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ERP Effects of Word Exposure and Orthographic Knowledge on Lexical Decisions in Spanish

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Abstract

Orthographic knowledge is affected by language processing, which is associated with word exposure. This study used event-related potentials (ERP) to explore this association in Spanish-speaking adults with different levels of orthographic competence (High Spelling Skills: HSS; Low Spelling Skills: LSS) while they performed a lexical decision task on previously exposed words (1 or 5 times). Both groups benefited from the exposure rate, but HSS reached significantly higher correct and faster responses, particularly with repeated words. Word recognition potential (RP) amplitude was higher bilaterally in HSS group, especially with repeated words, while P220 was found to be right-lateralized and sensitive to word exposure. Also, the amplitude of P600 varied as a function of word exposure and positively correlated with reading speed. Results suggest that LSS group is less sensitive to word exposure and fails to automatize strategies to word recognition that affect reading fluency.

Keywords

Word Exposure, Orthographic Competence, Lexical Decision, ERP

1. Introduction

It is generally accepted that reading experience activates adjustment processes that progressively facilitate visual

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word recognition by making it more automatic and effortless. Empirical data indicate that word knowledge is a critical predictor of reading proficiency, and that vocabulary knowledge is closely related to new word identification [1]. Moreover, it is also postulated that knowledge and mastery of the spelling structure of a word can depend on the adequate development of the mechanisms involved in visual orthographic memory [2].

The notion that extensive exposure to print develops the cognitive processes involved in word recognition has been supported by findings which suggest that greater automaticity in word recognition processes is associated with higher levels of reading comprehension ability [3] [4]. In fact, readers with a high level of exposure to print are faster and more accurate in naming pseudo words, in choosing the correct member of a homophone pair, and in making lexical decisions when non-words are pseudo homophones, all of which demonstrate the effects of exposure to print on the efficiency of phonological and orthographic word recognition processes [5].

The effects of exposure to print on reading accuracy have been explained as effects of repetition priming. Repetition priming has been related to temporary changes in word recognition mechanisms [6], the creation of relatively stable representations in implicit memory (see Tenpenny [7], for extensive review), or the transient activation of pre-existing lexical representations [8].

Word processing occurs in just a few hundred of milliseconds, therefore the study of its temporal course has been increasingly relevant to better understand the neural underlying substrates. In this regard, the event-related brain potentials (ERP) provide accurate data on the time course in which word processing occurs, thus becoming a useful high temporal resolution technique to evaluate these processes.

Martín-Loeches and colleagues studied the sentence context in reading with ERP among Spanish speakers and found word recognition potential (RP) to be sensitive to the sentence context [9]. Hence, they used a go/no-go paradigm in which linguistic and non-linguistic stimuli were visually presented via a rapid-stream stimulation procedure to compare RP and the early repetition effect (N250r) usually observed in repetition priming tasks, due to their apparent similarities. They found that RP preceded N250r, and that both differed in their scalp topography and sensitivity to the experimental conditions. This was interpreted as RP was reflecting domain general processes of structural analysis while N250r was linked to a separate and content-specific stage of information processing [10].

Several ERP components have been associated with linguistic features, such as N1 with orthographic form [11], RP (N150; word recognition potential) that distinguishes between word-like stimuli and other visually categorized stimuli such as faces, objects and symbol strings, being a probable index of the automatic word classification [12], N350 related with phonological analysis of orthographic word patterns [13], and N400 with semantic inconsistencies [14]. Also, the ERP approach applied to word-reading has recently suggested that training in word recognition produces significant effects on early visual attention and orthographic recognition, as reflected by the P100 and N150 components, respectively. These training effects may predict long-term changes in episodic memory, as reflected by P600, and thus imply long retention of the word's form and meaning [15].

1) RP and automated processes

The RP component has been reported as a typical neurophysiological response elicited by the automatic visual recognition [2] [13] [16]-[19]. Component variations obtained from lexical decision and visual priming tasks have been observed in occipito-temporal regions [2]. When processing words, RP reaches higher amplitudes over left occipito-temporal scalp locations, particularly when compared with non-orthographic stimuli (e.g. pseudo-words and non-words; see Bentin *et al.* [13]).

2) P2 and perceptual analysis

The P2 component has typically been related to perceptual analysis and the allocation of visuo-spatial attention. Luck and Hillyard [20] described a frontal P2 that peaked at about 225 ms after stimulus onset, and hypothesized that it was linked to higher order visual processing. Several other studies have suggested that variations in the location of P2 across the two hemispheres seem to depend on both task-related variables and participants' attentional states [21].

