

SEMANTIC PRIMING IN CHILDREN: AN EVENT-RELATED POTENTIAL (ERP) STUDY

ANTICIPACIÓN SEMÁNTICA EN NIÑOS: UN ESTUDIO DE POTENCIALES RELACIONADOS CON EVENTOS

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Abstract

Event-related potential (ERP) analysis associated with semantic priming is traditionally based on the comparison between experimental conditions of the mean amplitude values, which are within the range of the N400 component latency. In this study, we used a complete ERP dataset to examine whether middle- and long-latency components are modulated by semantic priming in school-age children. ERPs were recorded while normal children read pairs of words and decided whether the second word of the pair belonged to the same semantic category as the first word. We used nonparametric multivariate permutation analysis to compare whole ERP amplitude values between related and unrelated word pairs. We also obtained ERPs from a sample of children with poor reading skills (reading disabled children) to evaluate the effect of semantic priming in a population with known information retrieval failures. We found larger P200 amplitudes for responses to related word pairs compared to unrelated word pairs and larger N400 amplitudes for responses to unrelated word pairs compared to related word pairs in normal children. In contrast, children with reading disabilities did not exhibit any significant differences regarding either of these components. Thus, changes in the topographical distribution of ERP components over time might reflect the activation of several brain structures. These results suggest that semantic priming is a process that is not only associated with the N400 component.

Key words: Semantic priming, ERP, children, reading disability, nonparametric multivariate permutation analysis.

Resumen

El análisis de los potenciales relacionados con eventos (PRE) asociado con la instigación semántica tradicionalmente se basa en la comparación entre condiciones experimentales de los valores medios de amplitud que están dentro del rango de la latencia del componente N400. En este estudio, empleamos un grupo de datos completos de PRE para examinar si los componentes de latencias medias y largas estaban modulados por la instigación semántica en niños de edad escolar. Se registraron los PRE de niños normales mientras leían pares de palabras y decidían si la segunda palabra del par pertenecía a la misma categoría semántica que la primera palabra. Empleamos un análisis multivariado no paramétrico de permutaciones para comparar los valores completos de amplitud PRE entre pares de palabras relacionadas y no relacionadas. Se registraron los PRE de una muestra de niños con habilidades de lectura pobres (niños con discapacidad de lectura) para evaluar el efecto de la instigación semántica en una población con dificultades conocidas en la recuperación de información. Se encontraron amplitudes P200 más grandes para las respuestas a los pares de palabras relacionadas en comparación con los pares de palabras no relacionadas, y amplitudes N400 más mayores para respuestas a pares de palabras no relacionadas en comparación con los pares de palabras relacionadas en niños normales. En contraste, los niños con discapacidad en la lectura no exhibieron diferencias significativas en relación con esos componentes. De esta manera se concluye que los cambios en las distribuciones topográficas de los componentes PRE a lo largo del tiempo, pueden reflejar la activación de diferentes estructuras cerebrales. Estos resultados sugieren que la instigación semántica es un proceso que no solamente está asociado al componente N400.

Palabras clave: Instigación semántica, potenciales relacionados con eventos, niños, discapacidad de lectura, análisis multivariado no paramétrico con permutaciones.

Introduction

Priming is a phenomenon that, under certain circumstances, results in the facilitation of stimulus

processing given the prior processing of a similar stimulus. Although semantic priming evaluation

frequently employs lexical decision tasks (Meyer & Schvaneveldt, 1971), priming can also be evaluated with tasks in which the experimental subject must decide whether two words are semantically related. The magnitude of priming in these tasks is behaviorally demonstrated by a shorter reaction time (RT) and greater precision when the word pairs are related compared to when they are not (Neely, 1991; Silva-Pereyra, Rivera-Gaxiola, Fernandez et al., 2003).

According to the spreading activation model of semantic representation (Collins & Loftus, 1975), concepts are represented as nodes within a network, and the distance between one node and the next is determined by the semantic relationship between the two nodes. Priming occurs when the related word pairs are presented because a shared node network is activated (when a node is activated, the neighboring nodes are also activated), while the unrelated word pairs reveal that the activated networks for each word of the pair are completely different (Neely, 1991).

Semantic priming can also be studied with event-related potentials (ERPs). ERPs are an invaluable tool for studying cognitive processes because ERPs are sensitive to specific aspects of information processing in real time (Rodríguez-Camacho, Prieto, & Bernal, 2011). ERPs represent electrical brain activity that is associated with an event, whether it is a sensory stimulus or a motor or cognitive process (Coles & Rugg, 1995; Hillyard & Picton, 1987; Picton, Bentin, Berg, Donchin, Hillyard, Johnson Jr, et al., 2000). Some ERP waves are associated with a specific cognitive process, which is demonstrated when the ERP waves consistently occur with the same polarity, latency, and topography in response to specific tasks. These are known as ERP components. For example, the N400 component is a negative wave that appears at approximately 400 ms in adults (Kutas & Hillyard, 1980), and it has been associated with semantic processing.

If ERPs are evaluated with a semantic categorizing task, then semantic priming emerges when semantically related pairs elicit smaller amplitudes than unrelated pairs. Thus, the N400 amplitude has a strong negative correlation with both the word frequency and the semantic context (Kutas & Federmeier, 2011). The topographical

distribution of N400 has been observed in the central-parietal leads, and there has been a slight, yet significant, tendency in the right hemisphere (Silva-Pereyra, Harmony, Villanueva, Fernández, Rodríguez, Galán et al., 1999). Cortical recording studies have shown that the anterior portion of the superior temporal left gyrus exhibits the greatest activity when the N400 component is observed (Halgren, 1990; Nobre & McCarthy, 1995). Similar results have been reported in a study that localized the electrical sources for N400, in which bilateral activation of the anterior portion of the temporal lobe was observed (Silva-Pereyra, Rivera-Gaxiola, Aubert, Bosch, Galán & Salazar, 2003).

