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ADHD children outperform normal children in an artificial grammar implicit learning task: ERP and RT evidence

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ABSTRACT

This study focuses on Implicit learning (IL) in children. One of the main debates in this field concerns the occurrence of IL indicators in experimental settings and its manifestation in different populations. In this research, we are looking for evidence of the occurrence of IL in normal children and in children with Attention Deficit Hyperactive Disorder (ADHD), based on the relationship between accuracy, reaction time and event-related potentials (ERPs). Our results show differences between the analyzed groups with respect to markers for electrophysiological activity and reaction time, but not for accuracy. In consequence, we suggest that research in IL should explore different indicators and their relationship with the cognitive processing levels involved. In addition, IL might involve different forms of information processing in normal children and children with ADHD. We discuss the possible impact of these findings for future research.

1. Introduction

In recent decades, implicit learning (IL*)*, as a different area of implicit memory (Dienes & Perner, 1999) has become an increasingly important issue in cognitive psychology (Boehm, Sommer, & Lueschow, 2005; Chang & Knowlton, 2004; Forkstam & Petersson, 2005). According to Berry (1997), the term implicit learning is "used to characterize those situations where a person learns about the structure of a fairly complex stimuli environment, without necessarily intending to do so, and in such way that the resulting knowledge is difficult to express" (Berry & Dienes, in Berry, 1997, p. 1). In other terms, explicit learning is a conscious process that uses metacognitive strategies allowing access to information using the learner's intention (Frensch, 1998).

Several studies have demonstrated that explicit learning (EL) and IL operate independently. Specifically, IL is acknowledged as a form of knowledge acquisition that operates according to principles that are qualitatively different from those of EL and that exhibits a different neural representation (Ashby, Alfonso-Reese, Turken, & Waldrom, 1998; Augart, 1994; Whittlesea & Wright, 1997).

In this way, IL is an ancestor of metacognitive skills and plays a more fundamental role in cognition (Reber, 1993). According to this reasoning, IL should be more basic and more robust than EL. Therefore, it is a good way to teach complex regularities throughout life because it is available from birth to old age (Cherry & Stadler, 1995; Frensch & Miner, 1994).

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Furthermore, it is successful even in the presence of brain injuries or neuropsychiatric disorders (Moscovitch, Vriezen, & Goshen-Gottstein, 1993).

Attention Deficit Hyperactive Disorder (ADHD) is one of the most common neurobehavioral disorders of childhood, and it can persist through adolescence and into adulthood (e.g., Kessler et al., 2006). A child with ADHD has a chronic level of inattention, impulsive hyperactivity, or both, such that daily functioning is compromised. The American Psychiatric Association's Diagnostic and Statistical Manual-IV, Text Revision (DSM-IV-TR) estimates that 3–7% of children suffer from ADHD.

Even though there is substantial knowledge about ADHD in aspects like epidemiology (Biederman, 2004), main behavioral characteristics (Martel & Nigg, 2006), neuropsychological profile (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), structural changes (Ellison-Wright, Ellison-Wright, & Bullmore, 2008), neurochemical substrate (Overton, 2007) and many others, there have not been any studies about the occurrence of IL in children with ADHD. This is not a minor topic because, as a particular cognitive phenomenon, IL gives the opportunity to develop new approaches for the education and class adaptation of those children.

As one recognizes the importance of IL to ADHD research, it is impossible to ignore some theoretical and methodological obstacles that complicate the enterprise. We present a short discussion about some of these methodological problems.

2. The problem of implicit learning indicators

Since the initial studies (i.e., Reber & Lewis, 1977), IL has been demonstrated using a variety of experimental paradigms that differ in the type of indicator used and in the type of implicit knowledge acquired.

In the artificial grammar paradigm (AG), learning consists of complex rules that determine the sequence of letters making up short strings (Reber & Lewis, 1967, 1993). In the sequence learning paradigm, subjects respond to successive presentations of a stimulus at different locations and learn the sequence that these stimuli follow (Cleeremans & McClelland, 1991; Lewicki, Czyzewska, & Hoffman, 1987). Finally, in the complex systems task control paradigm, subjects manipulate values in one variable to reach certain values in a second, related variable (Berry & Broadbent, 1984; Broadbent, Fitzgerald, & Broadbent, 1986).

The present study focuses on the AG. In this paradigm, subjects are asked to learn a series of words from a specific AG in which each word has a maximum of six letters (Fig. 1). During the testing phase, they are asked to recognize new words generated from the same AG. Remarkably, subjects give a significant number of correct answers despite the fact that they are unable to verbalize the underlying grammar rules.

