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AUDITORY SENTENCE COMPREHENSION IN CHILDREN WITH READING DISABILITIES: AN EVENT-RELATED POTENTIALS STUDY.

COMPRENSIÓN AUDITIVA DE ORACIONES EN NIÑOS CON TRASTORNO DE LA LECTURA: ESTUDIO CON POTENCIALES RELACIONADOS CON EVENTOS.

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Abstract

In the present study, we propose to explore the Event-Related Potentials (ERP) components elicited in reading disabled (RD) and normal readers (NR) children by phonological and semantic processes using an auditory sentence comprehension task, that manipulate both phonological and semantic expectancies. Reading deficiencies in both these processes have been demonstrated in RD children, thus similar problems might also be expected for oral language in these children. Twenty-two male children (9-12 years old) with normal IQ, were classified by Neuropsychological Battery for Reading Disabilities into two groups: Normal Readers (NR, n=11) and Reading Disabled (RD, n=11). ERPs were recorded from 19 derivations of the I.S. 10-20. Children were presented with spoken sentences that ended with a word that was either (a) semantically congruent, and phonologically expected, (b) semantically incongruent, but

beginning with the same initial phonemes as the congruent completion, or (c) semantically incongruent, and phonologically unexpected. For each type of sentence, ERP were analyzed in two time windows: early time window (330-430 ms) related to phonological processing, as well as a later N400 window (515-615 ms) that would reflect the semantic processing. In both groups, the three types of sentences elicited a negative waveform with an onset at 200 ms that lasted until approximately 900 ms. This negative waveform had greater amplitude in response to semantically incongruent, compared to semantically congruent sentences. Results revealed a probably anomalous phonological processing in RD children, reflected by a greater ERP response to expected, than to unexpected, words in a given sentential context. However, both the N400 responses related to semantic processing, and the behavioral responses related to the correctness of sentences, were comparable between RD and NR children.
Key words: ERP in children, N400, reading disabilities, spoken language.

Resumen

Este estudio se orientó a explorar los componentes de los potenciales relacionados con eventos (PRE) elicitados en niños con discapacidad en la lectura (LD) y lectores normales (LN), con procesos fonológicos y semánticos empleando tareas de comprensión auditiva de oraciones que manipulaban tanto expectativas fonológicas como semánticas. Las deficiencias en la lectura de ambos procesos ha sido demostrada en niños LD, de modo que sería de esperarse problemas similares para el lenguaje oral en esos niños. Veintidós niños varones (9-12 años) con C.I. normal, se clasificaron en dos grupos a partir de la batería neurológica de discapacidad en la lectura: LN=11 y LD=11. Se registraron los PREs a partir de 19 derivaciones del I.S. 10-20. Se les presentaron a los niños oraciones habladas que terminaban con una palabra que podía ser: a) congruente semánticamente y fonológicamente esperada, b) incongruente semánticamente, pero iniciando con los mismos fonemas de un final congruente, o c) incongruente semánticamente y fonológicamente no esperada. Para cada tipo de oración se analizaron los PRE en dos ventanas temporales: de manera temprana (330-430 ms) en relación al procesamiento fonológico, así como en una fase posterior del N400 (515-615 ms) que reflejara el procesamiento semántico. En ambos grupos los tres tipos de oraciones elicitaron una forma de onda negativa al inicio de 200 ms que duraron hasta aproximadamente 900 ms. Esa forma de onda negativa tuvo mayor amplitud en respuesta a oraciones incongruentes semánticamente, en comparación con las congruentes. Los resultados revelaron un procesamiento fonológico probablemente anómalo en los niños LD, que se reflejó en una mayor respuesta PRE a la palabras esperadas, que a las no esperadas dentro del contexto de una oración, sin embargo, tanto las respuestas N400 relacionadas al procesamiento semántico, como las respuestas conductuales relacionadas a las oraciones correctas, fueron similares entre los niños LD como los LN.
Palabras clave: Potenciales relacionados a eventos en niños, N400, discapacidad en lectura, lenguaje hablado.

Introduction

The term learning disabilities (LD) describes the most common developmental disorder and refers to the inability to develop specific skills such as reading, arithmetic, language, or reasoning in spite of adequate instruction and a subject's normal intellectual coefficient (American Psychiatric Association [APA], 2003). In Mexico, the General Management of Special Education (from the Public Education Ministry) estimates that the prevalence of LD in this country is between 6 and 7% of the general school-age population (Fletcher & Kaufman, 1995).

Within the population of children diagnosed with LD, specific reading disability (RD) is the most prevalent subtype. It is considered that 4 in 5 LD children present as specifically disabled in terms of their ability to learn to read. The DSM-IV-TR (Diagnostic and Statistical Manual of Mental Disorders-Revised) defines that an essential feature of "Reading Disorder" is "reading achievement (i.e. reading accuracy, speed, or comprehension as measured by individually administered standardized test) that falls substantially below that expected given the individual's chronological age, measured intelligence, and age-appropriate education" (APA, 2003).Several reports in the literature have concluded that RD children are a heterogeneous group with diverse cognitive deficits in areas such as language processing, working memory, or attention (Fletcher, 2009; Swanson & Jerman, 2010).

Despite decades of intensive research, the study of LD remains a controversial field. For example, the underlying biological and cognitive causes of reading disabilities are still debated (Ramus & Ahissar, 2012). A large amount of evidence supports the concept that the core deficit in RD is in phonological processing (Ramus et al., 2003; Stanovich, 1988).Other authors have pointed out the importance of semantic processing for reading acquisition (Nation & Snowling, 1998; Vellutino, Scanlon, Spearing, 1995).