Developmental semantic priming ERP studies have shown remarkable reductions in the amplitude and latency of N400 with age, which support the hypothesis that linguistic abilities develop over time, and thus, children are less dependent on semantic context for language decoding as they grow older (Holcomb, Coffey, & Neville, 1992). In addition, there is a left lateralization of the N400 component during the first stage of elementary school (Wang, Dong, Ren, & Yang, 2009). However, similar to adults, school-age children displayed N400 lateralized to the right hemisphere. These children also showed a delayed N400 (i.e., approximately 530 ms) that was prolonged for several hundreds of milliseconds (Silva-Pereyra et al., 2003), which contrasts with the results observed in adults, where the maximum amplitude was around 400 ms.

There are several theories that attempt to explain the cognitive and neurobiological basis of these N400 effects, including the hypothesis that N400 is sensitive to lower-level factors (i.e., prelexical factors); however, there are those who also believe that only higher-level factors have an effect on meaning processing. A recent theory proposed by Kutas and Federmeier (2011) suggests that N400 is located at the junction where these processes intersect (i.e., at the level of the semantic access itself). Thus, N400 may be characterized as a temporal interval in which the unimodal sensory analysis produces multimodal associations in a manner that makes use of long-term memory. The N400 window provides a temporally delimited electrical snapshot of the intersection of a

feed-forward flow of stimulus driven by activity within a distributed, dynamically active neural landscape known as semantic memory. Taken together, this perspective suggests that N400 is an electrical reflection of the binding that creates a multimodal conceptual representation, which most likely involves multiple cerebral regions over time.

Importantly, these semantic priming studies have analyzed the average amplitude value of the N400 component within a given time window, which does not permit the assessment of changes in amplitude throughout the entire potential in relation to the experimental conditions. Consequently, it is not possible to provide a detailed evaluation of the topographical and amplitude changes of N400 that are associated with semantic priming over time. To the best of our knowledge, previous semantic priming studies have only explored the N400 component. Thus, the main objective of this study was to evaluate the effect of semantic priming on the amplitude of the entire ERP during the execution of a semantic task in healthy, school-age children. To analyze the entire ERP and to evaluate all of the amplitude values over time, a multivariate statistical method based on permutations was used (Galán, Biscay, Rodríguez, Pérez-Abalo, & Rodríguez, 1997). With this method, we simultaneously evaluated the amplitude differences for all of the time points and avoided type I errors (Blair & Karniski, 1993; Blair & Karniski, 1994; Raz, 1989). This method showed that the N400 component is an electrical reflex of a dynamic process in which different areas of the brain are involved at different times.

To study the effects of semantic priming on ERPs, we evaluated children with reading disabilities whose limitations extended beyond word decoding. Previous studies have demonstrated smaller amplitudes and greater latencies of the N400 component in children with reading disabilities while they read sentences (Brandeis, Vitacco, & Steinhausen, 1994; Silva-Pereyra & Rivera-Gaxiola, 2005). In a study employing magnetoencephalography (MEG), similar N400 patterns to those reported by previous studies conducted in children were observed in dyslexic adults (Helenius, Salmelin, Service, & Connolly 1999). Smaller N400 amplitudes in the frontal regions of children with

reading disabilities compared to controls were observed as the children read words (Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988). A recent study that combined functional magnetic resonance imaging (fMRI) and ERP (Schulz, Maurer, van der Mark, Bucher, Brem, Martin et al., 2008) reported that the N400 effect was reduced in dyslexic children compared to control children. In contrast, Silva-Pereyra, Rivera-Gaxiola, Fernandez et al. (2003) and Rüsseler, Probst, Johannes, and Münte (2003) did not observe any differences in the N400 amplitude between subjects with and without reading disabilities.

These conflicting findings regarding changes in the N400 amplitude in subjects with reading disabilities may be due to the manner in which the data were analyzed. Thus, a secondary objective of this study was to compare the responses to semantic priming between a group of children with reading disabilities and a group of normal, age-matched children using the permutation statistical analysis method. We hypothesized that changes in the amplitude and topography in the entire epoch would reveal differences between the populations in other ERP components or in a different N400 time window. We propose the presence of topographical amplitude differences for N400 in relation to time between children with reading disabilities and normal readers because of a deficiency in the retrieval of information from semantic memory in the children with reading disabilities, which may be a mechanism that underlies this disorder (Schulz et al., 2008).

Method

Participants

Normal-reading children.

Twelve right-handed children (5 females) participated in the study. Their ages ranged from 7 to 12 years old (mean 9.45 standard deviation \pm 1.10) and had a total intelligence quotient that was within the normal range or higher than average (Verbal scale, 108.58 \pm 10.69; Performance scale, 107.42 \pm 16.53; Total IQ, 109.08 \pm 12.77; evaluated with the Wechsler Intelligence Scale for Children-Revised (Wechsler, 2001). The Children's Neuropsychological Evaluation (Matute, Rosselli, Ardila, & Ostrosky-Solís, 2008) was employed to assess the reading,

writing, and arithmetic abilities compared to the normative Mexican data. The children scored within the normal limits in subtests of the Children's Neuropsychological Evaluation.

Children with reading disabilities.

Ten children with reading disabilities were selected (2 females) with an average age of 9.88 ± 0.82 years and an intelligence quotient (Weschler, 2001) greater than 70, such that cases of mental retardation were excluded (Verbal scale, 95 ± 21.26 ; Performance scale 98.9 ± 22 ; Total IQ, 96.8 ± 22). These children were referred by a social worker because they had academic performance issues and ranked below the 11th percentile on the Children's Neuropsychological Evaluation (Matute et al., 2008) reading subtest, which permitted the diagnosis of a reading disability. The children also had disabilities in performing calculations and with written expression.