Although there are different, well-established paradigms to investigate IL, researchers still debate about the most reliable indicators of this phenomenon (Berry & Dienes, 1993; Dulany, Carlson, & Dewey, 1984; Shanks & St. John, 1994). Traditionally, learning is identified as implicit to the extent that it is non-conscious and without intentionality, in contrast with explicit learning that requires a high level of consciousness. The actual problem of studying IL is measuring the non-conscious component of this learning.

Several studies focused on implicit learning have used accuracy and reaction time as dependent variables (Fabiani & Gratton, 2005; Shanks & St. John, 1994). This is a practice that casts doubt on the validity of the obtained results due to the dissociation between the learning a subject demonstrates and the learning a subject reports. This dissociation must be verified with a post-experimental survey to eliminate the possibility that the subject has become aware of the knowledge he acquired (Rosas & Grau, 2002).

Neural measurements such as electroencephalography (EEG), event-related potentials (ERP) and functional magnetic resonance imaging (fMRI) allow the investigation of the neuronal substrates of learning, taking into consideration brain structure and time (Dehaene-Lambertz & Peña, 2001; Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004; Peña, Nespor, & Mehler, 2002; Schendan, Searl, Melrose, & Stern, 2003; Thomas et al., 2004). These measurements allow the construction of time windows that avoid the conscious component of learning, while enabling access to the non-conscious component.

No previous study has taken into consideration questions about the temporal dynamics of AG. However, if this form of learning can be referred to as an automatic process, rigid and hard to modulate in the presence of cognitive tasks, then it

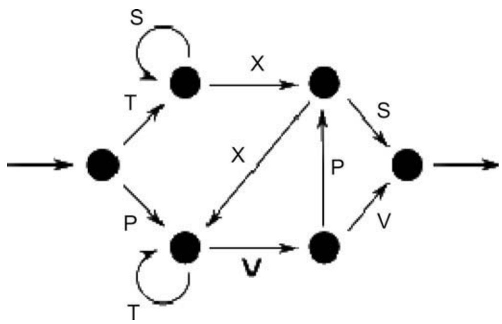


Fig. 1. Original artificial grammar.

is logical to suggest that when IL happens, it is without high cognitive demands. Therefore, the recognition of learned situations should be early in time (Reber, 1993).

An example of some studies about IL with neural measurements are those that reported that ERPs are sensitive to associative learning tasks (Rose, Verleger, & Wascher, 2000) and implicit structured sequence learning (Baldwin & Kutas, 1997). However, we found no studies that measured IL in an AG paradigm using indirect indicators of learning, like ERP, in children.

3. Implicit learning in children

There is evidence that IL is present in children of different ages (Domuta & Péntek, 2000; Gao, Xinying, & Huiyuan, 2005; Thomas et al., 2004). Of the few studies that have been carried out, two have been cited by Reber and were performed in the researcher's laboratory (Reber, 1993). Neither has been published. One maintains that, in a modified version of the AG paradigm, children between the ages of 4 and 14 reach similar performance levels. The other study found significant evidence of IL in preschool children when using a modified version of the serial reaction time task (Reber, 1993).

The results from two experiments by Lewicki, Thomas, and Czyzewska (1992) confirm the occurrence of IL in children aged four and five. The Lewicki matrix paradigm was used in the first experiment and an original version of the covariation learning paradigm was used in the second one.

Studies using clinical samples of children that investigate the independence of IL and certain cognitive resources like attention show a more unified pattern of results. Studies of IL in children with mental retardation reveal learning across different types of tasks. These results support the notion that IL is independent of attentional resources (Rosas & Grau, 2002; Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003; Vinter & Perruchet, 2002).

4. Implicit learning and children with Attention Deficit Hyperactivity Disorder

In the field of Attention Deficit Hyperactivity Disorder (ADHD), neuropsychological findings (i.e., Chhabildas, Pennington, & Willcutt, 2001; Geurts, Roeyers, Sergeant, Verté, & Oosterlaan, 2005) as well as neurophysiological and functional studies (Nigg, Doyle, & Sonuga-Barke, 2005; Pineda, Rosselli, Arias, & Henao, 1999) suggest that children diagnosed with this disorder exhibit a pattern of functioning that is distinct from children without developmental disabilities. Specifically, experimental evidence from studies using attentional change tasks suggest that the general pattern of cerebral activity in children with an ADHD diagnosis is different from that of children without compromised attention and executive functions (Silk et al., 2005).