The phonological hypothesis postulates that RD children have a specific impairment in the representation, storage, and/or retrieval of speech sounds. Learning to read requires learning the correspondence between letters and constituent sounds of speech (i.e. the grapheme-phoneme correspondence). If these sounds are poorly represented, stored, or retrieved, the learning of grapheme-phoneme correspondences will be affected accordingly. Support for the phonological hypothesis comes from findings that RD individuals perform particularly poorly on tasks requiring phonological awareness, such as conscious segmentation and the manipulation of speech sounds. The dysfunction of left hemisphere perisylvian brain areas underlying phonological representations (or connecting between phonological and orthographic representations) has been proposed as the neurological origin of the disorder (Ramus et al., 2003).

On the other hand, the relevance of semantic processing for reading efficiency has been demonstrated (Nation & Snowling, 1998; Swanson & Alexander, 1997). Particularly, subgroups of readers have been identified who have comprehension difficulty in the absence of decoding problems (Cain, Oakhill & Bryant, 2000; Oakhill, Cain & Bryant, 2003), and these individuals may have general semantic processing difficulties (Nation & Snowling, 1998, 1999). Support for this hypothesis comes from evidence that poor comprehenders perform more poorly than controls on a variety of semantic tasks (i.e. reading low frequency words, verbal fluency tasks, judging synonyms). In neuropsychological tests, Spanish-speaking RD children also exhibit semantic and syntactic difficulties (i.e. semantic errors in sentences completion; Jiménez et al., 2004; Silva et al.,1995; Yáñez, 2000). Recent neuroimaging studies have shown anomalous brain activity in RD children performing semantic tasks compared to controls (Kronbichler et al., 2006). Specifically, activity of the left inferior frontal gyrus, left inferior parietal lobule, and left middle temporal gyrus, areas critical for semantic processing in normal children, has been shown to be abnormal in RD children and adults (Booth, Bebko, Burman & Bitan, 2007).

However, the auditory comprehension of language is considered to be an integrative, adaptive, automatic, and complex process that requires sensitive cognitive and linguistic mechanisms (Belinchón, Igoa & Riviére, 1994). Many models of reading comprehension highlight the close relationship between comprehension processes in reading and listening comprehension (Fletcher, Lyon, Fuchs & Barnes, 2007), as well as the frequency with which difficulties in listening comprehension parallel problems with reading comprehension (Shankweiler et al., 1999; Stothard & Hulme, 1996). Most studies that have compared reading and listening comprehension in normative samples show high levels of overlap (Fletcher et al., 2007). A comprehensive study in RD children also supports the presence of a close relationship between listening comprehension and reading comprehension skills (Wise, Sevcik, Morris, Lovett & Wolf, 2007). Specifically, in this study, better listening comprehension skills were related to better word identification skills when reading. These data appear to justify the study of listening comprehension in RD children.

Event-Related Potentials (ERPs)

One of the most useful techniques to study the physiological basis of cognitive processes is the measurement of ERPs which allows researchers to study cognitive processing with a high-degree of temporal resolution (Hillyard & Picton, 1987). The different levels of representation of language (i.e. phonological, semantic, syntactic) can be studied separately using this technique, as each is associated with a distinct ERP patterns (components).

The N400 ERP component relates specifically to semantic aspects of language processing. This negative polarity component peaks approximately 400 ms after the word onset, and is maximal anteroposterior scalp sites (Kutas & Hillyard, 1980). The N400 amplitude increases when a subject is processing incongruent or unexpected words within a sentence context that is presented either visually or auditorily (Holcomb &Neville, 1991; Kutas e Hillyard, 1980; Rodríguez, Prieto & Bernal, 2011).The functional interpretation of N400 is that it reflects a "lexical integration" process, which is defined as the ability to relate a word, whether read or heard, with its context at the semantic, syntactic, and pragmatic level (Brown & Hagoort, 1993). Thus, after a word has been activated in the mental lexicon, its meaning has to be integrated into a higher-level conceptual representation of the context within which it occurs. Larger amplitudes of N400 are associated with more difficult integration processes (Brown & Hagoort, 1999; Brown, Hagoort & Kutas, 2000; Chwilla, Brown & Hagoort, 1995).

In listening comprehension, it is generally accepted that the semantic context of a sentence exerts a strong influence upon there cognition of the incoming words. In ERP studies of spoken sentence comprehension, early effects of sentential context on spoken word recognition have been described. An early negative shift preceding N400 was initially related to phonological processing of words; however, this interpretation has not been unanimously accepted.

Connolly and Phillips (1994) have described the so-called Phonological Mismatch Negativity (PMN). They presented sentences with different contextual restrictions that varied along phonological/semantic dimensions. PMN was elicited for words whose initial phonemes were unexpected as a function of the context restriction preceding a particular word. For example "he caught the ball with his…glove," in which the word "glove" is semantically and phonologically less expected than the ending of "hand." Another example would be the phrase "he mailed the letter without a…roof," in which the word "roof" is both semantically and phonologically unexpected (Connolly & Phillips, 1994). In this work, the N400 component was elicited in response to words that were semantically incongruous with the sentence context. Because the amplitude of this early negative shift varied as a function of the congruence of the sentence's initial phoneme(s) with the contextually most expected word, Connolly and Phillips (1994) proposed that PMN is sensitive to phonological expectations derived from sentence context.

