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Neuroeducative Sensoriomotor Program Improves Electrophysiological and Cognitive Functions in Children With Attention-Deficit Disorder

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Abstract

Children with Attention-Deficit Disorder, predominantly inattentive type (ADD-I), have many difficulties in bottom-up pattern processing. Few studies in children with ADD-I have paid attention to early neurobiological components of Event-Related Potential (ERP), like the P100, which is associated with initial bottom-up attentional processing. The aim of the study was to examine the P100 during visual frequent stimuli and evaluated the results once the sensoriomotor bottom-up program, known as HERVAT, was complete. HERVAT stands for hydration, balance, breathing, ocular motility, hearing and touch. The present study utilized an experimental design via pre-test and post-test in three groups (ADD-I with HERVAT, ADD-I without HERVAT and control group). We recorded the results pre-test and post-test for P100, Intelligence Quotient (IQ) and attention. We found that ADD-I + HERVAT group have a P100 latency close to the control group, as well as an increased in IQ, attention and parietal activity. Our conclusion is that the HERVAT program improves bottom-up processes, which are relevant for cognitive functions, by training sensory and motor subcortical networks. This program could be an interesting alternative for improving cognitive and learning abilities in children with ADD-I.

Keywords: ADD-I; HERVAT; Neuroeducative program; P100; Sensoriomotor; IQ

Introduction

Attention plays a key role in the way children learn because no learning can be attained without paying attention first. Their learning, behavior and even the way they interact with each other is based on multiple brain processes which are modulated by attention. As children focus on what they are learning, two processes have to happen: old neural circuits become stable while new neural connections are created [1]. Therefore, attention is a basic cognitive process, necessary not only for the retrieval of stored information but also for acquiring new knowledge.

Children with Attention-Deficit/Hyperactivity Disorder (ADHD) suffer from attention difficulties which significantly impede their academic performance. ADHD is one of the most common and widespread childhood mental health disorders, affecting 3 to 8% of children worldwide, where 36 to 57% of those boys and girls pertain to the predominantly inattentive type (ADD-I) [2,3].

ADD-I children exhibit functional impairment at home, school and with their peers [4,5] and often develop an executive dysfunction, which prevents them from properly regulating and monitoring their actions and thoughts. They are easily distracted which makes them prone to boredom, their working memory difficulties result in unmotivated or restless actions and the social challenges they face may lead to introvert behaviors [6-8]. It has been hypothesized that children with attention problems may have an inadequate early sensory processing when detecting, organizing and controlling the intensity and nature of sensory input responses [9-11]. Several studies have demonstrated the importance of early bottom-up sensory processing in both healthy and ADHD subjects as distracting stimuli contribute to increased inattention and emotional task performance [12-19].

One way to evaluate attention processes of external stimuli that do not require selective attention is to analyze the early components of Event-Related Potential (ERP) [20,21]. The P100 ERP component, which has a latency that varies between 80-150 ms, processes the early stages of perception associated with visual spatial attention and bottom-up patterns [22-24]. It has been found that children with ADHD have a shortened P100 in oddball paradigms and in go/no-go tasks as a result of an early deficit in sensory integration [25-27].

Many educational programs exist which aim to improve the cognitive and learning abilities in children with ADD. Despite the lack of any noticeable improvement in these cognitive programs, previous research highlights bottom-up subcortical activity like balance, coordination and motor control functions, ocular motility, auditory perception and tactile stimulation, to enhance cognitive cortical processes in fronto-parietal circuits affected by this deficit [28-45]. By not targeting cognitive exercises, we hypothesize that a training based on bottom-up sensoriomotor routines could be an alternative way to improve early attentional processes in children with ADD-I.

Given that early ERPs can be affected by initial attention processes [22,14,16] we analyze the P100 on visual frequent stimuli that do not require selective attention in children with ADD-I. By evaluating the children's responses both before and after the bottom-up sensoriomotor training program, known as HERVAT (Spanish acronyms for hydration, balance, breathing, visual ocular motility, auditory tones discrimination, touch discrimination), we aim to determine if this program can improve attention that will lead to better academic performance [46].