Neuropsychological findings have suggested that children suffering from ADHD show systematic deficiencies in tasks requiring attention (particularly in continuous performance tasks), state regulation or error monitoring, temporal information processing, and executive functions (Nigg et al., 2005; Pineda et al., 1999). Generally speaking, it has been asserted that these children are slower at processing information and tend to make a significantly higher number of mistakes in tests (Geurts et al., 2005; Romine et al., 2004).

Little is known about the relationship between ADHD and IL. Domuta and Péntek (2000) address this question using a modified AG paradigm in preschool children with ADHD. Their results showed that preschool children could learn implicitly the rules for the task and that normal children outperformed those with ADHD ($t = -2.68$, $p < .01$).

Given the significant amount of evidence supporting the existence of IL in children and the relatively little knowledge available about this kind of learning in children with ADHD, the present study focuses on the following questions: (1) Is it correct that normal children are better than ADHD children at IL? (2) Are there any differences in the quality of performance in the AG task among accuracy, reaction time and ERP? (3) Do different indicators obtained from the same task provide insight onto different cognitive processes?

5. Method

5.1. Participants

Twenty-nine right-handed children (17 male and 12 female), aged 6 to 11 years (Mean = 7.31, years, SD = 0.98), were separated into two groups: (1) normal children (nine males and six females) and (2) children diagnosed with ADHD (eight males and six females).

The sample of children with ADHD was recruited by contacting parents of children who had previously received this diagnosis from a neuropediatric specialist, and inviting them to participate in the study. The other group (for ease of reference, labeled "normal children") was recruited from public schools of the metropolitan region of Santiago de Chile.

In line with international diagnostic protocols, children who were included in the ADHD group met the following diagnostic standards: (a) a behavioral assessment by parents and teachers, (b) test results of a cognitive evaluation that demonstrated a high degree of discrimination between groups (e.g., coding and digit span in Wechsler Intelligence Scale-third edition (WISC-III), Geurts et al., 2005; Romine et al., 2004), and (c) medical analysis and results integration using medical criteria (American Academy of Pediatrics, 2000). All participants were volunteers and had parental consent to participate in the study.

Table 1
Sample characteristics.

	Normal children		ADHD children	
	Media (*M*)	Standard deviation (SD)	Media (*M*)	Standard deviation (SD)
Age	7.52	1.12	7.04	0.73
Total IQ	10.24	1.98	10.76	2.13
Coding WISC-III	9.67	2.50	8.50	4.22
Digit span WISC-III	10.79	2.29	12.15	3.41
Conner's Scale	10.33	7.19	23.63	5.37

We only considered the hyperactive and mixed types of ADHD for our ADHD group ($n = 14$) according to DSM-IV-TR criteria (American Psychiatric Association, 2000). Children with the inattentive type of ADHD were not considered in this study because it has been hypothesized that inattentive types make use of different kinds of cognitive resources (Geurts et al., 2005). None of the participants diagnosed with ADHD were under pharmacological treatment.

For our analysis, we considered age, educational level and total and partial IQ results (Table 1). All participants fell within an average range of intelligence, evaluated by the WISC-III test as standardized in Chile (Ramírez & Rosas, 2007). In addition, as a means of verifying the diagnosis and classification of participants, the Abbreviated Conner's Scale (Conners, 1979a; Conners, 1979b; Vicari et al., 2003) was used. Results showed a statistical difference between groups ($t = -4.26$, $p = .01$).

All data included in this manuscript were obtained in compliance with the regulations of the Ethical Committee for Human Research of the Pontificia Universidad Católica de Chile, FONDECYT Project number 1050886.

5.2. Procedure

5.2.1. Design

The experiment had two parts: a learning phase and a test phase. In this investigation, the total duration of the experiment was, approximately, 85 min. The learning phase had some variations according to the speed of each child, but the median was 25 min. The test phase had a fixed duration (described in the next section). All the children had 30 min to play with a babysitter between the learning and test phases, using tools and pencils but not including PC games. During the interval between phases, all children received a snack, which was selected following parental advice, to avoid possible allergic reactions.

5.2.2. Learning phase

The learning phase consisted of the IL portion of an AG, similar to that used by Reber (1993; see Fig. 1), which has been adapted for children through the use of fun computer software. In this game, the letters belonging to the grammar were replaced by circus animals (Fig. 2). Therefore, words from the AG were replaced by "strings" of animals. Children were told the following story: "*This is Mr. Pepés Circus. He travels along the country in a train. There is one animal in each car of the train. Mr. Pepe arranges the animals in such a way that they feel comfortable with each other*".