3) N400 and semantic processing

The N400 is a mid-parietal negativity closely related to semantic processing. Its amplitude has been shown to be sensitive to the degree of semantic incongruity, as well as to several factors such as word frequency [22], repetition [23], expectancy [24], priming [25] and word-concreteness, among others.

4) P600 and grammatical analysis

It was originally considered that the P600 reflected syntactic violations, but presently it has been associated with a broad range of linguistic expressions, as a lateralized-to-the-right ERP index of morphosyntactic processing, or as a correlate of the degree of sentence integration (see Bornkessel-schlesewsky and Schlesewsky [26], for review).

On the other hand, it has been shown that children with reading difficulties have concurrent spelling problems [27] [28], and that adolescents with low orthographic knowledge show slow reading and difficulty in recognizing phonological spelling errors in Spanish [29].

Previous results have shown that participants with low levels of orthographic knowledge show lower reading performance. However, the effects of exposure to texts have not yet been elucidated in these subjects. In this context, our main interest was to evaluate, using ERP, the effect of word repetition priming on orthographic word recognition in two groups of native Spanish-speaking adults with different orthographic competence. Our hypothesis was that subjects with higher orthographic competence would benefit more from word exposure than those with lower skills when they had to perform a lexical decision task as reflected by behavioral measures and ERP responses.

2. Methods

2.1. Participants

Thirty-four healthy, right-handed participants were selected from a pool of 430 students. All subjects had a Wechsler Intelligence Scale III [30] global IQ of 90 or higher (but below 120), and were seniors at a normal high school or starting a college program (see **Table 1**). They were divided equally into two groups according to their performance on five orthographic-knowledge tasks (*Battery of Orthographic-Knowledge* [31]): *High Spelling Skills* (HSS; 17; mean age = 20.46, SD = 4.45 years; total spelling errors in the 15th percentile or lower); and *Low Spelling Skills* (LSS; 17; mean age = 20.58, SD = 4.46 years; number of errors in the 85th percentile or above). The two groups were matched according to age, handedness, and educational level, though gender varied (HSS: 7 females; LSS: 4 females). All had normal or corrected-to-normal visual acuity, and none had a past history of psychopathology, or neurological, neurosurgical or psychiatric disorders, nor had they been diagnosed with ADHD or any emotional disturbance or behavioral disorder, according to the DSM-IV criteria. All participants underwent a neurological examination and a baseline EEG with normal results. Ethical approval for all procedures was obtained prior to the study. All subjects were paid for their participation and gave their written informed consent.

The most frequent orthographic error in Spanish is the phonological spelling of words (pseudohomophones). Unlike English, this error implies in most cases a change of only one letter: e.g., omitting the silent H, or substituting homophonic letters, such as B-V, C-S-Z, LL-Y and G-J, but keeping the phonology of the real word. In order to examine the relationship between orthographic abilities and reading performance, all subjects were instructed to read aloud an expository text. **Table 1** shows the results of the reading tests, where significant between-group differences were found for reading speed: ($t(32) = 2.21$, $p < 0.05$; and reading errors: $t(32) = -3.07$, $p < 0.01$).

All participants were properly trained before performing the experimental task. Stimulus delivery, response collection and data acquisition onset were all synchronized and controlled by MINDTRACER software (Neuronic S.A., 2003).

2.2. ERP' Acquisition

During the experimental session, participants were seated in a comfortable chair in a darkened, sound-attenuated room. Electroencephalograms were recorded simultaneously from the Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, O1, O2, T3, T4, T5, T6, Fz, Cz and Pz active scalp sites using an elastic cap (Electro-cap International, Inc.). Also,

Table 1. Reading performance.

Group	IQ	Reading Skills		
		Speed	*Errors*	*Comprehension*
High Spelling Skills (n = 17)	111.8 (7.5)	170.5 (27.4)	2.71 (2.9)	7.2 (2.1)
Low Spelling Skills (n = 17)	101.06 (13.9)	147.97 (31.6)	6.71 (4.5)	6.3 (2.3)

Mean (standard deviation). Reading speed is presented in words per minute.