Materials and Methods

Participants

36 children were divided into three groups. The first group "ADD-I+HERVAT" consisted of 12 children (3 girls, aged 7-11 years) with ADD-I that participated the HERVAT program. The HERVAT program includes daily exercises of hydration, balance, breathing, visual ocular motility, auditory tones and touch discrimination before classes began. The second group "ADD-I" were 12 children with ADD-I that did not participate in the HERVAT program (3 girls, aged 7-11 years); and the third group was the control group with 12 children not diagnosed as ADD-I who did not take part in the HERVAT program (3 girls, aged 7-11 years). The ADD-I and control groups were involved in the same activities as the ADD-I+HERVAT group with the exception of the HERVAT exercises. The inclusion criteria within the first two groups was a clinical diagnosis fulfilling the criteria for ADD (DSM-5) with no pharmacological treatment prescribed, in order to ensure that medication did not compromise the results. The exclusion criteria were: low birth weight (<2500 g), pre-term birth (requiring care in an incubator), fetal distress or Apgar score lower than 7 (Apgar test determines if newborns are in need for additional medical care with a score of less than 7), pervasive developmental disorder or any other type of brain damage or mental disability, abnormal EEG findings and/or epilepsy (including febrile seizures in infancy) and learning difficulties. All groups had similar characteristics with regard to age, sex, academic level and sociocultural status. These children attend their school in the Autonomous Community of Madrid, Spain. No children had any neuropediatric or neuropsychiatric disorders.

The study was carried out with the written informed consent of all parents and was approved by the Ethics Committee of Hospital Clinico San Carlos, Madrid.

Procedures

Once ADD was diagnosed using both the DSM-5 (American Psychiatric Association) and the Kiddie-Schedule for Affective Disorders and Schizophrenia interviews (Present and Lifetime in the Spanish version and the ADHD Rating Scale-IV), two subsequent tests were carried out. One to determine intelligence, the G-factor, the other to assess attention level, the d2 Test [47-49].

The EEG study comprised of a visual recognition task. The visual oddball paradigm test consisted of 2 visual stimuli: vertical and horizontal lines. The vertical lines, which were the target stimulus in our protocol, were randomly distributed with an occurrence of 20% throughout the test, whereas horizontal lines, considered the standard stimulus, had a frequency of 80%. Lines were 0.5 cm wide and 5 cm long, with duration of 300 ms and a response time of 700 ms the children had to respond by pressing the space bar every time the target stimulus appeared on the screen.

The HERVAT program included 6 types of tasks:

- Hydration (a sip of water)
- Balance (static balance for one minute)
- Breathing (10 deep breaths)
- Visual (eye-to-eye motility following a dot on the screen that goes from left to right and from top to bottom for one minute)
- Auditory (discriminate between two types of frequency tones for one minute)
- Tactile (differentiate between letters and numbers, drawn on the palm of the hand, for one minute).

The test lasted 5-8 minutes and was carried out 3 times a day before each class throughout the entire academic year. During this time, the total amount of sessions that the children performed was around 450.

Analysis of EEG data

Evoked potentials were recorded using the 128-channel EEG system ATI-Pentatek. Data was processed based on a reference mean, once acquisition with a band pass filter of 0.05 to 30 Hz and a sampling speed of 512 Hz was obtained. Impedance was maintained below 5 kΩ. Electrodes were placed on both mastoids as on-line references. 100-µV "noises" or "artefacts" were used as exclusion criteria to rule out blinking movements. The tests of each child were visually assessed to ensure that the recordings were clean. The "noise" created by eye and muscle movements were identified visually off-line and eliminated before determining the data average and P100. Noisy channels were replaced by moderate linear interpolations of clean channels. Latency values were obtained separately for each condition and each participant by analyzing for 40 msec (20 msec before and after the peak), with the greatest amplitude for the Pz electrode within the time interval 100- 170 msec for P100.