Van Den Brink, Brown and Hagoort (2001) later described an ERP component, termed N200, that precedes N400 for three types of sentences: fully (phonological and semantic) congruent, fully incongruent, and initially congruent (semantically incongruent but with the same initial phoneme (s) as the most expected word). As these authors also found an early negative potential in response to words that were fully congruent with the preceding context, they argued that this effect cannot be attributed to phonological mismatch, but rather is responsive to the "goodness-of-fit" between the activated lexical candidates and the preceding context. These authors suggest that N200 reflects processes that occur in the interphase of lexical form and contextual meaning. In such a process, lexical candidates activated by their forms (sharing the same initial phonemes) are evaluated, and eventually discarded, in terms of the contextual specifications of the sentence. They concluded that the N200 is separable from the N400, and that it reflects contextual influences upon lexical selection specifically in spoken word recognition.

van Petten, Coulson, Rubin, Plante and Parks (1999) also observed early effects of sentence context upon spoken word recognition. In their study, the ERP results support the hypothesis that semantic processing can begin upon incomplete acoustic information, i.e., before the isolation point of final words. The authors argue that this early ERP effect is not a distinct component from the N400, nor did the grand average waveforms show biphasic activity. They concluded that a more probable explanation for these results is that sentential context generates semantic, and not phonological, expectations.

Finally, Díaz and Swaab (2007) tried to find evidence of the presence of PMN that distinguishes the processes of early lexical processing from those of semantic integration, which are reflected in the N400. For this purpose, they recorded ERPs elicited in response to word lists and sentences, while manipulating the semantic and phonological expectations as well as the congruency of the final words. ERP components sensitive to phonological processing were elicited only when the phonological expectancy was violated in the lists of words, but not during sentential processing, during which only a single negative waveform (N400) was observed. In agreement with van Petten et al. (1999), the authors concluded that, during sentential processing, ERP components that reflect the "goodness-of-fit" between the semantic features of the lexical candidates are elicited in response to the phonological input and the previous semantic context.

In children, studies of the N400 ERP component have focused on the maturation of linguistic processes and, to a lesser extent, upon deficits in these processes. Within the first category, significant decreases in both the amplitude and latency of N400 have been correlated with increasing age for both reading and listening comprehension, indicating that, in a general sense, these N400 alterations reflect a better comprehension of language (Atchley et al., 2006; Hahne, Eckstein & Friederici, 2004; Holcomb, Coffey & Neville, 1992; Juottonen, Revonsuo & Lang, 1996). On the other hand, only one report concerning the auditory comprehension of sentences in children with developmental dyslexia has been published to date (Sabisch, Hahne, Glass, von Suchodoletz & Friederici, 2006). These authors report no significant differences in theN400 component between dyslexics and a control group, and conclude that the lexical integration process of dyslexic children is no different from that of controls for the auditory processing of sentences.

In a spoken word recognition task that involved implicit phonological processing, Bonte and Blomert (2004) demonstrated anomalies in the early N1 and N2 ERP components, but normal N400 component, in dyslexic children compared to controls. This finding suggests that dyslexic children may have deficits at the phonological level, but intact processing at the lexical level, of word recognition.

In the present study, we propose to explore the ERP components elicited in RD and normal readers by phonological and semantic processes using an auditory sentence comprehension task, in which the sentences used, were intended to manipulate both phonological and semantic expectancies. Reading deficiencies in both these processes have been demonstrated in RD children, thus similar problems might also be expected for oral language in these children (Fletcher et al., 2007). Our hypothesis is that there is an ERP component that is related to phonological processing, whether part of the N400 waveform or not, in addition to the N400 effect related to semantic processing. When compared to normal readers, in RD children, we expect to see decreases in the amplitude of ERP components elicited in response to the manipulation of phonological and/or semantic expectancies, which reflect the RD individual's proposed deficiencies in these processes.

Method

Participants

Twenty-nine male children (9-12 years old) were classified into two groups: Normal Readers (NR) and Reading Disabled (RD). Because the EEG recordings of seven children were not useable, the final sample consisted of 22 children (11 NR and 11RD).
Characteristics of the sample are shown in Table 1.

Table 1.
Descriptive data for normal readers and reading disabled chidren.

	NR	RD		
N	11	11		
SEX	MALE	MALE		
HANDEDNESS	RIGHT	RIGHT		
	M (SD)	M (SD)	t	p
AGE	10.36 (1.02)	10.8 (1.16)	-0.97	0.344
TIQ	101.09 (9.66)	98.55 (11.95)	0.549	0.589
Reading accuracy (Z)	0.52 (0.47)	-1.21 (1.66)	3.333	0.003
Reading speed (Z)	-0.19 (0.56)	1.33 (1.04)	-4.28	0.000

NR: Normal readers children; RD: Reading disabled children
Z: z-scores.
t-test results for TIQ (Total IQ) and z-scores for Reading accuracy and speed from NBRD.
M: Mean; SD (Standard deviation)

None of the participants had a history of neurological disorders, and all had normal vision and audition according to the neurological examination. Socioeconomic status was similar between the two groups of children. All participants' parents gave informed consent.
The groups were classified according to the following criteria: a) having a normal IQ according to WISC-R, b) to be classified as RD, a child's scores of accuracy and speed in word reading had to be between one and two standard deviations below normal.

Instruments: a) Interview for children with learning disabilities: this explores pre, peri, and postnatal data, as well as information regarding the child's development and socioeconomic and school-related factors that might interfere with scholastic achievement. b) The Weschler Intelligence Scale for Children-Revised (WISC-R).c) Clinical neurological examination. d) Subtests of word reading (speed and accuracy), reading comprehension, and written order comprehension from the Neuropsychological Battery of Reading Disabilities (NBRD) (Yáñez, Bernal, Marosi & Rodríguez, 2002).

Stimuli

For the ERP recordings, sentences from the corpus by Rodríguez-Camacho et al. (2011) were used. This corpus contains termination norms for the final word of sentences obtained through the cloze method in Mexican children (Taylor, 1953). High and low cloze probability sentences were obtained from this corpus. A sentence was considered to be a high cloze probability sentence when it was completed with the same final word by 70% of the subjects. Below this percentage, a sentence was considered to be a low cloze probability sentence.

