR. The decrease is reflected in the severity of the reflex. (37–39). The Asymmetric Tonic Neck Reflex (ATNF), and Palmer Grasp primitive reflexes both left and right sides of the participants' bodies were examined. Each participant was required to get down on his hands and



knees. This posture, first suggested by Brain (40), was found by Zemke and Draper (41) to provide one of the most sensitive methods of measuring the ATNR in both children and adults. The participant's head was placed in the midline so that the face was parallel with the floor, and the examiner ensured that the knees and hips were flexed as closely as possible. The participant was blindfolded so that visual cues would not confound the results. All of the participants underwent the procedure twice with instructions to relax and then to keep the arms straight and not let their elbows bend. Measurements of both elbows will be made first with the head in a neutral position, next with the head rotated to the right (chin to right shoulder) and finally with the head rotated to the left (chin to left shoulder). In each case, the examiner positioned the participant's head and then reminded him or her to keep it in place while measurements were taken. All reflexes were tested bilaterally. The palmar grasp reflex was elicited bilaterally for each participant by applying gentle pressure by horizontally stroking the palm of the hand. In response, the participant closed the palm or made a fist if abnormal or not if normal.

### *Cognitive/behavioral assessment*

All participants were given the Wechsler Individual Achievement Tests [WIAT-II] (42), 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), (32) appropriate for each participant's age, both before and after the 12-week intervention program. Selections from the WIAT that included Listening Comprehension, Mathematical Problem Solving, and Spelling were included in this analysis as they represented right vs. left hemisphere oriented tasks (5). The Mathematical Reasoning Subtest of the WIAT was selected as it evaluates the capability of the participants to add, subtract, multiply, and divide one- to three-digit numbers and to understand numerical and geometry concepts and measurements, graph theory, and the ability to find solutions for mathematical word problems. While IQ subtests mainly measure thinking and reasoning skills, the WIAT-II subtests are measures of academic achievement. Our concern was whether hemispheric specific training effects the level of attainment with diminished attention effects and whether we could conclude that the evidence is enough to warrant a clinical trial on the notion of hemisphere-specific training. Of concern should be the test-retest reliability of the WIAT subtest performed prior to and after the 12-week intervention program.

McCrimmon and Climie (43), however, reported that for both pre-K to Grade 5 and Grades 5–12 demonstrated adequate test-retest reliability for both grade bands across both subtest and composite scores. Fourteen of 16 subtests demonstrated reliability scores between 0.82 and 0.94 (average to the excellent range), with Listening Comprehension and Sentence Composition scoring in the adequate range (0.75 and 0.79

respectively). Composite score coefficients ranged from 0.87 to 0.96 (good to excellent).

### **Statistical Analysis**

A repeated-measures model was employed so that the variability between subjects could be eliminated. Therefore, each participant was used as his or her own control. We decided to employ the Wilcoxon Rank Sum test, as the data were not normally distributed. The minimum *df* that was employed was 1,674 and the maximum *df* employed was 1,910.

Pearson Product Moment Correlation Coefficients were employed in order to compare the results within the pretest parameters and separately within the post-test parameters. The pairs of pre-test and post-test parameters examined included correlations between: asymmetrical tonic labyrinthine reflexes both right and left, Palmar reflexes both right and left, DL, and SMT training.

We decided to restrict the analysis to eight parameters to avoid statistical bias in the analysis. Subsequent studies will examine additional academic parameters more comprehensively. In addition to reflex function having been examined bilaterally, academic-cognitive performance measures reflected brain hemisphere-specific function [cf. (5)].

Two statistical tests were selected with the first examining correlations between different assessments before and separately after treatment. The correlation of all the details before and after all the details were examined. The statistical tests performed employed the R statistics packages: "Coin" "pspearman," R package "P-spearman," and also by R Package "Coin." *P*-value updated the number of comparisons ( $7 \times 8$ ) divided by 2 as the matrix was identical on both sides of its diagonal,  $2 \times$  twice—one for initial and one for post-tests since compared each post-test with its initial-test by using the Wilcoxon non-parametric test.