Measurements

At the beginning (pre-test) and end (post-test) of the study, Intelligence Quotient (IQ), attention scores (attention and early ERPs (P100) were recorded. P100 was estimated based on 123 electrode recordings for all participants and localized in the brain based on the solution to the EEG inverse problem using the Bayesian Model Averaging (BMA) [50]. The BMA is an estimation obtained by averaging the predictions of the different models under consideration weighted by its model probability. Individual data was obtained using low-resolution electromagnetic tomography to calculate the electrical tomography of the brain [51]. Each model was defined by restricting the solution to a specific anatomical structure or to a combination of structures using the software package Statistical Parametric Mapping (SPM, Math Works, Natick, United States). The SPM is used for the statistical analysis of brain imaging data sequences. To determine the statistically significant sources of P100, SPM were used to establish the maps based on a voxel-wise Hotelling T2 distributiuon vs zero [52]. The resulting probability maps from the threshold for the expected proportion of false positives between tests that were significant, were limited to a false discovery rate of q=0.05 and represented as 3D activation images [53,54]. Cortical projections were visualized using CARET software according with the MNI coordinate system [55,56].

Statistical analysis

Shapiro-Wilk test was used to test the normality of P100 and IQ variables, as well as the Attention score. When the normality assumption was clearly violated, data was normalized using Blom transformation [57]. Homogeneity of these measures for the three groups at baseline was analyzed using one-way Anova tests. Particularly interesting, the homogeneity of the measures for the two groups of ADD-I children was carried out using t-tests. Correlation analyses were used to examine the relationship among measures. In order to evaluate the effects of the training program, a repeated-measures Anova was used with the group as the between-subjects factor (ADD-I+HERVAT, ADD-I and CONTROL), whereas the within-subjects repeated measures were the measures in each time point (pre-test and post-test). All statistical analyses were performed using SPSS 25 statistics software.

Results

Previous analysis

Normalization of the Scores: Shapiro-Wilk tests showed that P100 and IQ measures satisfied the normality assumption (all p>0.16) but not Attention (all p<0.005). Analyses were conducted for the measures at pre-test and post-test points in each group. Accordingly, results for the d2 Attention Test, a score or rank measure, were Blom transformed, now fulfilling the normality assumption (all p>0.09). We will use Nattention to denote this new variable.

Homogeneity of Control, ADD-I +HERVAT and ADD-I Groups with respect to Age and Gender: The groups are homogeneous with respect to gender (9 boys and 3 girls in the three groups) and age (mean ages are 9.9, 9.9 and 9.25 years respectively).

Homogeneity of Control, ADD-I +HERVAT and ADD-I Groups with respect to P100, IQ and Nattention at Pre-test Point: The mean values and their corresponding standard deviations (SD) at pre-test point are given in Table 1, Differences were not statistically significant for P100 (F=2.00, p=0.152) and Nattention variable (F=0.06, p=0.940), but not so for IQ (F=9.04, p=0.001).

However, the interesting comparison between the two groups of ADD-I children showed that there were no statistically significant differences between the IQs of both (t=-0.036, p=0.971). The mean values and their corresponding standard deviations (SD) at pre-test point are given in **Table 1A**.

IQ	Group	Mean	SD
IQ pre	ADD-I+Hervat	98.67	5.59
	ADD-I	98.75	5.69
	Control	108.33	7.7
IQ post	ADD-I+Hervat	102.25	2.77
	ADD-I	98.83	5.39
	Control	113.17	7.02

Table 1A: Means values and standard deviations of the IQ at pre and post-test points for all three groups.

Correlation analyses: Pearson correlation analysis between these three variables at pre-test point, in each group, did not show a significant linear relationship between them (all p>0.35).

Behavioural Measurements

Intelligence Quotient (IQ): Table 1A shows the mean values and their corresponding standard deviations in the pre-test and post-test points. The variances of the groups (pre and post) were homogeneous according to the value of the Levene statistic, p=0.740 and p=0.09 for F2,33 distribution, respectively. The three effects were significant: the repeated-measures analysis showed significant differences between the IQs throughout the pre-post period (F1,33=13.00, p=0.001), significant differences between the IQs of the groups (F2,33=17.19, p<0.001), and finally, the interaction of the IQ*group was statistically significant (F2,33=3.51, p=0.04).