The sentence corpus included three types of sentences: 1) "Totally Congruent" (TC): Semantically congruent and phonologically expected [i.e. "Yo vivo en mi casa" ("I live in my house")]; 2) "Initially Congruent" (IC):Semantically incongruent and phonologically expected (because the final word shares its onset phoneme with the most expected word), [i.e. "Los bebés toman letras" ("babies drink mirrors")("leche" "milk" would be the most expected word) ; 3) "Totally Incongruent" (TI):Semantically incongruent and phonologically unexpected [i.e. "La gallina pone un tren" (The hen lays a train")].

"Phonologically expected" for the final word in the sentence was defined by the cloze probability. For high cloze probability sentences, it was inferred that the last word was both semantically and phonologically expected for that particular sentence.

TC and IC sentences were obtained from high cloze probability sentences. TC sentences were transcribed without any change. To construct IC sentences, the final words were replaced by other words that had the same onset phoneme, but which were semantically incongruent with the original sentence. TI sentences were obtained from low cloze probability sentences. To construct TI sentences, the final words were replaced by semantically incongruous words. There placement words for IC and TI sentences were obtained from specialized dictionaries: "Del español usual en México" (Lara, 2002), "Diccionario del léxico infantil de México" (Ávila, 1989) and "Cómo usan los niños las palabras" (Alva et al., 2001).

ERP recording

Two-hundred and ten (70 of each type) sentences were presented audibly to the children. A pseudo-random presentation was used, with the constraint that no more than three sentences of the same type could be presented sequentially. Each sentence was presented through earphones using the stimulation software E-Prime (Psychology Software Tools, Inc.). In each case, the final word in the sentence was a noun. Sentences were recorded by a female speaker with normal intonation and were digitalized at 44.1 KHz, with an intensity of 60 dB, monaural at 16 bits, and were stored on a hard drive (Holcomb et al., 1992). The final words had an average duration of between 500 and 700 ms. A 500 ms pause was presented between the sentence context and the final word.

The electroencephalogram (EEG) was recorded using MEDICID 02 (Neuronic, Cuba) equipment synchronized to the E-Prime stimulation software. The bandwidth of the amplifiers was from 0.05 to 30 Hz. The sampling interval was 5 ms, with epochs of 1280 ms and a pre-stimulus time of 100 ms. Monopolar recordings at 19 derivations of the 10-20 International System were obtained at the Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3 T4, T5, T6, Fz, Cz, and Pz locations with linked earlobes (A1-A2) as reference, using a custom elastic cap (Electrocap International Incorporated; Ag/AgCl2 electrodes). The electro-oculogram (EOG) was recorded using two electrodes placed at the outer and the supraorbitary rim of the left eye. Electrode impedance was kept below 10 kOhms.

Procedure

Children were comfortably seated in an acoustically shielded and dimlylit room with which they had been previously familiarized. The subjects were asked to listen attentively to the sentences and to decide whether the sentences were "right" or "wrong", pushing a different button of the mouse in each case (right button for correct sentences and left button for incorrect sentences). The response button was counterbalanced. For motivation, the children were told that they would receive a prize at the end of the session. Each recording session began with ten training sentences. Each sentence appeared on the monitor inside black rectangle presented upon a blue background, to which subjects were told to direct their gaze throughout the presentation of the sentence. This presentation method is intended to prevent ocular movements and to maintain an adequate level of attention, both of which were constantly monitored by one of the investigators. To avoid contamination of the ERP by motor responses, children were asked to delay their response by three seconds after reading the last word of each sentence. At this time, the text: "Answer!: Right or Wrong?" appeared in the monitor and remained for four seconds, which was the maximum response time allowed. The children were instructed to blink only when the sign appeared on the screen. The children were allowed to rest every four to five minutes.

Data analysis

Behavioral responses.

A mixed-ANOVA was used for comparisons between groups in the measures of reaction time and the percentage of correct responses to the sentences used in the ERP recording session.

Electrophysiological data.

EEG segments were visually edited to exclude any artifacts or EEG activity exceeding ± 80 µV. EEG segments were averaged separately for each type of sentence. For each subject, the number of EEG segments for each type of sentence was kept constant (around 20 segments).

To facilitate the identification of the N200 and N400 ERP components, we conducted a series of mixed-ANOVAs on 50 ms windows encompassing from 200 to 700 ms relative to the onset of the final word on the midline and lateral electrodes with condition, electrode, and hemisphere as within-subjects factors, and with group as a between-subject factor. With this analysis, we found significant effects for condition or condition x electrode interaction in each window from 300 to 650 ms.

Based on the analysis of 50 ms windows, and the visual inspection of the grand average, we performed the statistical analysis in two time windows for both groups of children. These consisted of an early time window (ETW; 330-430 ms) which, according to literature reports, may capture an early negative effect related to phonological processing (termed "PMN" (Connolly and Phillips, 1994), "N200" (van den Brink et al., 2001), or "early N400" (van Petten et al., 1999; van den Brink and Hagoort, 2004)), as well as a later N400 window (515-615 ms) that would reflect the N400 effect (Díaz & Swaab, 2007).

Mean amplitudes of ETW and N400 were analyzed separately by mean of a four-way mixed-ANOVA (omnibus-ANOVA) with the following within-subjects factors for the lateral electrodes (F3-F4,C3-C4,P3-P4,F7-F8,T3-T4,T5-T6): condition (i.e. sentence type; 3 levels), anteroposterior electrodes (3 levels: frontal, central and parietal), hemisphere (2 levels: right and left), lateral electrodes (2 levels: paracentral and lateral), and group (2 levels: normal readers and RD) as between-subject factor. For the midline electrodes, a three-way mixed-ANOVA was performed with the following within-subjects factors: condition (sentence type; 3 levels) and anteroposterior electrodes (3 levels: frontal, central, and parietal) as within-subjects factors, and group (2 levels) as a between-subject factor. The Huynh-Feldt correction was applied to all analyses with more than one degree of freedom in the numerator. Post-hoc analyses were carried out using Least Square Differences (LSD).