Additionally, testing for association/correlation between paired samples was employed. This second part examined the difference between the initial and final results by employing non-parametric statistical testing with one- and two-sample Wilcoxon tests employed on vectors of data. Since we performed repeated tests on the same set of data, a correction was made for non-parametric testing.

### **RESULTS**

With reference to right asymmetrical tonic neck reflexes a significant decrease of 26% was recorded between pre- and post-testing ( $W = 1464500$ ;  $df = 2003$ ;  $p < 0.0001$ ). Similarly, results from pre- vs. post-testing revealed a significant decrease of 25% in left asymmetrical tonic neck reflexes ( $W = 1452500$ ;  $df = 2008$ ;  $p < 0.0001$ ). Further, the right Palmer reflexes were found to be significantly reduced by 39% between initial testing and post-intervention ( $W = 2230200$ ;  $df = 1915$ ;  $p < 0.0001$ ).

Left Palmer pre-post difference revealed significant reduction of 38% ( $W = 2235500$ ;  $df = 1914$ ;  $p < 0.0001$ ). The examination of pre-post differences in DL among the participants indicated a significant increase in 98% of the participants ( $W = 778020$ ;  $df = 2134$ ;  $p < 0.0001$ ). SMT pre-post difference revealed a significant increase of 100% significant increases were observed

**TABLE 1** | Wilcoxon rank-sum test with continuity correction.

Parameters	Statistic parameter	Pre-test	Post-test	% Change	W	p	df
Asymmetrical tonic neck reflex right	Average	1.404	1.045	-26%	1,464,500	$P < 0.0001$	2,003
	SD	1.330	1.123				
Asymmetrical tonic neck reflex left	Average	1.389	1.048	-26%	1,452,500	$P < 0.0001$	2,008
	SD	1.342	1.114				
Palmar reflex standing left	Average	1.414	0.871	-38%	2,235,500	$P < 0.0001$	2,137
	SD	1.268	1.043				
Palmar reflex standing right	Average	1.395	0.851	-39%	2,230,200	$P < 0.0001$	2,137
	SD	1.267	1.013				
Dichotic listening	Average	5.445	10.795	98%	778,020	$P < 0.0001$	2,134
	SD	2.959	6.567				
Interactive metronome	Average	4.391	8.928	10%	752,040	$P < 0.0001$	2,094
	SD	3.362	4.667				
Listening comprehension standard score	Average	96.593	103.490	7%	1,213,000	$P < 0.0001$	2,094
	SD	17.967	18.010				
Math problem solving standard score	Average	93.004	98.080	5%	1,331,500	$P < 0.0001$	2,091
	SD	29.043	28.897				

**TABLE 2** | Pearson product-moment correlation— Pre-test.

	Asymmetrical tonic neck reflex right	Asymmetrical tonic neck reflex right	Dichotic listening
Asymmetrical tonic neck reflex left	$R = 0.9143181$ $df = 2,000$ $p < 0.0001$		
Palmar reflex standing left		$R = 0.8740643$ $df = 2,130$ $p < 0.0001$	
Interactive metronome			$R = 0.5041327$ $df = 2,075$ $p < 0.0001$

**TABLE 3** | Pearson product-moment correlation—Post-test.

	Asymmetrical tonic neck reflex right	Asymmetrical tonic neck reflex right	Dichotic listening
Asymmetrical tonic neck reflex left	$R = 0.8810236$ $df = 1,674$ $p < 0.0001$		
Palmar reflex standing left		$R = 0.8471731$ $df = 1,910$ $p < 0.0001$	
Interactive metronome			$R = 0.5538061$ $df = 1,902$ $p < 0.0001$

between pre- and post-testing of 7% ( $W = 1213000$ ;  $df = 2094$ ;  $p < 0.0001$ ). Mathematical problem-solving results obtained when comparing pre-intervention with post-intervention revealed significant increase of 5% ( $W = 1331500$ ;  $df = 2091$ ;  $p < 0.0001$ ). The results are summarized in **Table 1**.