10-mm diameter gold disk electrodes (Grass Type E5GH, Astro-Med, Inc.) were placed on the infraocular ridge of the left eye and the outer canthus of the right eye to record electrooculograms, using linked earlobes as references. Interelectrode impedances were maintained below 5 kΩ, with a sampling period of 5 ms on the MEDICID-04 system. Signals were amplified at a bandpass of 0.5 - 30 Hz.

Epochs of data from all channels were excluded from averages when the voltage in a given recording epoch exceeded 100 µV on any EEG or EOG channel. At least 20 correct, artifact-free trials were obtained from each condition and participant using 100 ms as pre-stimulus baseline. All scoring was conducted baseline-to-peak through visual inspection. Individual and group grand-averages were calculated only for 1.100-second EEG time epochs with correct responses. Only correct, artifact-free trials—randomly selected across each EEG recording—were used to generate the ERPs.

2.3. General Procedure

Before performing the experimental task, participants were exposed to a list of 360 words, composed by 120 correctly-spelled Spanish nouns (2 or 3 syllables, word frequency between 50 and 100 per million). Half of the stimuli (60) appeared only once in the stimuli list, while the other half appeared 5 times. The words appeared as white lower case letters on a black background using a 17" LCD computer monitor during 1300 milliseconds (ms), with an inter-stimulus interval of 1000 ms. Participants were instructed to read aloud each word. All participants read the same list.

After completing the previous assignment, participants were asked to perform a lexical decision task. To create the experimental stimulation list, half of the words that previously appeared once (30) and 5 times (30) were randomly selected. The remaining words from the former stimulation list were transformed into misspelled words by adding a homophone substitution (e.g. **v**oat [boat] and **v**rick [brick]). The presentation features of the stimuli were identical to those used before. Participants were instructed to respond as fast as possible by pressing a keyboard key with their index finger, depending on the correct or misspelled nature of each stimulus.

Behavioral and ERP statistics

Repeated measures ANOVAs were performed on correct answers and reaction times, considering Group (HSS *vs*. LSS) as the between-subjects factor, while *Exposure* (1 and 5) and *Spelling* (correct and misspelled) were analyzed as within-subject factors.

Guided by the visual inspection of the grand-averaged ERPs, data analysis was restricted to F3, F4, C3, C4, P3, P4, T5 and T6, where the main changes occurred. Greenhouse-Geisser's corrections were used when needed. Post-hoc analyses using Bonferroni correction were also applied when necessary.

Four time windows were analyzed: 150 - 250, 250 - 350, 350 - 450, and 500 - 700 ms for the RP, P200, N400 and P600 components respectively. For the RP component, *Exposure* (1 and 5), *Spelling* (correct and misspelled) and *Recording Site* (T5 and T6) were measured as within-subject factors. For the P200 analysis, *Exposure*, *Spelling*, *Hemispheric location* (left and right) and *Topographical distribution* (frontal, central, parietal and temporal) were considered as within-subject factors. Finally, for N400 and P600 component analysis, *Exposure*, *Spelling*, *Hemispheric location* and *Topographical distribution* (frontal, central and parietal) were considered as within-subject factors.

3. Results

3.1. Behavioral Results

There were significant differences between groups regarding the amount of correct responses [$F(1, 32) = 94.54$, $p < 0.001$, $\eta^2 = 0.75$], where HSS group showed higher accuracy (**Table 2**). A significant effect of *Exposure* was found [$F(1, 32) = 4.20$, $p < 0.05$, $\eta^2 = 0.12$] showing that accuracy increased when the stimuli were repeatedly presented. A significant effect for *Spelling* was also found ($F(1, 32) = 83.94$, $p < 0.001$, $\eta^2 = 0.72$) with more accurate trials for correct spelling. There was also a significant interaction between *Spelling* and *Group* [$F(1, 32) = 25.98$, $p < 0.001$, $\eta^2 = 0.45$], where post-hoc Tukey's tests indicated that LSS performed significantly worse than HSS when words were misspelled, taking misspelled as correctly spelled words ($p < 0.001$).