Participants were asked to observe each animal sequence until they were able to memorize it. When they did, they accessed a screen where they had to recall the sequence. When a child succeeded in reproducing the correct sequence, an animation appeared to provide feedback of his success. Subsequently, the next sequence was displayed. If the child made a mistake, the correct sequence was displayed and the children were asked to copy it. There were no restrictions on the number of trials for the reconstruction of the examples. For the AG learning phase, 16 sequences (up to six animals each) were used. The children who could not complete the 16 examples were excluded from the sample. Two of thirty-one children were excluded.

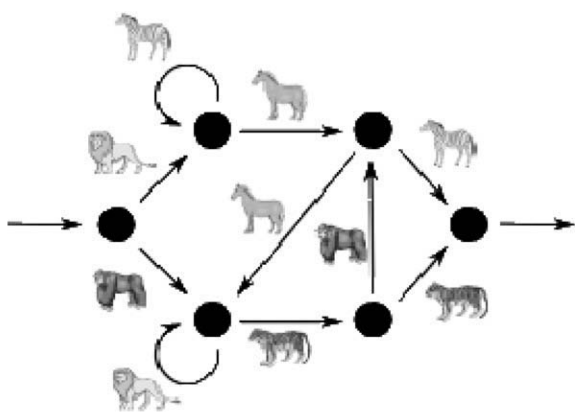


Fig. 2. Adapted artificial grammar.

Reber's (1967) original procedure was modified in three ways for this experimental setting: (1) in the initial experiment, Reber asked subjects to memorize the strings in groups of 20. In this case, because the participants were young children, they were not forced to memorize the strings in groups, but were asked instead to re-build them one by one; (2) the visual presentation of stimuli that determined the analysis of cognitive process in this study; and (3) the protocol for the post-experimental questionnaire, meant to establish the level of consciousness of the underlying AG, was not used, as an earlier evaluation demonstrated that children could not understand the questions (Thibaut & Rosas, 2007).

5.2.3. Testing phase

About 45 min after the learning phase, children were asked to recognize new exemplars of the same AG learned in the learning phase. In accordance with the original story, they were told that: "*You come to the railway station and find two circus trains. Only one of them is Mr. Pepés. Help us identify which one belongs to him*".

For each trial, two sequences were presented simultaneously on a PC display screen. Children were requested to select the sequence most similar to those they saw before. None of the sequences shown in the learning phase were used in the testing phase. A set of 11 correct and 11 incorrect sequences were presented according to the grammar rules. Both correct and incorrect sets of sequences had, for each animal, the same frequencies of occurrence and the same number of subsequences in which the same animal was repeated for the same number of times. Incorrect examples were chosen so that it would not be possible to turn an incorrect sequence into a correct one just by exchanging one kind of animal with another.

All test sequences had a length of seven animals because all sequences from the grammar up to a length of six symbols had already been used in the learning phase. The 11 incorrect sequences were built out of the 11 correct ones by randomly applying transformations that changed the order of the animals. In these transformations, the first and last animal, were left unchanged and subsequences consisting of only one repeated animal were not broken up.

Therefore, correctness of a sequence could not be assessed by examining the frequency of appearance of each animal, the length of consecutive animal repetitions, or the occurrence of the first or last symbol. Each incorrect item was tested to effectively break the grammar rules even under a bisection of the animal set. Every incorrect sequence that followed this rule had equal probability of being chosen. Consequently, the only notable property incorrect sequences did not share with correct ones was not conforming to the grammar.

During this phase, each screen presented two sequences centered horizontally, one positioned towards the top of the screen and one towards the bottom in relation to a center fix point, both of them. Each of these sequences could be correct or incorrect, so this organization generates four possible conditions that are presented to all children: (a) top sequence correct, bottom sequence correct (C–C), (b) top sequence correct, bottom sequence incorrect (C–I), (c) top sequence incorrect, bottom sequence correct (I–C), and (d) op sequence incorrect, bottom sequence incorrect (I–I).

In order to select their answer, children were asked to press the upper button of a button box if they chose the upper sequence as the correct answer. Likewise, if they chose the bottom sequence as the correct answer, the bottom button had to be pressed (Fig. 3). Children were instructed to answer as quickly as possible.

It should be noted that in two of the four conditions, there was no correct answer for children to select. However, since the instructions indicated that one and only one sequence in each test was correct, children had to choose one. These conditions were included in the experiment to obtain an indirect indicator of IL during the test phase. The finding that subjects consistently exhibited distinct electrophysiological responses in the four conditions can be considered an indirect indicator of IL.