We additionally examined the correlations between right and left reflexes before and after the 12-week intervention program previously described. For all of the pre-intervention relationships, we found a significantly strong Pearson Product Movement Correlation between right and left asymmetric tonic reflexes ( $r_{ppm} = 0.9143$ ; reflexes both right and left ( $r_{ppm} = 0.874$ ;  $df = 2130$ ;  $p < 0.0001$ ). When comparing DL with SMT performance, we found a significant correlation as well ( $r_{ppm} = 0.504$ ;  $df = 2075$ ;  $p < 0.0001$ ). With reference to post-intervention relationships, we observed a significantly strong Pearson Product Movement Correlation between right and left asymmetric tonic reflexes ( $r_{ppm} = 0.881$ ;  $df = 1674$ ;  $p < 0.0001$ ). A similar result was obtained when examining the Palmer reflexes

both right and left ( $r_{ppm} = 0.847$ ;  $df = 1910$ ;  $p < 0.0001$ ). When comparing DL with SMT performance we found a significant correlation as well ( $r_{ppm} = 0.553$ ;  $df = 1902$ ;  $p < 0.0001$ ). The results of the correlated data are to found in **Tables 2, 3**.

## DISCUSSION

This outcome study aimed to examine the relationship between RPRs, sensory-motor performance as measured by a metronomic-type task and by DL as well as by examining academic-cognitive performance representing the right and left hemisphere control in achievement tests of listening comprehension and mathematical reasoning.

The reduction of primitive reflexes was found to be highly associated with increased performance in mathematical problem solving and listening comprehension as measured by the components of the Wechsler Individual Achievement Test (42)

in children from 89 centers distributed in various locations across the USA with ADHD.

Numerous studies have been performed over the past 30 years demonstrating the effects of RPRs on behavior and learning. Research has additionally demonstrated that individuals significantly reduce symptoms and effect change in diagnosis when participating in a protocol that focuses on specific reflexes. One such study that tested 109 boys from ages 7 to 10 found an association between retained tonic labyrinthine, Moro, symmetrical and asymmetrical tonic neck reflexes with ADHD symptoms and mathematics achievement (12, 44).

If one were to assume that the problem of developmental delay is related to the maintenance of primitive reflexes, that would, in turn, be associated with desynchronization and ineffective interhemispheric communication [for a more complete overview of these relationships cf. (5, 18)], then the best way to address the symptoms is to improve coordination between areas of the brain. To best achieve this goal, a multimodal approach that would incorporate an amalgamation of biochemical, somatosensory, motor, cognitive, and behavioral interventions collectively focused on improving general health, so that right and left hemispheric function become temporally coherent (45–49). This outcome study aimed to achieve precisely that.

The present study has been limited by the lack of a group of age-matched controls not undergoing such training or by groups undergoing alternative forms of intervention with both

retained and non-RPRs. A more expansive multifactorial testing of numerous components of cognitive function as well as studies of effective connectivities by means of quantitative EEG and fMRI studies are also indicated for the future.

For now, integrating somatosensory, motor, and hemisphere specific training based on sound principles of neurodevelopment with school and educational environments that incorporate hemisphere-specific training along with comprehensive programming to reduce maintained primitive reflexes, after careful controlled clinical trials and investigations of neuroplastic effects can be a promising approach as part of a multicomponent system that could potentially reduce the effects of developmental deficits and delays in both developing and developed countries with little expense.

## DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

## AUTHOR CONTRIBUTIONS

RMe, GL, and RMu contributed equally to the design and development of the project. AO, GL, and RMu contributed to the statistical analysis and results section of the paper. All authors contributed to the article and approved the submitted version.

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**Conflict of Interest:** RM has a fiduciary relationship with Brain Balance Program®.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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