For the follow-up analysis, which assessed the effect of sentence type (condition) on the Early Time Window (ETW) and N400 amplitudes separately for each group, a RM-ANOVA was performed with the aforementioned factors (excepting group).

Results

Behavioral measures

Percentage of correct responses.

No significant between-group differences were found in the percentage of correct responses to the three types of sentences. A main effect of condition was found (F (1.53, 30.59) =9.54, p= 0.001). Post hoc analysis showed that IC sentences (=94.6%; mean differences=-6.4, p= 0.002) and TI sentences (=93.4%; mean differences = -5.14, p= 0.010) displayed a greater percentage of correct responses compared to TC sentences (=88.2%; see Table 2).

Reaction Times (RT)

No significant between-group differences were found for RT in the three types of sentences. A main effect of condition was found (F (1.81, 36.24)=74.95, p= 0.000). Post-hoc analysis showed that TC sentences were associated with the fastest RT (Me= 4525.23 ms) as compared to IC (Me= 4784.77 ms; mean differences = -259.55, p=0.000) and TI (Me= 4581.68 ms; Mean differences=-56.45, p=0.026). IC sentences had slower RT than did TI sentences (Mean differences=203.09, p= 0.000; Table 2).The apparent great values for RT are due to the experimental design as measures of RT in this study were deferred.

Table 2.

Mean percentages of correct responses and reaction times (± sd) for each type of sentence in each group.

	NR	RD		
SENTENCE	HITS	REACTION TIMES	HITS	REACTION TIMES
TYPE 1	90.9 (5.1)	4540.2 (283.5)	85.5 (10.8)	4510.2 (207.8)
TYPE 2	96.1 (2.1)	4775.7 (314.1)	93.1 (3.8)	4793.9 (226.1)
TYPE 3	94.4 (5.5)	4575.5 (281.9)	92.3 (5.0)	4587.9 (251.8)

NR: Normal readers children; RD: Reading disabled children

Electrophysiological measures

Figure 1 depicts ERP elicited in response to the final words of the three types of sentences (TC, IC, TI) for the NR (left panel) and the RD (right panel) groups in nine representative derivations. In both groups, the three types of sentences elicited a negative waveform with an onset at 200 ms that lasted until approximately 900 ms. This negative waveform had a greater amplitude in response to semantically incongruent (i.e. IC and TI),compared to semantically congruent (TC), sentences. The N400 effect was most noticeable in the central and parietal regions compared to the frontal regions in both groups, and showed maximal amplitude between 500 and 600 ms.

In the NR group, a discrete negative shift, with an ill-defined waveform, was observed at frontal electrodes mainly in response to TC and IC sentences. This shift was observed at the central electrodes in response to both IC and TI sentences. In the RD group, the discrete negative shift was observed to be more defined at Fz and Cz in response to TC sentences, and also had a greater amplitude at the central, compared to the frontal electrodes, in response to TC sentences. This discrete negative shift could be associated with the N200 component that has been described for adults, as it was elicited for all three types of sentences disregarding its congruence (see van den Brink et al., 2001). However, this negative shift has not been previously described in ERP studies examining responses to auditory sentences in children (Atchley et al., 2006; Holcomb et al., 1992; Sabisch et al., 2006; see Fig. 1).