The results by groups are as follows: IQ increases significantly over the pre-post period in the ADD-I+HERVAT and Control groups (p=0.017 and p=0.01, respectively). IQ remains stable throughout the pre-post period in the ADD-I group (p=0.838). Differences between the IQs of both ADD-I groups at post-test point were close to statistical significance (p=0.06) **(Figure 1A).**

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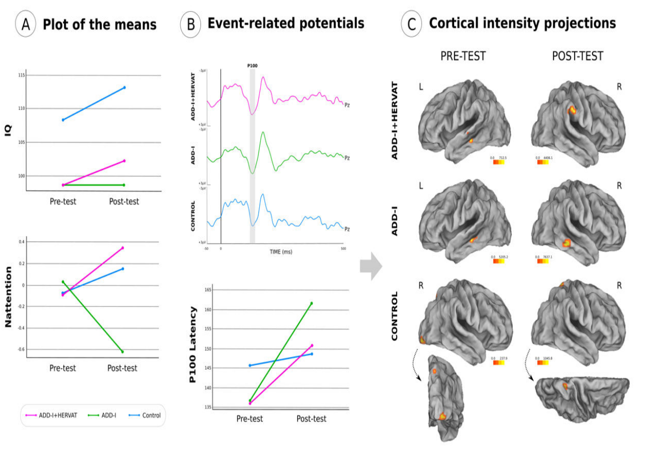

Figure 1: 1A: Mean IQ (Top) and Mean Nattention score (Bottom); 1B: ERP waves at Pz electrode in all groups. P100 component was determined by localizing the maximal amplitude in the respective time window using the Pz electrode (Top) and mean P100 latency (Bottom); 1C: Maximal intensity projections are displayed in yellow/red color at p<0.001.

Attention: Table 1B shows the mean values and their corresponding standard deviations in the pre and post-test points for the Nattention variable. The variances of the groups (pre and post) were homogeneous according to the value of the Levene statistic, p=0.49 and p=0.43 for F2, 33 distribution, respectively. The only significant effect is due to the Nattention × group interaction (F2, 33=4.32, p=0.02).

Nattention	Group	Mean	SD
Nattention pre	ADD-I+Hervat	0.088	0.81
	ADD-I	0.029	0.74
	Control	0.076	1.08
Nattention post	ADD-I+Hervat	0.345	0.79
	ADD-I	0.621	0.45
	Control	0.15	1.02

Table 1B: Means values and standard deviations of the Nattention at pre and post-test points for all three groups.

The results by groups are as follows: Attention decreases significantly over the pre-post period in the ADD-I group (p=0.0005) as it increases, although not significantly, in ADD-I +HERVAT and Control groups (p=0.12 and p=0.23, respectively). Consequently, at post-test point there are significant differences between the attention levels of ADD-I group and the other two groups (p=0.011 and p=0.0025) **(Figure 1A).**

Electrophisiological measurements

P100 Event-related Potential Latency: We analyzed the first positive wave (P100) of the event-related potential. The configurations of these waves were similar for the cerebral responses in the three groups **(Figure 1B).**

Table 1C shows the mean values and their corresponding standard deviations in the pre and post-test points for P100. The variances of the groups (pre and post) were homogeneous according to the value of the Levene statistic, p=0.23 and p=0.13 for F2,33 distribution, respectively. Repeated-measures analysis showed significant differences between the P100 latencies throughout the pre-post period (F1,33=14.71, p=0.001) and close to significant differences (p=0.068) for the interaction of the P100 * group.

P100 latency	Group	Mean	SD
P100 pre	ADD-I+Hervat	136.08	12.26
	ADD-I	136.75	16.54
	Control	145.67	9.59
P100 post	ADD-I+Hervat	150.75	24.32
	ADD-I	161.58	34.97
	Control	148.67	13.34

Table 1C: Mean values and standard deviations of the P100 at pre and post-test points for all the three groups.

The results by groups are as follows: P100 increases significantly over the pre-post period in the ADD-I and ADD-I +HERVAT groups (p=0.007 and p=0.019 respectively) as it increases slightly in the Control group (p=0.19) **(Figure 1B)**.

P100 source localization: Using independent Hotelling´s T2 while visualizing horizontal lines (non-target trials) at P100 (p<0.001) in: 1) left middle temporal (-65,-30,-9) in ADD-I+HERVAT pre-test and right supramarginal (66,-30,32) in ADD-I+HERVAT post-test; 2) left middle temporal (-65,-30,-8) in ADD-I pre-test and right middle temporal (66,-40,-12) and inferior temporal (54,-62,-12) in ADD-I post-test; and 3) right inferior occipital (29,-91,-12) and superior parietal (18,-74,54) in Control pre-test and right superior parietal (18,-50,68) in Control post-test **(Figure 1C).**

Discussion

Once the HERVAT program was completed, we found that attention levels increased in ADD-I+HERVAT children in parietal areas, by targeting early stages of attentional processes through bottom-up sensoriomotor exercises. As a result, their IQ and Attention scores improved and the P100 latency resembled that of the control group.