Exposure and *Spelling* significantly interacted ($F(1, 32) = 12.83$, $p < 0.005$, $\eta^2 = 0.29$), where post-hoc analysis showed an effect of exposure on spelling only for correctly-spelled words ($p < 0.001$). Further, reaction time analysis showed a significant difference between groups ($F(1, 32) = 7.91$, $p < 0.01$, $\eta^2 = 0.20$), indicating that

HSS responded faster than LSS. A significant effect of *Exposure* was also found ($F(1, 32) = 4.90$, $p < 0.05$, $\eta^2 = 0.13$), with larger reaction times in trials with only one exposure. A significant effect of *Spelling* was found for reaction times ($F(1, 32) = 215.58$, $p < 0.001$, $\eta^2 = 0.87$), indicating prolonged responses for incorrectly-spelled words. Finally, a significant interaction between *Exposure* and *Spelling* was found ($F(1, 32) = 16.95$, $p < 0.001$, $\eta^2 = 0.35$). Post-hoc analysis showed an effect of exposure on spelling only for correctly-spelled trials with larger reaction times for the stimuli with less exposure ($p < 0.001$).

3.2. ERP Results

Recognition Potential

A significant interaction between Groups and Exposure was found ($F(1, 32) = 5.41$, $p < 0.05$, $\eta^2 = 0.15$), indicating greater negative readings for HSS, particularly when the stimuli were repeatedly presented. **Figure 1** shows the ERP waveforms during the performance of the lexical task in both groups and **Figure 2** shows the voltage distribution of the main ERP components.

Table 2. Behavioral performances during the lexical decision task.

GROUP	Word Exposure	Correct Word		Spelling Error	
		Correct Responses[a]	Reaction Times[b]	Correct Responses	Reaction Times
High Spelling Skills	1	27.5 (2.6)	830.7 (100.9)	24.6 (2.8)	970.7 (145.2)
	5	29.0 (0.7)	776.7 (92.5)	24.6 (2.9)	991.6 (119.9)
Low Spelling Skills	1	24.7 (2.6)	929.6 (137.2)	13.5 (5.9)	1118.9 (181.9)
	5	26.8 (2.6)	862.4 (119.8)	12.4 (5.7)	1116.3 (136.6)

[a]Mean (standard deviation); [b]Reaction times are presented in milliseconds.