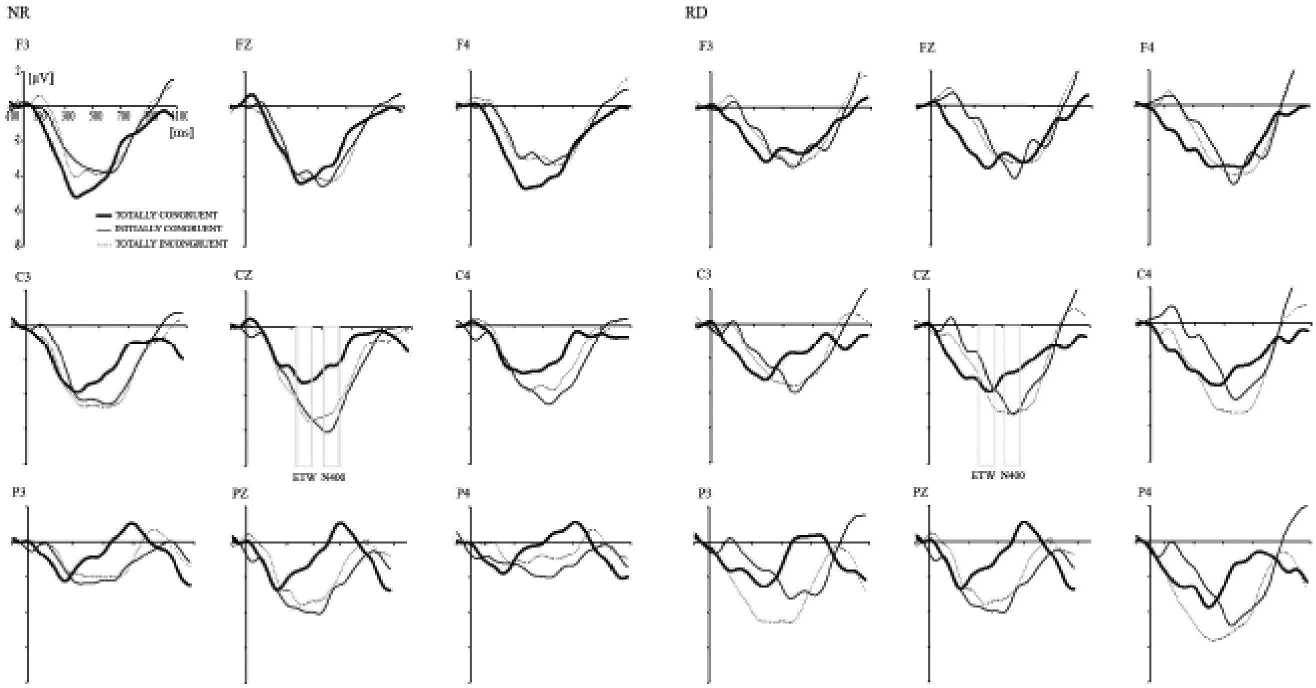

Figure 1. Grand averages for the three types of sentences in nine representative derivations. Left panel: Normal Readers (NR) children. Right panel: Reading Disabled (RD) children. ETW (early time window): 330-430 milliseconds. N400: 515-615 milliseconds. Negativity plotted downwards.

Mixed-ANOVA

Early Time Window (ETW).

A significant group x condition x laterality interaction was identified for the lateral electrode analysis (Table 3). For midline electrodes, a significant group x condition interaction was revealed (Table 3). The post-hoc analysis showed that the NR group displayed a greater amplitude in response to TI, compared to TC, sentences (TI sentences=-4.92 μV; TC sentences=-2.50 μV; mean differences LSD=2.42, p= 0.009), while for the RD group, responses of greater amplitude were elicited to TC sentences compared to IC sentences (TC sentences=-4.43μV; IC sentences=-2.50 μV; mean differences LSD=-1.93, p= 0.035).

Table 3.
Mixed ANOVAS for ETW and N400

			ETW (330-430 ms)		N400 (515-615 ms)	
	Factor	df	F	p	F	p
Lateral	Group	1,20	1.19	0.28	<1	
	Cond	2,40	<1		4.19	0.022**
	Group x Cond	2,40	1.74	0.19	<1	
	Group x Cond x AP	2.69,53.63	<1		<1	
	Group x Cond x Hemis	2,40	<1		<1	
	Group x Cond x Lat	2,40	4.03	0.025**	<1	
	Group x Cond x AP x Hemis	3.24,64.90	2.11	0.110	1.85	0.14
Midline	Group	1,20	<1		<1	
	Cond	2,40	<1		12.66	0.000**
	Group x Cond	2,40	6.20	0.005**	<1	
	Group x Cond x AP	3.99,79.74	1	0.41	<1	

Significant effects are marked with **
df: degrees of freedom
Cond=condition, Hemis=hemisphere, Lat=lateral electrodes, AP=Anteroposterior electrodes.
Post-hoc analyses were conducted for significant results and reported in the text.

N400

The main effect of condition was significant for the lateral electrodes region (Table 3). Post-hoc analysis revealed that, for both groups, the amplitude of the N400 component elicited in response to IC (=-2.62 μV; mean differences LSD=0.84, p= 0.04) and TI (=-2.74 μV; mean differences LSD= 0.95, p= 0.013) sentences was significantly greater compared to that for TC sentences (=-1.79 μV).

For the midline electrodes, a main effect of condition was also found (Table 3). Post-hoc analysis revealed that, for both groups, the N400 amplitude in response to IC (=-5.04 μV; mean differences LSD = 2.63, p = 0.000) and TI (=-4.52 μV; mean differences LSD= 2.11, p = 0.002) sentences was significantly than that for TC sentences (=-2.42 μV).

RM-ANOVA: ETW

NR group.

Two significant interactions, condition x anteroposterior and condition x laterality, were identified for the lateral electrodes region (Table 4). Post-hoc analysis revealed that TI sentences elicited greater amplitudes in this time window than did TC sentences in the right parietal electrodes (TC sentences =0.1 μV; TI sentences =-1.9 μV; mean differences LSD=2.008, p= 0.017).

For the midline electrodes, the interaction of condition x anteroposterior was found to be significant (Table 4). Post-hoc analysis revealed a greater ETW amplitude in response to TI, compared to TC, sentences at electrodes Cz (TC sentences =-2.79 μV; TI sentences =-5.73 μV; mean differences LSD=2.94, p= 0.016) and Pz (TC sentences =-0.44 μV; TI sentences =-4.40 μV; mean differences LSD=3.96, p= 0.001).

Table 4.
RM ANOVA for ETW

		Normal Readers			Reading disabled		
	Factor	df	F	p	df	F	p
Lateral	Cond x AP	2.69, 26.91	4.74	0.011**			
	Cond x Lat	2,20	5.19	0.015**			
	Cond x AP x Hemis				3.08,30.88	3.42	0.028**
Midline	Cond x AP	4,40	4.64	0.004**			

Significant effects are marked with **
df: degrees of freedom
Cond=condition, Hemis=hemisphere, Lat=lateral electrodes, AP=Anteroposterior electrodes.
Post-hoc analyses were conducted for significant results and reported in the text.

RD group

A significant condition x anteroposterior x hemisphere interaction was identified for the lateral electrodes (Table 4) in the RD group. Post-hoc analysis revealed that, for the right hemisphere in both frontal (TC sentences =-3.24 μV; IC sentences =-0.76 μV; mean differences LSD=-2.48, p= 0.013; TC sentences =-3.24 μV; TI sentences =-1.20 μV; mean differences LSD=-2.04, p= 0.010) and central (TC sentences =-1.92 μV; IC sentences=-0.039 μV; mean differences LSD=-1.78, p= 0.041) region, TC sentences elicited a greater ERP amplitude than did IC and TI sentences in this time window.