At a behavioral level, the RTs observed in different conditions could likewise be considered an indirect indicator of IL. Our conclusions are strengthened if the two indicators coincide: if subjects' RTs in the four conditions follow the same pattern observed in the electrophysiological register, we can assume that they are making an unconscious discrimination between the conditions.

5.2.4. EEG recording

The stimuli were presented at the center of the screen in the foveal angle with a random duration between 900 and 1100 ms. In this phase, reaction time (RT) and electrophysiological (EEG) changes in the scalp were recorded, so as to obtain event-related potentials (ERPs).

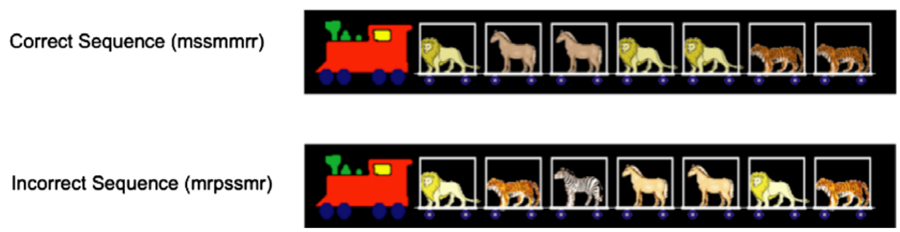


Fig. 3. Stimuli presentation format for selection task.

The electrophysiological signals were recorded on-line while the children engaged in the experiment, using a 64-channel system from Electrical Geodesic Inc., and NetStation software. A/D sampling frequency was set at 250 Hz. A band pass digital filter between 0.5 Hz and 30 Hz was later applied to remove unwanted frequency components.

Continuous EEG data was segmented from 200 ms prior to stimulus to 800 ms after stimulus. All segments with artifacts were detected with EEG software and the bad channels were marked for replacement. Cases with trials having more than five bad channels were eliminated. Artifact-free segments were averaged separately to obtain the ERPs for each of the four predictability levels and for the two groups of participants. The EEGLAB toolbox for Matlab™ was used for EEG off-line processing and analysis of the ERPs.

The analysis was carried out based on the average of a group of five occipital electrodes (33, 37, 38, 40 and 41). These electrodes were selected for theoretical and practical reasons. Since only visual stimuli were presented to the subjects and visual information is first processed in the occipital lobe (Gandhi, Heeger, & Boynton, 1999; Ito & Gilbert, 1999; Shulman et al., 1997), it makes sense to center the analysis in this cortical area. Beyond this theoretical consideration, empirical analysis showed that the five selected electrodes were not statistically different from each other with respect to amplitude and latency of the principal components.

The analyses were performed using five statistically significantly 40 ms time windows (approximately: 130, 225, 400 and 600 ms). To define these temporal windows, an exploratory analysis was made taking 40 ms windows throughout the entire signal and the four final windows were fixed for accumulative significance. Intergroup and intragroup comparisons were considered for these time windows using full factorial ANOVA and post hoc comparisons.

6. Results

6.1. Accuracy

Our results showed a statistically significant interaction ($F = 10.2043$, $p = .0015$) between group and conditions. In the correct–incorrect condition we found similar accuracy for both groups, while in the incorrect–correct condition we observed a statistically significant difference between the groups. In this difference, accuracy was below what was expected by chance (0.5) in normal children, and above for children with ADHD (see Fig. 4).

6.2. Reaction time

A 2×4 full factorial ANOVA showed a statistically significant interaction between the two factors considered (groups vs. condition) ($F = 2.8012$, $p = .038$). Normal children showed a uniform pattern in RT among the different conditions, whereas children with ADHD were faster in the correct–correct and incorrect–correct conditions and slower in the correct–incorrect and incorrect–incorrect conditions (Fig. 5).