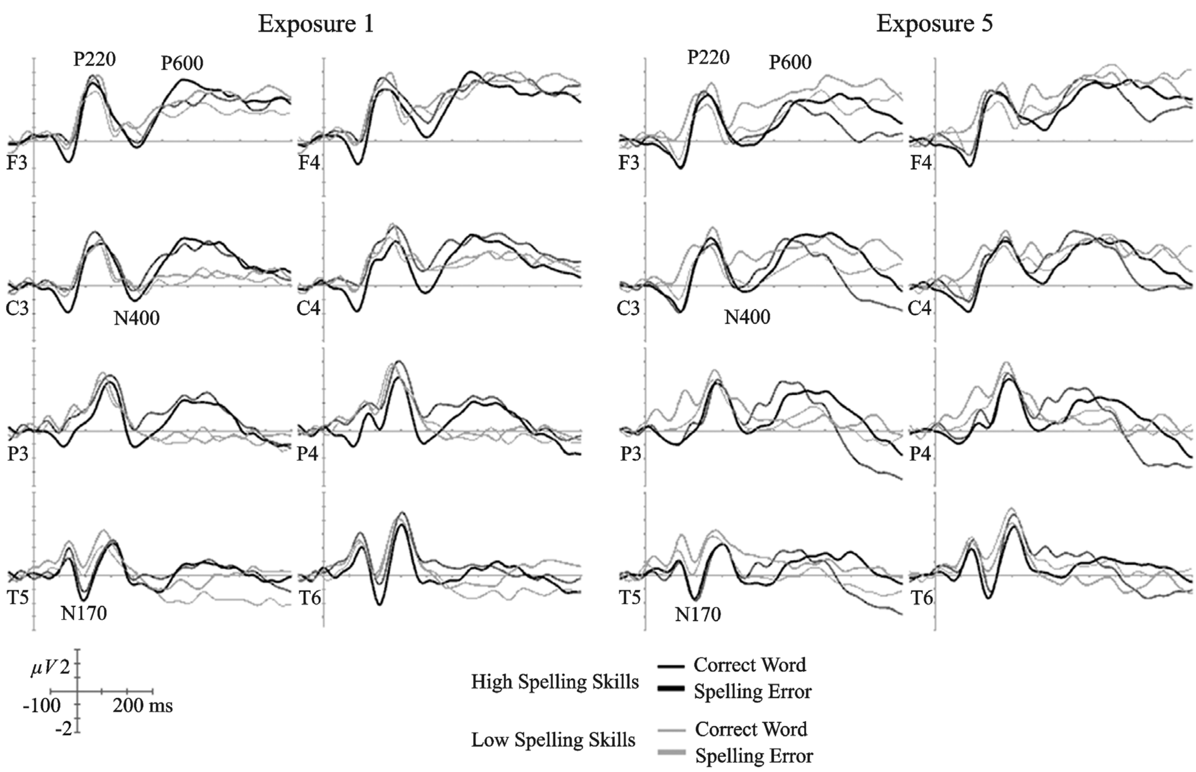

Figure 1. Grand-averaged waveforms elicited by previous word-exposure conditions while performing the lexical task are shown. Two levels of the factor *Exposure* (1 and 5) for words (thin lines) and misspelled words (thick lines), are represented in the two groups.

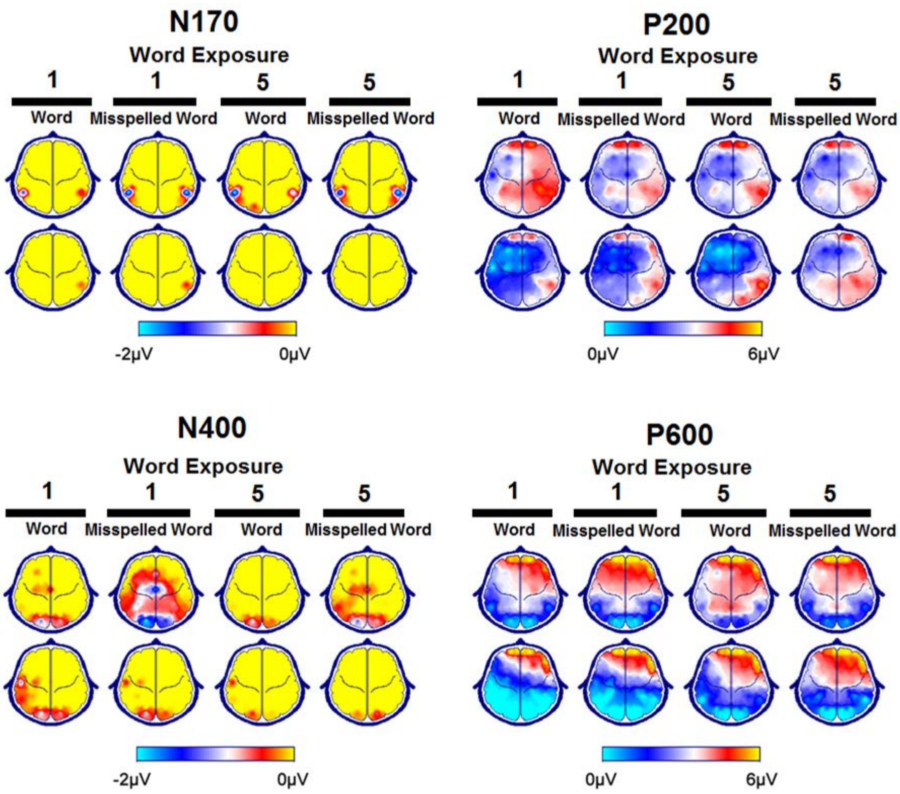

Figure 2. Topographic maps corresponding to the grand-averaged waveforms elicited by previous word-exposure conditions in High Spelling Skills (top rows), and Low Spelling Skills (bottom rows) groups are shown. Time cursors were placed at 200 ms (RP: N170), 280 ms (P200), 400 ms (N400), and 600 ms (P600).

***P*200**

A significant difference for *Hemispheric location* was found ($F(1, 32) = 11.19$, $p < 0.005$, $\eta^2 = 0.26$), with higher voltages at the right hemisphere (see **Figures 1-2**).

***N*400**

No significant differences were found for the factors *Spelling* and *Group* under N400 condition. However, their interaction was significant ($F(1, 32) = 4.79$, $p < 0.05$, $\eta^2 = 0.13$), as post-hoc analysis demonstrated a greater negativity for incorrectly-spelled stimuli that was significant only for HSS ($p < 0.05$). There was a lateralized effect of *Hemispheric allocation* ($F(1, 32) = 18.50$, $p < 0.001$, $\eta^2 = 0.37$) with more negative voltages in the left hemisphere. The interaction between *Topographical distribution* and *Hemispheric allocation* was statistically significant ($F(1.42, 45.45) = 7.43$, $p < 0.005$, $\eta^2 = 0.24$, $\varepsilon = 0.41$), reflecting greater negativities over the central areas ($p < 0.05$) (See **Figures 1-2**).