No significant effects were found for the midline electrodes in the RD group.

N400

NR group.

Two significant interactions: condition x anteroposterior and condition x laterality were identified at the lateral electrodes region (Table 5). Post-hoc analysis revealed that, at the parietal electrodes, the amplitude of the N400 component elicited in response to IC (TC sentences=0.17 μV; IC sentences=-1.97 μV; mean differences LSD=2.137, p= 0.025) and TI (TC sentences=0.17 μV; TI sentences=-1.73 μV; mean differences LSD=1.90, p= 0.007) sentences was greater than that elicited in response to TC sentences.

For the midline electrodes, a main effect of condition, as well as the interaction condition x anteroposterior, were significant (Table 5). Post-hoc analysis revealed that the N400 amplitude for IC (TC sentences=-2.47 μV; IC sentences=-5.67 μV; mean differences LSD=3.20, p= 0.000) and TI (TC sentences=-2.47 μV; TI sentences=-4.77 μV; mean differences LSD=2.30, p= 0.013) sentences was greater than that in response to TC sentences. These amplitude differences displayed a centroparietal topographical distribution for both types of incongruent sentences: central (TC sentences=-3.12 μV; IC sentences=-6.95 μV; mean differences LSD=3.84, p= 0.017; TC sentences=-3.12 μV; TI sentences=-5.81 μV; mean differences LSD=2.70, p= 0.017); parietal (TC sentences=-0.68 μV; IC sentences=-5.07 μV; mean differences LSD=4.39, p= 0.002; TC sentences=-0.68 μV; TI sentences=-4.11μV; mean differences LSD=3.43, p= 0.003).

Table 5.
RM ANOVA for N400

		Normal Readers			Reading disabled		
	Factor	df	F	p	df	F	p
Lateral	Cond				2,20	3.36	0.05**
	Cond x AP	2.40,24.03	5.08	0.011**			
	Cond x Lat	2,20	8.15	0.003**			
	Cond x AP x Lat						
Midline	Cond	2,20	11.83	0.000**	1.6,16	3.45	0.06
	Cond x AP	3.72,37.18	3.53	0.017**			

RD group
A main effect of condition and a condition x anteroposterior x laterality interaction were identified for the lateral electrodes region (Table 5). The N400 amplitude elicited in response to IC (IC sentences =-2.47 μV) and TI (TI sentences =-2.60 μV) sentences was greater than that for TC sentences (TC sentences =-1.52 μV). Post-hoc analysis showed that these differences in N400 amplitude (the N400 effect) had a parietal (TC sentences=0.17 μV; IC sentences=-1.19 μV; mean differences LSD=1.37, p= 0.05; TC sentences=0.17 μV; TI sentences=-1.17 μV; mean differences LSD=1.34, p= 0.061) and a posterior-temporal (TC sentences=-0.43 μV; IC sentences =-2.59 μV; mean differences LSD=2.17, p= 0.061; TC sentences=-0.43 μV; TI sentences=-2.67 μV; mean differences LSD=2.24, p= 0.015) distribution.

Discussion

Behavioral results

Both groups of children showed similar performance in the auditory sentence comprehension task as regards measures of accuracy and RT. This suggests that, at the behavioral level, the semantic processing of RD and NR children is alike. Both groups of children were more accurate with IC and TI, as compared to TC sentences. In addition, TC and TI sentences resulted in significantly shorter RT than did IC sentences in both groups.

Both IC and TI represent semantically incongruous sentences that would be unexpected in the context of everyday speech, and therefore attract a higher level of attention. According to Sabisch et al. (2006), the level of attention increases when anomalies are detected that do not occur frequently in everyday conversation. This is a likely explanation for these behavioral results.

Electrophysiological responses

Utilizing ERP measurements, the present study investigated auditory sentence comprehension in RD and normal (NR) children. We examined both the phonological and the semantic processes, utilizing sentences that manipulated both phonologic and semantic expectancies, in order to find, at the electrophysiological level, deficiencies for these processes in RD children.

While the methods of stimulation and the sentences used in ERP studies of auditory sentence comprehension in children are not exactly the same across studies, the electrophysiological findings are similar; all of these studies have described the presence of a long-lasting negative ERP waveform that has an onset at 200 ms and which continues until approximately 900 ms or more (Atchley et al., 2006; Holcomb et al., 1992; Sabisch et al., 2006). The present study showed a similar ERP waveform (see Figure 1).

N400
In this study we observed the N400 effect (a N400 amplitude greater in response to incongruent, than to congruent, sentences) for both groups of children as well as for both types of incongruent sentences (IC and TI). The well-known N400 effect has been described in adults as well as in previously cited children studies. The most accepted functional interpretation of the N400 effect is that it reflects an increased difficulty

in the lexical integration process in response to incongruent sentences (Connolly & Phillips 1994; Díaz & Swaab, 2007; Hagoort & Brown, 2000; van den Brink et al., 2001). According to our hypothesis, the N400 effect was expected for NR, but not for RD, children. The RM-ANOVA, performed separately for each group, revealed a significant interaction for the factor of condition, showing clearly the presence of the N400 effect in both groups of children. This finding is possibly related to a similar lexical integration process in both RD and NR children.

Moreover, there were no differences between groups regarding topographical distribution or ERP waveforms, and a centroparietal topography was shown for the N400 effect in both groups.