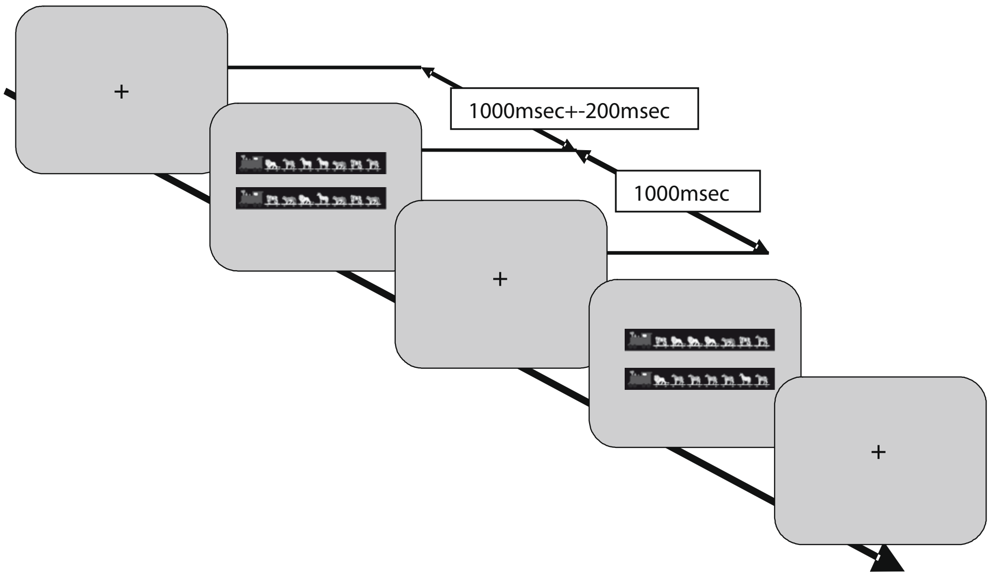
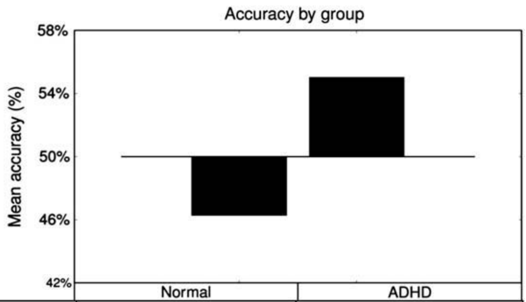


Fig. 4. Single trial of the testing phase.



	Normal	ADHD
Mean	47	54
SD	10,1	8,3
N	15	14

Fig. 5. Description data about accuracy by group.

6.3. Event-related potentials (ERPs)

To estimate the EEG results, four children from the ADHD sample were excluded due to ‘‘noisy” data from the EEG registers. For the purpose of statistical comparison, 10 children were randomly selected from the normal group. The percentage of eliminated trials was less than 5%.

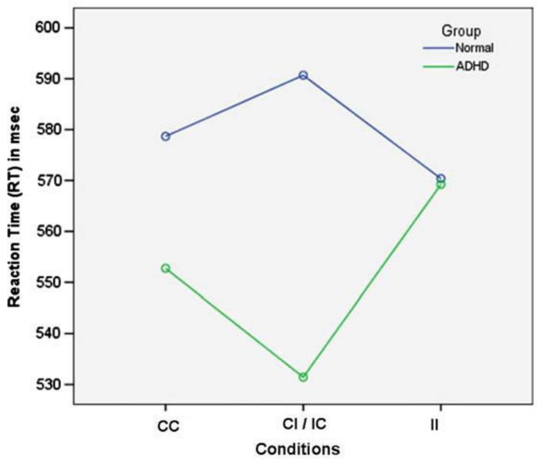
The neurophysiological response pattern under the four experimental conditions for children in both the normal and ADHD groups in all conditions, was characterized by PNP type morphology (positive at 130 ms – negative at 230 ms – positive at 400 ms) (Fig. 6).

Considering the different experimental conditions differences were observed between the groups for each time window (Fig. 7). When compared by conditions, the ADHD group began to exhibit significantly different responses to different conditions early, after only 130 ms had elapsed. Specifically, reactions to the C–C and I–C conditions were statistically significant, ($F = 4.211$, $p < .05$), as were those to I–C and I–I ($F = 5.657$, $p < .05$). The group of normal children demonstrated a comparable pattern only in the CC–CI comparisons.

At about 225 ms, the normal group also began to show different reactions to different conditions, namely in response to C–C and I–I ($F = 6.430$, $p < .05$). In this time window, the ADHD group responded differently to all the C–C (Table 1) condition comparisons and in the C–I and I–I ($F = 4.871$, $p < .05$) groups.