None of the children had any neurological or psychiatric disturbances. To ensure that this was the case, the children were evaluated by a neuropediatrician, and the Conners' scale was applied to parents and teachers to exclude children with attention deficit disorder or attention deficit/hyperactive disorder. Semi-structured interviews also indicated that the children did not suffer from severe emotional problems. The children did not have any noticeable socio-cultural handicaps (the mother had at least an elementary school education and a per capita income that was greater than 50 percent of the minimum wage).

The study protocol complied with the Declaration of Helsinki (2008) regarding human subjects, and the Ethics Committee from the Institute of Neurobiology, Universidad Nacional Autónoma de México, approved the experimental protocol. Written informed consents were obtained from both the children and their parents prior to enrolment in the study.

Materials

The task consisted of 120 word pairs, of which 60 were related (e.g., perro – gato [dog – cat]) and 60 were not (guitarra – caballo [guitar – horse]). A pair of words was considered related if they belonged

to the same semantic category. Unrelated pairs of words did not belong to the same semantic category, and the second word did not begin or end with the same phoneme as the first word. Several semantic categories were used: animals, toys, furniture, food, clothing, body parts, musical instruments, professions, places, and tools. All of the words were singular subjects written in Spanish, had no more than three syllables, did not contain any accents, were obtained from children's bibliographic sources (Ahumada & Montenegro, 1990, 2007; Mondada, 1992a,b,c,d,e; Pestum, 1996) and had a single meaning (according to the Dictionary from the Royal Spanish Language Academy, *Real Academia de la Lengua Española*).

A pilot study was performed of the stimuli in 12 adults, followed by a second sample that consisted of eight elementary school-aged children. This pilot study helped to determine the presentation time for each word, which was 2200 ms, so that both groups (normal-reading and reading-disabled subjects) could read the word.

Procedure

The Mind Tracer program (Neuronic S.A.) was used to deliver the stimuli. Each child was instructed to press one button on the computer mouse if the words were related and another button if they were not related. Given that the subjects naturally held the mouse with both hands and used their thumbs to press the buttons, the use of the mouse button was counterbalanced among the subjects. Thus, the likelihood that the execution was related to hand use was excluded.

Each word pair included the presentation of a warning signal (a cross) on the computer monitor for 300 ms to indicate that the stimulus was about to be presented, and 500 ms later, the first word of the word pair was presented for 2200 ms. The second word of the pair was presented 500 ms later for a duration of 2200 ms and, finally, 500 ms after the second word was presented, a closing signal (a question mark) was shown for 800 ms. Once this signal appeared, the child had to use the mouse to respond within 2 s. If the child took longer than 2 s, the response was considered to be an omitted response, and the presentation of a new sequence

was automatically initiated. Figure 1 shows the stimuli presentation sequence.

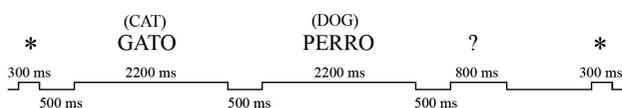


Figure 1. The stimuli presentation sequence

Prior to the start of the experimental task, the subject performed a brief test to verify that he or she understood the task and had become familiarized with the activity. The subject was comfortably seated 50 cm in front of the stimulation computer monitor, which was located in a soundproof chamber with dim lighting. At the established viewing distance, a large sized stimulus was subtended at a visual angle of approximately $4.584^\circ \times 0.573^\circ$. The task was divided into four blocks, and each block consisted of 30 pairs of words and had an approximate duration of 4 minutes. Between blocks, the child was given a brief period of rest if he or she desired.

The electroencephalogram was registered through a MEDICID-4 (Neuronic S.A.) system that consisted of 19 tin electrodes for the 10-20 International System (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, and Pz) within a standard electro-cap (Electro-Cap International Inc.), which was referenced to the short-circuited earlobes (A1-A2). Blinking and eye movements were monitored via a bipolar recording of two electrodes placed on the external edge of the right eye, in addition to one electrode placed above and one below the eye. The impedance of the electrodes was maintained at less than 10 kOhms. The bandwidth of the recording ranged from 0.5-30 Hz, and the sampling rate was 5 ms. EEG segments with artifacts due to eye movements, excessive muscle activity, or amplifier blockade were eliminated offline prior to averaging. On average, the group of normal children produced 24.50 ± 5.12 useable responses for related words and 24.33 ± 5.17 useable responses for unrelated words. Moreover, the group of children with reading disabilities produced 25.20 ± 6.19 useable responses for related

words and 26.00 ± 8.69 useable responses for unrelated words.

We selected 1000 ms segments from the electroencephalogram that had 100 ms of pre-stimulus time and were free of artifacts and synchronized with the second word of the pair. Furthermore, at least 17 segments were required for each of the experimental conditions (related and unrelated words). The EEG segments were subjected to a baseline correction and were selected only when the answer was correct. To obtain the ERP, the segments from each condition were separately averaged in approximately equal numbers.

Statistical analysis

The ERP data are multivariate in nature, and the sample size is not sufficiently large to expect a normal distribution. Picton et al. (2000) suggested that despite advantages in employing parametric statistics, the use of nonparametric techniques, such as permutation statistics (Blair & Karniski, 1993; Galán et al., 1997) or bootstrapping (Wasserman & Bockenholt, 1989) may be more appropriate because these techniques do not make assumptions regarding data distribution. Given the size of the sample and the comparisons made between the two experimental conditions (related and unrelated pairs) throughout the entire ERP analysis window, we performed a multivariate nonparametric permutation analysis (Galán et al., 1997). This method considers a global hypothesis that evaluates the presence of any differences between the brain responses to related words and unrelated words, with the understanding that the brain response is a non-specific phenomenon of all of the derivations. It also considers as many marginal hypotheses as there are electrode sites, and the difference between the responses of a specific electrode was analyzed for each electrode site. This allowed the determination of not only the presence of differences between the electrodes but also those time points at which such differences were significant.