At the beginning of the academic year, both ADD-I+HERVAT and ADD-I children showed activation in middle temporal areas in response to non-target stimuli. Using only temporal ventral pathways indicate a bottom-up attentional deficit in processing visual information in ADD children. This deficiency in selecting visual information and quickly categorize it prevents the subjects from activating the dorsal parieto-frontal stream pathway in tasks that require attention [58,42-44,59]. This is because the dorsal network is likely to engage in attentional modulation of early sensory activity [60]. Nevertheless, by the end of the year, only ADD-I+HERVAT children activated dorsal pathways in parietal areas, resembling the control group. Exercising early attention in children with ADD with the HERVAT program activate dorsal parietal areas. This suggests a certain degree of attentional control of ocular motility and visual object recognition. In the ADD-I group, activation remained the same, because children with ADD show fronto-striatal and cortical-posterior circuit dysfunctions [43,45] which could be responsible for multisensory perception.

The HERVAT program appears to induce parietal activity in response to non-target stimuli, by focusing on subcortical activity. This in turn improves cortical connections, due to a slow, non-synaptic, subcortical learning process, that takes place in certain axons or dendrites [61]. Non-synaptic plasticity can increase or decrease neuronal excitability as well as redirect synapsis towards the cortex [62-65]. This enables HERVAT exercises to activate cortical activity, such as balance and postural control skills, ocular motility, auditory perception and passive tactile stimulation, to enhance cognitive cortical processes in fronto-parietal circuits affected by this deficit [31-37,39-45,66]. Cerebellar activation plays a decisive role in balancing exercises, because balance control requires the integration of somatosensory, vestibular and visual information. This is necessary for attention, executive control, language, working memory and spatial learning [36-39,67-70]. These findings confirm that subcortical networks are strongly connected to attentional processes.

The P100 latency in ADD-I+HERVAT children was close to the control group after completing HERVAT program, which suggests that the program leads to an improvement in the involvement of subcortical structures in the transmission of visual information to cortical regions. This may result in diminished cognitive effort in response to non-target stimuli. In this respect, early stages of information processing appear to be reciprocally modulated by higher processing areas (top-down effects), despite the fact that attentional processes of executive functions are more closely related to late waves, such as the P300 [46]. One feasible explanation is the lack of differences in early attentional processes regarding target and non-target stimuli [71].

After successfully completing the HERVAT program, we also observed an enhancement in IQ and attention scores in ADD-I +HERVAT children, which indicates that bottom-up, subcortical, sensoriomotor processes are necessary for improving attentional functions which take place within subcortical networks. Lower IQs in children with ADHD and ADHD-I lead to deficits in attention, logical and mathematical thinking, and interpersonal and intrapersonal relationships, all of which affect school learning. This might explain why targeting attention through sensoriomotor stimulation resulted in an improvement of the IQ scores of ADD-I+HERVAT children [72,73].

Conclusion

The cortical-subcortical relationship plays an essential role in learning, and therefore the HERVAT program could be an effective method for improving early attention of frequent stimuli. Bottom-up, sensoriomotor stimulation could improve non-target early attentional processes in children with ADD-I, which could in turn positively modulate these deficits in later cognitive stages. These results suggest there is a need for incorporating exercises, such as those which the HERVAT program comprises, to be integrated into educational programs in the future, in order to improve attention in children with ADD-I.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors.

Ethics Statement

The studies involving human participants were reviewed and approved by the Ethics Committee of Hospital Cl nico San Carlos, Madrid. Written informed consent to participate in this study was provided by the participants' legal parents.

Author Contributions

TO designed the study. EOT performed the study and collected the data. AT analyzed the data. TO, EOT, AT, MILI, IM, and JQ contributed to the final manuscript writing. All authors contributed to the article and approved the submitted version.

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Conflict of Interest

The 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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