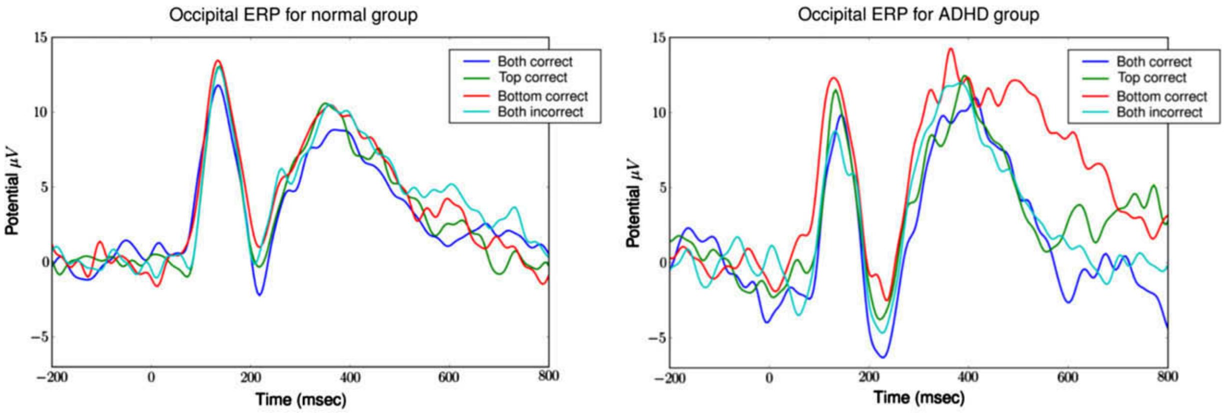
Significant differences were once again observed at the time window close to 300 ms, but only in the ADHD group. These differences appeared when comparing reactions to the C–C and C–I conditions ($F = 4.067$, $p < .05$), and CC vs. II ($F = 6.651$, $p < .05$).

Finally, in the late time window, at about 600 ms, significant differences were observed in both groups, although the statistical results suggested that there were distinctions between the reactions to the different conditions in the group of



	CC		CI / IC		II	
	Mean	SD	Mean	SD	Mean	SD
Normal	578,7	101,6	590,7	81,5	570,4	83,9
ADHD	552,7	76,4	531,4	82,0	569,2	78,1

Fig. 6. Reaction times in the different modalities in which the stimuli are presented.



Normal group – Significance of difference for all condition pairs.

Conditions compared		Time ranges (msec) 130	225	300	400	600
Both correct	Top correct					
Both correct	Bottom correct					*
Both correct	Both incorrect		*		*	***
Top correct	Bottom correct					
Top correct	Both incorrect					**
Bottom incorrect	Both incorrect					

ADHD group – Significance of difference for all condition pairs.

Conditions compared		Time ranges (msec) 130	225	300	400	600
Both correct	Top correct					**
Both correct	Bottom correct	***	***	***		***
Both correct	Both incorrect			*		
Top correct	Bottom correct			*		*
Top correct	Both incorrect		*			
Bottom incorrect	Both incorrect	***				***

Fig. 7. Results ERP potential.

children with ADHD. This suggested that there may be a number of different comparisons to be made within the group of children with ADHD.

6.4. ROI analysis

The anteroposterior ROI was included all frontal and occipital electrodes. In the inter-hemispheric ROI, at the 110–150 time window we found statistical differences in the ADHD group for the conditions CI ($p < 0.05$) and II ($p < 0.05$). The CI condition showed the highest positive activity pattern in the right hemisphere, whereas for the II condition this positivity was found in the left hemisphere.

In the 280–320 time window, we found differences for both groups. The conditions CI and IC in the ADHD groups ($p < .01$) showed a positive dominance by the right hemisphere in CI and by the left for the IC. The IC condition showed differences for the normal group ($p < .05$) with a positive dominance in the left hemisphere ($p < .05$).

7. Discussion

The principal finding of our study is that normal children and those with ADHD perform differently on accuracy, reaction time and EEG signal of IL on a modified AG task. While this provides no direct indication of IL in either group, *both RT and ERP* suggest the occurrence of IL and do so in both experimental groups.

The present discussion is organized into three main topics: (a) IL and the necessary distinction between its direct and indirect indicators, (b) the differences between normal and ADHD groups in the processing of IL, and (c) guidelines for future research emerging from our study.

7.1. Indirect indicators of IL: a new answer to an old question

One of the most hotly debated topics in the field concerns the detection and measurement of IL. Since Reber (1967) published his original findings, discussions of the phenomenon revolve around the question of whether subjects are aware of the regularities they are subjected to in the learning phase. A key hypothesis (Shanks & St. John, 1994) postulates that while subjects may become aware of certain local regularities, and while this awareness may increase accuracy in the forced selection task beyond that expected by chance, subjects will still be unable to articulate the underlying pattern explicitly. This hypothesis has been widely debated and has not been yet rebutted with experimental data.