A permutation test is a type of statistical significance non-parametric test in which the distribution of the test statistic under the null hypothesis is obtained by calculating all of the potential values of the test statistic under

rearrangements of labels that represent the observed data points. If the labels are exchangeable under the null hypothesis, then the resulting tests yielded exact significance levels. Depending on the previously fixed significance level, the null hypothesis will be accepted or rejected, precluding that no differences or differences existed between the compared data. For example, consider two groups with their respective sample means and a null hypothesis positing that these two groups have an identical probability distribution:

1. The difference of the means between the two samples is calculated, and an observed value is obtained for the original groups.
2. The differences of the sample means are calculated and recorded for every possible way of dividing these values into two groups. The set of these calculated differences is the exact distribution of the possible differences under the null hypothesis that group label does not matter.
3. The one-sided p-value of the test is calculated as the proportion of the sampled permutations where the difference in the means is greater than or equal to the observed value for the original groups. If we select a 5% significance level ($p=0.05$), then we can sort out the recorded differences and then observe if the observed value for the original groups is contained within the middle 95%. If the answer is yes, the null hypothesis is accepted; if the answer is no, then we reject the null

hypothesis, and the conclusion is that the groups are different.

This analysis was applied to the entire potential, i.e., every 5 ms, from a latency of -100 ms up to 900 ms, where zero is the time at which the stimulus was presented. The analysis began at -100 ms because it was important to verify at the pre-stimulus period that there were no differences between the conditions.

Results

Behavioral results

A nonparametric multivariate permutation analysis was used to evaluate the RT and the percentage of correct responses. Normal readers did not exhibit any significant differences in the RT or in their answer precision between related and unrelated words.

Table 1 shows the mean and standard deviation values for the behavioral variables in both groups. In children with reading disabilities, the RT for the related words was significantly shorter than the RT for the unrelated words ($p<0.001$). We observed that the number of incorrect responses (omissions and false alarms) was significantly greater in children with reading disabilities than in normal readers, with the most striking difference observed in the number of omissions ($p=0.01$) rather than the number of false alarms ($p=0.03$). There were no significant differences between the two groups in terms of RT for either condition.

Table 1.
Behavioral Results. Mean and Standard deviations (SD) of both groups of children.

	Percentage of incorrect responses		Reaction Times	
	Related words	Unrelated words	Related words	Unrelated words
Normal children	5.9 (5.1)	4.5 (4)	486.7 (255.2)	512.1 (290)
Children with reading disabilities	12.3 (5.5)	16.6 (15.5)	568.5 (205.3)	660 (211.6)

Electrophysiological results

When we compared the point-to-point amplitude (every 5 ms) of the entire potential for related and unrelated words among these conditions, we observed a significant global difference in normal readers ($p=0.02$). The ERPs were signifi-

cantly distinct at different time windows, which may be associated with different components. The time intervals and the electrode under which these significant differences were recorded are shown in Table 2.

Table 2.

Differences between conditions (Unrelated word versus related word pairs) in normal readers regarding electrode position and time windows.

Electrode position (level of significance)	Time intervals in which significant differences were noted ($p<0.05$)
Fp1 ($p = .01$)	165-255 ms
Fp2 ($p = .003$)	160-280 ms
F3 ($p = .04$)	215-260 ms
F4 ($p = .02$)	215-280 ms, 320-375 ms, 470-555 ms
P3 ($p = .01$)	175-255 ms, 535-570 ms
F8 ($p = .02$)	240-295 ms, 315-390 ms
Fz ($p = .005$)	195-290 ms, 340-365 ms, 510-585 ms, 630-675 ms
Cz ($p = .02$)	220-260 ms, 540-555 ms
Pz ($p = .04$)	200-245 ms, 535-565 ms

There was a positive wave that was more pronounced in the latency amplitude (160-280 ms), which was earlier in the Fp1, Fp2, and P3 derivations (160–255 ms) than those in the F3, F4, F8, Fz, Cz, and Pz (195–295 ms) for related words. On the basis of their latency and topographical distribution, we considered this positive wave to be the P200 component. The ERPs for both the experimental conditions and amplitude maps corresponding to the latencies, where a significant difference was found, are shown in Figure 2. Between 315 and 390 ms, we observed a greater amplitude potential in the unrelated words under electrodes F4, F8, and Fz. We also observed this difference in F4 and Fz; however, it occurred between 470 and 585 ms. In the 535-570 ms latency range, we observed the same

effect in the P3, Cz and Pz derivations. At a later point, under the Fz electrode and between 630 and 675 ms, we observed significant differences that corresponded to the N400 effect.

In contrast to the statistical results of normal readers, the group of children with reading disabilities did not show any significant ERP differences between the two experimental conditions. To compare the ERP data of children with reading disabilities and that of normal readers, a difference wave was calculated between the experimental conditions (i.e., ERPs to the unrelated minus the ERPs to the related pair of words). Significantly smaller amplitudes over the frontal leads (i.e., Fp1, Fz and Fp2) in the range of the P200 were found in children with reading disabilities compared with normal readers ($p < 0.001$).