Both the electrophysiological and behavioral measurements (judgment of correctness of sentences) conducted in this study showed that processes of auditory sentence comprehension are similar in both RD and NR children. Comparable results, showing a similar N400 component for both the RD and the control children, were obtained by Sabisch et al., (2006), who did not find differences in N400 amplitude or topographical distribution between children with developmental dyslexia and controls in the auditory comprehension of sentences. This suggests that the semantic processing underlying auditory comprehension is conserved in RD children.

Similarly, no differences in the N400 component were observed between dyslexic and normal readers by Bonte and Blomert (2004) in an alliteration priming task that utilized words and non-words, as well as in a categorization task using figures and words (Silva-Pereyra et al., 2003).More recently, Jednoróg, Marchewka, Tacikowski, Grabowska (2010) also described an intact effect of semantic priming in dyslexic children who listened to word lists in an implicit semantic priming task. However, Rodríguez et al. (2006) showed a lack of an N400 effect in RD children, as compared to controls, in a sentence reading task. The contrasting findings between our study and theirs may reflect the idea that RD children display deficits in the lexical integration process (reflected in the N400 component) when performing the reading of sentences, but not when they comprehend sentences presented to them aurally.

Our results indicate that, during the auditory comprehension of sentences, the processing of semantic anomalies is similar for RD and NR children, as the N400 ERP component showed similar features for both groups.

ETW

One of the objectives of the present study was to explore ERP responses to phonological expectations generated by the semantic context of sentences in both RD and control children. ERP studies in adults have described two types of ERP responses to the auditory presentation of sentences that manipulate phonological and semantic expectations: a) a clear biphasic ERP waveform composed of an early negative shift followed by the N400 component, in which the early shift is described as an independent component (i.e. PMN or N200), b) a single negative waveform in which this early negative shift is most likely not distinct from the N400 (Díaz & Swaab, 2007; van Petten et al., 1999).

As the present work is the first study, in children, that manipulates phonological/semantic expectations in sentences, we expect to observe an ERP component related to phonological processing that could be either part of the N400 waveform (i.e. Díaz & Swaab, 2007; Van Petten et al., 1999), or an independent component (i.e. Connolly & Phillips, 1994; van den Brink et al., 2001). In previous ERP studies of children, no reports exist that describe a negative component or deflection preceding the N400 effect. A visual inspection of ERP recordings from the previously mentioned articles appears to show a single negative waveform similar to that observed in the present study (see Atchley et al., 2006; Holcomb et al., 1992; Sabich et al., 2006).

In the current study, we observed a long-lasting negative-polarity ERP waveform that had an onset at approximately 200 ms and which continued until 900 ms. According to a previous analysis using50 ms time window, and the inspection of our ERP waveforms in addition to those in literature reports, we selected an Early Time Window (ETW:330-430 ms) in order to capture a possible effect that maybe related to phonological processing. In the mixed omnibus ANOVA, this ETW showed a significant interaction in the direction described by van den Brink et al. (2001) for the NR group (i.e. greater negativity for TI respect to TC sentences), while we found a contrary effect for the RD group (i.e. greater negativity for TC respect to IC sentences) that could be related to deficiencies reported in auditory phonological tasks in these children (Wise et al., 2007). These differences might reflect distinct forms of phonological processing for congruent and incongruent sentences in the two groups. However, from these results, we cannot confirm whether this is the case. Given the small size of our sample, and the great variability shown in ERP measures for ETW, our results do not clearly support the presence of differences between NR and RD children for ERP responses that possibly reflect phonological processing. More ERP studies on phonological auditory processing in children are needed to assess directly this topic.

Similar to the studies of Díaz and Swaab (2007) and van Petten et al., (1999), we obtained a single N400 effect that likely reflects the influences of context upon lexical selection in spoken language comprehension. We agree with the interpretation by Díaz and Swaab (2007), who suggest that, when processing sentences, “either (1) the processing of phonological aspects of stimuli does not have a central role in comprehension or (2) that, once initial phonological processing has occurred, other levels of analysis, such as semantic and contextual processing, begin to take on immediate importance.” In a more general sense, this indicates that, although phonological processing is an integral aspect of spoken language comprehension, semantic and contextual information very rapidly influence the processing of words in meaningful contexts, as reflected in ERP analysis.

Using paradigms that utilize word lists, some investigators have pointed out differences between dyslexic and normal children. In an ERP study of phonological processing during the recognition of spoken words in dyslexic and normally reading children, Bonte and Blomert (2004) showed deviant priming effects in the early N1 and N2 components in dyslexic individuals, while later N400 priming effects were comparable to those of normal readers. This suggests that selective anomalies exist for dyslexics at the phonetic/phonological level of spoken language, although late semantic processing, as reflected by the N400 component, shows no differences compared to normal readers. Similarly, in a phonological priming task, dyslexics differed from controls in both the phonologically incongruent and congruent conditions, as measured by theN400 component. This suggests the presence of abnormal ERP responses related to both the integration of similarities between the consecutive stimuli, and the ability to detect incongruent stimuli (Jednoróg et al., 2010) in dyslexic individuals. However, due to the use of different paradigms and experimental manipulations, it is difficult to establish a direct comparison between the above mentioned results and our findings. The obvious difference between these studies with ours is the use of sentences in which semantic influences on spoken word recognition are stronger than when processing single words.

The current work reflects one of the few ERP studies that examine the electrophysiological mechanisms involved in auditory comprehension of sentences in children. One important contribution is the simultaneous study of phonological and semantic processes in spoken sentences, which revealed a probably anomalous phonological processing in RD children, reflected by a greater ERP response to expected, than to unexpected, words in a given sentential context. However, both the N400 responses related to semantic processing, and the behavioral responses related to the correctness of sentences, were comparable between RD and NR children. These data show that N400 can be considered a valuable tool to investigate the neural basis of reading disabilities especially those related to semantic and phonological aspects of the impairment.

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