This problem has been partially circumvented by the introduction of indirect indicators of IL, for example, RT in response to valid and invalid sequences of exemplars of a given pattern or rule. This procedure acknowledges that evidence of learning may be obtained from indicators other than explicit and aware responses of participants (Fischer, Wilhelm, & Born, 2007).

Our results demonstrate that children show different RTs in different experimental conditions after having been subjected to a learning phase. We hypothesized that children could distinguish between the conditions just in the presence of mediated learning. This finding was supported by both RT and ERP indicators. Nevertheless, the results showed that children were unable to give correct answers in the presence of valid and invalid examples.

How should these results be interpreted? On the one hand, based on direct indicators, there is no evidence of learning. However, if we pay attention only to indirect indicators, we can say that learning has taken place. What is meant by "learning" in this case? If learning is the behavioral report of accuracy, then we can say that it does not exist. But if all the indirect evidence shows that the participants behave in a different way to the stimuli, we must recognize a change in the cognitive structure that allows for a differentiation in the stimuli presented. We think that we have observed something similar to a priming effect, one which does not reach the threshold required for *correct* decisions, but does prove a degree of learning. This requires a more careful look at the meaning of the indirect indicators of IL.

7.2. ADHD children perform better than normal children in an AG task: this provides support to the existence of differences in information processing between these groups

We argue that the difference between direct and indirect indicators of IL demonstrates a transformation in the cognitive structure mediating the ongoing processing of the stimuli displayed in an AG paradigm. We also propose that this difference is evidence of non-conscious learning. One of the most remarkable findings of our study was the difference in responses shown by normal and ADHD children towards indirect and direct indicators of IL.

While neither group of children achieved above-chance levels of accuracy (the direct indicator), their levels of accuracy were significantly different from one another. This finding is difficult to interpret, in part because children in the normal group tended to exhibit a *below chance* level of accuracy. However, the consistency of the findings between our two indirect indicators, in addition to their proven ability to distinguish between groups, invites us to conclude that there are differences in the ways in which these children process information.

Our results show that children with ADHD respond early to differences between conditions; conditions which can only be distinguished on the basis of learning that, in this experimental setting, occurred implicitly. This ability was not found in normal children. This suggests that children with ADHD perform better in tasks in which the presentation of stimuli has given them the opportunity to acquire regularities from the environment without requiring the investment of metacognitive resources.

The differences in performance between the two groups in our study support the idea that IL is independent of attention and working memory, whose decline in ADHD has been demonstrated in several investigations. In addition, we suggest that despite the limited research on IL in children, there are suitable experimental paradigms that permit the exploration of implicit learning in this population, and the field should be expanded with new research.

Regarding the electrophysiological evidence, we observed differences in the patterns of neural activity, both among groups and among conditions within each group. Between groups, we can offer two observations. First, the two groups have a similar morphology of components, a finding that validates the idea that there is a common perceptual process in both groups. However, the second finding is that the two groups displayed significantly different amplitudes. Considering such differences, it is possible to suggest that children with ADHD have specific differences with normal children with respect to certain neural processes, perhaps reflecting an investment of different attentional resources.

Furthermore, the finding that children in the ADHD group show significantly different response times to different conditions within the earliest time windows (130 ms and 225 ms), suggests that the recognition of implicitly acquired regularities occurs at an early stage. This finding also suggests that information is being processed by a relatively simple neurocognitive system, less dependent on high levels of cognitive activity such as monitoring, control, attention, and the executive functions of decision-making and problem solving.

These neurophysiological findings are consistent with the results obtained by RT measures. The differences in performance between the standard conditions (CI–CI) and the II and CC conditions allow us to make finer distinctions between groups at both levels of analysis. These differentiations between conditions are possible only where IL has occurred. Children with ADHD demonstrate the greatest differentiation between standard and other conditions.

We think that future research should focus on two general lines: (a) studies aiming to overcome some of the limitations of our research and (b) studies that confirm the validity of our main findings. On the first point, we consider it important to strengthen the training stage up to the point where it becomes possible to obtain valid and reliable IL results using direct indicators. Recall that the training stage of our procedure used 12 exemplars, while in Reber's original paradigm, each subject was exposed to 60 exemplars. This reduction was made since a pilot study suggested that children start to show signs of boredom after 12 exemplars. It is entirely possible that the lack of accuracy observed in our study is due to the low number of learning trials. Under these constraints, achieving any observable difference from indirect indicators (strength, direction or patterns) would give greater support to our thesis. On the second point, we think it is necessary to develop and widen the use of experimental paradigms that further study the cognitive processing differences between children with ADHD and normal children.

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