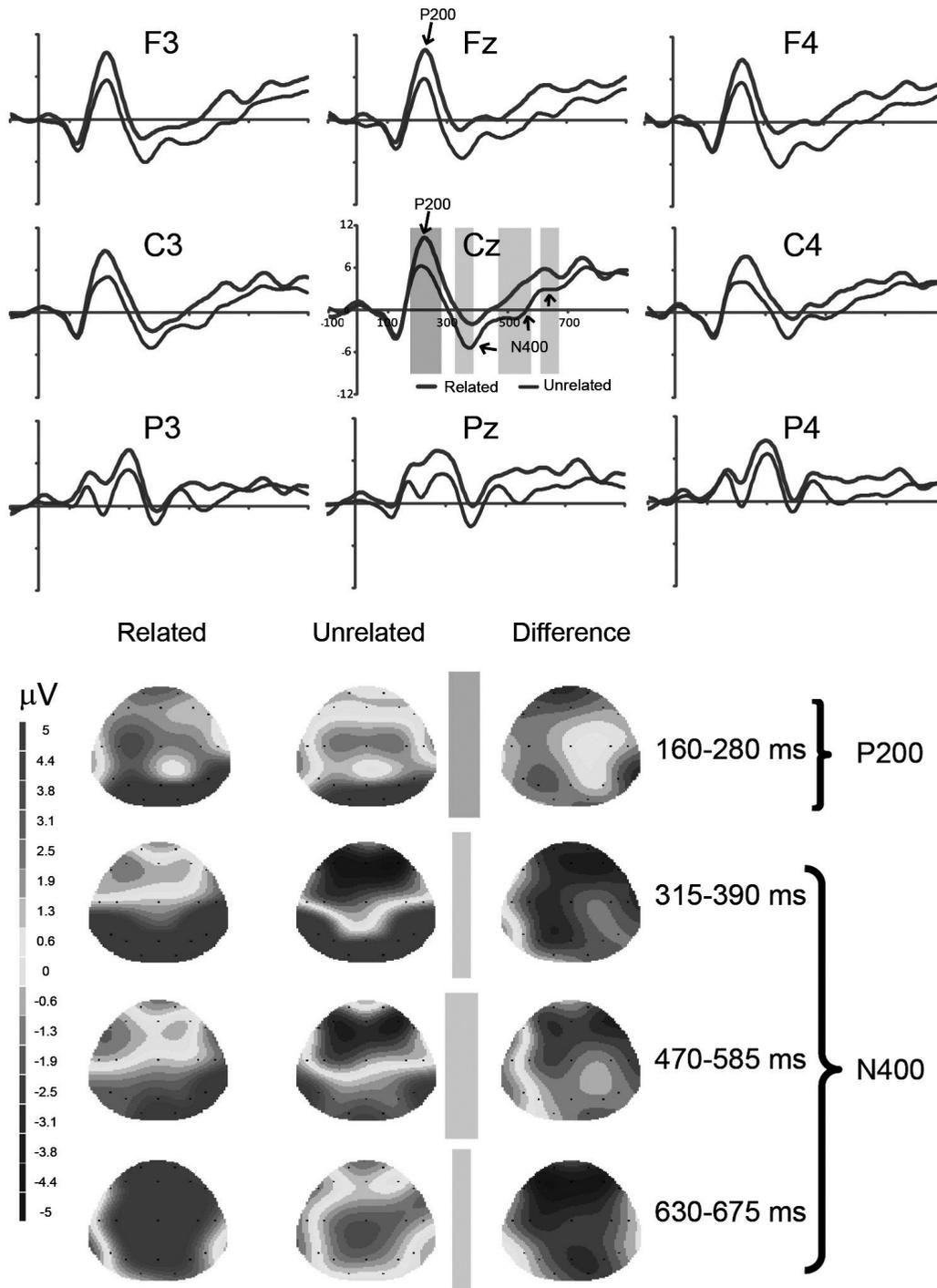


Figure 2. The average potential of normal-reading children in some derivations (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4). The P200 and N400 components, which were significantly different between the experimental conditions (related and unrelated words), are indicated by the arrows. The lower panel shows the amplitude maps for each experimental condition and the difference wave between the conditions through the different time windows that were determined to be significant. Please note the temporal changes in the topographical distribution of the N400 effect. This indicates a frontal distribution that begins in the right hemisphere and spreads bilaterally.

Discussion

There were no semantic priming effects in normal readers in terms of the RT and the percentage of correct responses. It is likely that there were no effects on the behavioral results due to the task characteristics, i.e., the children's answers were delayed in time. To balance the answer time between the normal readers and the children with reading disabilities, a question mark was added so that the children knew when to press the button and, thus, make their semantic judgment some time before the appearance of the question mark. The wait time likely masked the priming effect.

However, normal readers exhibited effects on the amplitude within different temporal windows that corresponded to the different ERP components (i.e., P200 and N400). Given the analysis made in this study, the brain response associated with semantic priming was not limited to the N400 component. There was also a significant effect in the time range of the P200. This effect was more pronounced in the frontal part of the left hemisphere as described in previous studies (Silva-Pereyra et al., 2003). The anterior distributed P200 has been associated with attention demands (Johnson, 1989) and with stimuli evaluation (Luck & Hillyard, 1994). Furthermore, the amplitude decreases with age (Taylor & Khan, 2000), but increases with task difficulty (Stelmack et al., 1988; Taylor & Khan, 2000). Moreover, the P200 left/right asymmetries have been related to reading skills (Segalowitz, Wagner, & Menna, 1992). However, recent studies have associated this component with semantic processing and modulation of the N400 effect (Federmeier, Mai, & Kutas, 2005; Huang, Lee, & Federmeier, 2010; Wlotko & Federmeier, 2007). In these studies, frontal P200 to stimuli presented in the right visual field are larger in more constraining contexts and have been linked to left hemisphere mechanisms that prepare the language processing system for the apprehension of predictable words (Kandhadai & Federmeier, 2010). The pattern of P200 was similar to that observed of N400. Thus, with central visual presentation of stimuli, it can be difficult to differentiate between P200 effects and those results obtained from the onset of N400,

particularly when there is substantial overlap of the scalp distributions of the two components. However, other ERP studies have shown an amplitude modulation of P200 during semantic tasks (Landi & Perfetti, 2007; Silva-Pereyra, et al., 2003). In summary, strong context-based expectations for upcoming words appear to change how the perceptual processing system allocates attention and analyzes subsequent stimuli (Federmeier, Mai, & Kutas, 2005; Huang, Lee, & Federmeier, 2010; Wlotko & Federmeier, 2007).

The results of the present study also show that the N400 effect is a process that temporally changes its pattern of cerebral region activation (i.e., three significant windows within the N400 wave where the unrelated words elicited greater amplitudes than the related word pairs). Differences in the amplitude and topography over the course of time show that different cognitive components may be utilized in semantic processing as suggested by Holcomb and McPherson (1994). That is, different cerebral structures are activated at different moments during the retrieval of semantic information (Newman, Ikuta, & Burns, 2010). Several studies have further made the distinction between several different peaks within the N400 component time window, which are thought to differentiate between cognitive processes; however, they followed the procedure of averaging the amplitudes in the latency spectra (Coch, Maron, Wolf, & Holcomb, 2002; Dykman, Ackerman, Loizou, & Casey, 2000). According to the spreading activation model (Collins & Loftus, 1975), once a node is activated by the first word in the pair, recognition of the second word is more rapid. However, if the second word of the pair was not previously activated as a neighboring word of the first, then this is reflected by a greater N400 amplitude. The N400 arises in a time period where the stimulus-driven activity enters into temporal synchrony with a broad, multimodal neural network, whose current states have been shaped by recent and long-term experience of a wide range of types (e.g., on the basis of world experience, long-standing and recent linguistic and nonlinguistic inputs, attentional states, and affect/mood) (Kutas & Federmeier, 2011).

The N400 activity can be modulated by factors that affect either the input or the configuration of activity in semantic memory. For example, manipulations of attention may affect either or both of these levels. Enhanced P200 responses, which may reflect a preparatory attentional response elicited by language contexts that induce a strong expectation for particular upcoming stimuli (Federmeier et al., 2005; Wlotko & Federmeier, 2007). This may be the role of cognitive processes as reflected by P200 in the semantic priming equation.

A limitation of this study is that the analysis of topographical changes in the amplitude over time does not differentiate between concomitantly modulated ERP components. Thus, it is possible that the P200 component reflects attentional processes that are evoked during the complex semantic priming process at the same rate at which the processes underlying the N400 component are reflected.

Regarding children with reading disabilities, there was a significant priming effect observed in their behavioral data. These results were consistent with previous studies (Silva-Pereyra et al., 2003), which demonstrated a greater number of errors (omissions and false alarms) in the group of children with reading disabilities than normal readers. In contrast to these behavioral results, there were no semantic priming effects on any of the ERP components (i.e., P200 and N400) in these children. These children equally responded electrophysiologically to both the related and unrelated pair of words, which is reflected in the lack of the N400 effect (Brandeis et al., 1994; Holcomb, Ackerman, & Dykman, 1985). Some studies have shown that children with reading disabilities make errors in the retrieval of semantic information from memory (Jednorog, Marchewka, Tacikowski, & Grabowska, 2010) and display P200 amplitude differences compared to controls in semantic processing tasks (Landi & Perfetti, 2007).

A potential explanation for these ERP results may be that these children have deficiencies in pre-activated information in semantic memory by rendering some information as more important (this may be reflected by the lack of a P200 amplitude effect; that is, greater P200 amplitudes

for related with respect to unrelated word pairs) with consequences for the state of semantic memory, which is then encountered by subsequent stimuli (N400 that is equal to both related and unrelated word pair conditions and the lack of the N400 effect). Other studies have provided evidence that show that children with reading disabilities have no P200 amplitude effects during a visual semantic categorization task (Silva-Pereyra et al., 2003). The relationship between reading disabilities and the P200 component has been observed as a minor activation of the right superior parietal region (Silva-Pereyra, Bernal, Rodríguez-Camacho, Yañez, Prieto-Corona, Marosi et al., 2010).

Conclusion

In conclusion, the method employed to evaluate ERPs over a broad window of time, which encompasses the entire second following the stimulus presentation, demonstrates that the N400 component is more than a fixed response of specific brain regions. However, it appears that there are different activation patterns for multiple brain regions that vary across time and whose maximum amplitude is approximately 400 ms. Nevertheless, future studies will be necessary to clarify the relationship between cognitive processes associated with P200 and N400.

References

- Ahumada, R., & Montenegro, A. (1990). *Juguemos a leer (libro de lectura y manual de ejercicios)*. México, DF: Editorial Trillas.
- Ahumada, R., & Montenegro, A. (2007). *Juguemos a leer. Libro de lectura*. México, DF: Editorial Trillas.
- Blair, R. C., & Karniski, W. (1993). An alternative method for significance testing of waveform difference potentials. *Psychophysiology*, 30, 518-524. Available via: <http://dx.doi.org/10.1111/j.1469-8986.1993.tb02075.x>
- Blair, R. C., & Karniski, W. (1994). Distribution-free statistical analyses of surface and volumetric maps. In R. W. Thatcher, M. Hallett, T. Zeffiro, E. R. John & M. Huerta (Eds.), *Functional Neuroimaging* (pp. 19-28). New York: Academic Press.

- Brandeis, D., Vitacco, D., & Steinhausen, H. C. (1994). Mapping brain electric micro-states in dyslexic children during reading. *Acta Paedopsychiatrica*, 56, 239-247.
- Coch, D., Maron, L., Wolf, M., & Holcomb, P. J. (2002). Word and picture processing in children: an event-related potential study. *Developmental Neuropsychology*, 22, 373-406. Available via: http://dx.doi.org/10.1207/S15326942dn2201_3
- Coles, M. G., & Rugg, M. D. (1995). Event-related potentials: An introduction. In M. G. Coles & M. D. Rugg (Eds.), *Electrophysiology of Mind: Event-Related Brain Potentials and Cognition* (pp. 1-26). Oxford: Oxford University Press.
- Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, 82, 407-428. Available via: <http://dx.doi.org/10.1037//0033-295X.82.6.407>
- Declaration of Helsinki. (2008). Sixth revision, 59th Meeting of the World Medical Association. Seoul.
- Dykman, R. A., Ackerman, P. T., Loizou, P. C., & Casey, P. H. (2000). An event-related potential study of older children with an early history of failure to thrive. *Developmental Neuropsychology*, 18, 187-212. Available via: http://dx.doi.org/10.1207/S15326942DN1802_3
- Federmeier, K. D., Mai, H., & Kutas, M. (2005). Both side get the point: hemispheric sensitivities to sentential constraint. *Memory and cognition*, 33, 871-886. Available via: <http://dx.doi.org/10.3758/BF03193082>
- Galán, L., Biscay, R., Rodríguez, J. L., Pérez-Abalo, M. C., & Rodríguez, R. (1997). Testing topographic differences between event related brain potentials by using non-parametric combinations of permutation tests. *Electroencephalography and Clinical Neurophysiology*, 102, 240-247. Available via: [http://dx.doi.org/10.1016/S0013-4694\(96\)95155-3](http://dx.doi.org/10.1016/S0013-4694(96)95155-3)
- Halgren, E. (1990). Insights from evoked potentials into the neuropsychological mechanisms of reading. In A. B. Scheibel & A. F. Wechsler (Eds.), *Neurobiology of Higher Cognitive Function* (pp. 103-150). New York: Guilford Press.
- Helenius, P., Salmelin, R., Service, E., & Connolly, J. F. (1999). Semantic cortical activation in dyslexic readers. *Journal of Cognitive Neuroscience*, 11, 535-550. Available via: <http://dx.doi.org/10.1162/089892999563599>
- Hillyard, S. A., & Picton, T. W. (1987). Electrophysiology of cognition. In F. Plum (Ed.), *Handbook of Physiology: Section I. The Nervous System* (vol.5). Higher Functions of the Brain (part II) (pp. 519-584). Bethesda: American Physiological Society.
- Holcomb, P., Coffey, S., & Neville, H. (1992). Visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology*, 8, 203-241. Available via: <http://dx.doi.org/10.1080/87565649209540525>
- Holcomb, P. J., Ackerman, P. T., & Dykman, R. A. (1985). Cognitive event-related brain potentials in children with attention and reading deficits. *Psychophysiology*, 22, 656-667. Available via: <http://dx.doi.org/10.1111/j.1469-8986.1985.tb01663.x>
- Holcomb, P. J., & McPherson, W. B. (1994). Event-related brain potentials reflect semantic priming in an object decision task. *Brain and Cognition*, 24, 259-276. Available via: <http://dx.doi.org/10.1006/brcg.1994.1014>
- Huang, H. W., Lee, C. L., & Federmeier, K. D. (2010). Imagine that! ERPs provide evidence for distinct hemispheric contributions to the processing of concrete and abstract concepts. *Neuroimage*, 49, 1116-1123. Available via: <http://dx.doi.org/10.1016/j.neuroimage.2009.07.031>
- Jednorog, K., Marchewka, A., Tacikowski, P., & Grabowska, A. (2010). Implicit phonological and semantic processing in children with developmental dyslexia: evidence from event-related potentials. *Neuropsychologia*, 48, 2447-2457. Available via: <http://dx.doi.org/10.1016/j.neuropsychologia.2010.04.017>
- Johnson, R., Jr. (1989). Developmental evidence for modality-dependent P300 generators: a normative study. *Psychophysiology*, 26, 651-667. Available via: <http://dx.doi.org/10.1111/j.1469-8986.1989.tb03167.x>
- Kandhadai, P., & Federmeier, K. D. (2010). Hemispheric differences in the recruitment of semantic processing mechanisms. *Neuropsychologia*, 48, 3772-3781. Available via: <http://dx.doi.org/10.1016/j.neuropsychologia.2010.07.018>

- Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, 62, 621-647. Available via: <http://dx.doi.org/10.1146/annurev.psych.093008.131123>
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science*, 207, 203-205. Available via: <http://dx.doi.org/10.1126/science.7350657>
- Landi, N., & Perfetti, C. A. (2007). An electrophysiological investigation of semantic and phonological processing in skilled and less-skilled comprehenders. *Brain and Language*, 102, 30-45. Available via: <http://dx.doi.org/10.1016/j.bandl.2006.11.001>
- Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, 31, 291-308. Available via: <http://dx.doi.org/10.1111/j.1469-8986.1994.tb02218.x>
- Matute, E., Rosselli, M., Ardila, A., & Ostrosky-Solís, F. (2008). Evaluación Neuropsicológica Infantil (ENI). México DF: Manual Moderno.
- Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, 90, 227-234. Available via: <http://dx.doi.org/10.1037/h0031564>
- Mondada, A. V. (1992a). Prácticas de ortografía, 2: Segundo grado: ortografía funcional para el segundo grado de enseñanza primaria con base en cuadros ortográficos. México, DF: Fernández Editores.
- Mondada, A. V. (1992b). Prácticas de ortografía, 3: tercer grado : ortografía funcional para el tercer grado de enseñanza primaria con base en cuadros ortográficos México, DF: Fernández Editores.
- Mondada, A. V. (1992c). Prácticas de ortografía, 4: cuarto grado: ortografía funcional para el cuarto grado de enseñanza primaria con base en cuadros ortográficos. México, DF: Fernández Editores.
- Mondada, A. V. (1992d). Prácticas de ortografía, 5: quinto grado: ortografía funcional para el quinto grado de enseñanza primaria con base en cuadros ortográficos. México, DF: Fernández Editores.
- Mondada, A. V. (1992e). Prácticas de ortografía, 6: Sexto grado: ortografía funcional para el sexto grado de enseñanza primaria con base en cuadros ortográficos. México DF: Fernández Editores.
- Neely, J. H. (1991). Semantic priming effects in visual Word recognition: a selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic Processes in Reading: Visual Word Recognition* (pp. 264-336). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Newman, S. D., Ikuta, T., & Burns, T., Jr. (2010). The effect of semantic relatedness on syntactic analysis: An fMRI study. *Brain and Language*, 113, 51-58. Available via: <http://dx.doi.org/10.1016/j.bandl.2010.02.001>
- Nobre, A. C., & McCarthy, G. (1995). Language-related field potentials in the anterior-medial temporal lobe: II. Effects of word type and semantic priming. *The Journal of Neuroscience*, 15, 1090-1098.
- Pestum, J. (1996). Maya y el truco para hacer la tarea. México DF: Editorial Fondo de Cultura Económica.
- Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr., et al. (2000). Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology*, 37, 127-152. Available via: <http://dx.doi.org/10.1111/1469-8986.3720127>
- Raz, J. (1989). Analysis of repeated measurements using nonparametric smoothers and randomization tests. *Biometrics*, 45, 851-871. Available via: <http://dx.doi.org/10.2307/2531687>
- Rodríguez-Camacho, M., Prieto, B., & Bernal, J. (2011). Potenciales relacionados con eventos (PRE): Aspectos básicos y conceptuales. In J. Silva-Pereyra (Ed.), *Métodos en las Neurociencias Cognoscitivas* (pp. 41-67). México DF: Manual Moderno.
- Rüsseler, J., Probst, S., Johannes, S., & Münte, T. (2003). Recognition memory for high- and low-frequency words in adult normal and dyslexic readers: an event-related brain potential study. *Journal of Clinical and Experimental Neuropsychology*, 25, 815-829. Available via: <http://dx.doi.org/10.1076/jcen.25.6.815.16469>

- Schulz, E., Maurer, U., van der Mark, S., Bucher, K., Brem, S., Martin, E., & Brandeis, D. (2008). Impaired semantic processing during sentence reading in children with dyslexia: combined fMRI and ERP evidence. *Neuroimage*, 41, 153-168. Available via: <http://dx.doi.org/10.1016/j.neuroimage.2008.02.012>
- Segalowitz, S. J., Wagner, W. J., & Menna, R. (1992). Lateral versus frontal ERP predictors of reading skill. *Brain and Cognition*, 20, 85-103. Available via: [http://dx.doi.org/10.1016/0278-2626\(92\)90063-R](http://dx.doi.org/10.1016/0278-2626(92)90063-R)
- Silva-Pereyra, J., Bernal, J., Rodríguez-Camacho, M., Yanez, G., Prieto-Corona, B., ... Rodríguez, H. (2010). Poor reading skills may involve a failure to focus attention. *Neuroreport*, 21, 34-38. Available via: <http://dx.doi.org/10.1097/WNR.0b013e328332c566>
- Silva-Pereyra, J., Harmony, T., Villanueva, G., Fernandez, T., Rodríguez, M., Galan, L., ... Reyes, A. (1999). N400 and lexical decisions: automatic or controlled processing? *Clinical Neurophysiology*, 110, 813-824. Available via: [http://dx.doi.org/10.1016/S1388-2457\(99\)00009-7](http://dx.doi.org/10.1016/S1388-2457(99)00009-7)
- Silva-Pereyra, J., & Rivera-Gaxiola, M. (2005). Event related potentials in poor readers. In H. D. Tobias (Ed.), *Trends in Dyslexia Research* (pp. 121-149). Hauppauge, NY: Nova Science Publishers, Inc.
- Silva-Pereyra, J., Rivera-Gaxiola, M., Aubert, E., Bosch, J., Galan, L., & Salazar, A. (2003). N400 during lexical decision tasks: a current source localization study. *Clinical Neurophysiology*, 114, 2469-2486. Available via: [http://dx.doi.org/10.1016/S1388-2457\(03\)00248-7](http://dx.doi.org/10.1016/S1388-2457(03)00248-7)
- Silva-Pereyra, J., Rivera-Gaxiola, M., Fernandez, T., Diaz-Comas, L., Harmony, T., Fernandez-Bouzas, A., ... Marosi, E. (2003). Are poor readers semantically challenged? An event-related brain potential assessment. *International Journal of Psychophysiology*, 49, 187-199. Available via: [http://dx.doi.org/10.1016/S0167-8760\(03\)00116-8](http://dx.doi.org/10.1016/S0167-8760(03)00116-8)
- Stelmack, R. M., Saxe, B. J., Noldy-Cullum, N., Campbell, K. B., & Armitage, R. (1988). Recognition memory for words and event-related potentials: a comparison of normal and disabled readers. *Journal of Clinical and Experimental Neuropsychology*, 10, 185-200. Available via: <http://dx.doi.org/10.1080/01688638808408235>
- Taylor, M. J., & Khan, S. C. (2000). Top-down modulation of early selective attention processes in children. *International Journal of Psychophysiology*, 37, 135-147. Available via: [http://dx.doi.org/10.1016/S0167-8760\(00\)00084-2](http://dx.doi.org/10.1016/S0167-8760(00)00084-2)
- Wang, S., Dong, X., Ren, Y., & Yang, Y. (2009). The development of semantic priming effect in childhood: an event-related potential study. *Neuroreport*, 20, 574-578. Available via: <http://dx.doi.org/10.1097/WNR.0b013e328329f215>
- Wasserman, S., & Bockenholt, U. (1989). Bootstrapping: applications to psychophysiology. *Psychophysiology*, 26, 208-221. Available via: <http://dx.doi.org/10.1111/j.1469-8986.1989.tb03159.x>
- Weschler, D. (2001). *Escala de inteligencia de Weschler para niños-revisada (WISC-R) México, DF Editorial Manual Moderno.*
- Wlotko, E. W., & Federmeier, K. D. (2007). Finding the right word: hemispheric asymmetries in the use of sentence context information. *Neuropsychologia*, 45, 3001-3014. Available via: <http://dx.doi.org/10.1016/j.neuropsychologia.2007.05.013>

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