***P*600**

The factor *Topographical distribution* was significantly different [$F(1.12, 35.86) = 23.36$, $p < 0.001$, $\eta^2 = 0.42$, $\varepsilon = 0.56$]. Post-hoc analysis showed differences between all three major regions (frontal, central and parietal; $p < 0.005$), with greater voltage in the frontal area. In addition, a significant interaction was found between *Topographical distribution* and *Group* ($F(2, 32) = 4.18$, $p < 0.05$, $\eta^2 = 0.12$) with differences between all three regions in LSS ($p < 0.005$), while HSS showed differences in the frontal and central regions compared to parietal ones ($p < 0.05$). The interaction between *Topographical distribution* and *Exposure* was significant ($F(1.45, 46.30) = 4.54$, $p < 0.05$, $\eta^2 = 0.12$, $\varepsilon = 0.72$), indicating differences between the three regions but only for non-repeated stimuli ($p < 0.001$). In addition, trials with repeated stimuli showed significant differences when comparing frontal and central regions with parietal areas ($p < 0.005$) (see **Figures 1-2**).

The *Hemispheric location* analysis showed a lateralized effect [$F(1, 32) = 11.92$, $p < 0.005$, $\eta^2 = 0.27$] with greater voltages over the right hemisphere. Its interaction with *Topographical distribution* was also significant [$F(1.52, 48.68) = 20.47$, $p < 0.001$, $\eta^2 = 0.39$, $\varepsilon = 0.76$], and post-hoc analysis showed differences between all three recording regions over the right ($p < 0.001$), with significant differences between frontal and central areas compared to parietal ones ($p < 0.05$) over the left.

ERPs and Reading

Finally, a positive significant correlation between the amplitude of P600 and reading speed was found at P3 (0.391, $p < 0.05$) and P4 (0.364, $p < 0.05$).

4. Discussion

Behavioral results showed that LSS was significantly less efficient in detecting orthographic errors than HSS. However, this effect was particularly evident when manipulating words after repeated exposure. In the present experiment, behavioral performances might be better explained on the basis of early sub-lexical perceptual processing differences, since the phonological representations of the competing stimuli (words and pseudo homophones) led to identical lexical representations.

Given the suggestion that the recognition potential reflects specialized visual word orthographic processing [2] [13], which probably depicts increased visual processing expertise in pre-lexical orthographic processing [32], the higher RP amplitudes observed in HSS may reveal early differences among groups in their orthographic processing abilities. This result is in line with the suggestion that a family of early specific negativities with varying sources and scalp distributions is generated by any visual category with much experience [33].

When detecting misspelled words, HSS showed a more bilateral topographic distribution for the RP component than LSS, a group in which RP seemed to be restricted to the left hemisphere. The bilaterality observed for RP in the HSS might reflect the advantages of strategies based on bilateral hemispheric orthographic processing. This may well be part of an interhemispheric cooperation effect during word processing, particularly in conditions in which task demands are higher [34] as when errors are processed. In contrast, later steps in the orthographic processing stream can depend more on specialized and lateralized regions, when reading becomes automatic.

In experiments where participants had to perform an orthographic-discrimination task, P2 had not shown significant asymmetries [35]. In the present experiment, greater voltages were observed on the right hemisphere, which might be due to the strategy used to detect the spelling errors. In addition, the negativity subsequent to P2 also showed a clear laterality effect over the left hemisphere, with a central parietal dominance, while N400 showed greater differential amplitudes only when misspelled words were detected by HSS.

The amplitude of the N400 has been interpreted as an inverse function of lexicality, such that pronounceable pseudo words produce larger N400 amplitudes than words. However, the modulation of its amplitude might reveal processing costs during the retrieval of characteristics related with the visual word-form stored in memory (see Kutas and Federmeier [36], for review). In the present experiment, the pseudo homophones only differed from actual words by one letter; thus, pseudo homophones and words were both visually similar and phonologically identical. In these conditions, error detection might elicit a conflict that could only be solved by rehearsing the memory-stored visual representation of the word, in order to make the visual comparison.

In this regard, one could expect that HSS might have better memory representations of the word-form, but this could decrease the "plausibility judgment" of the pseudo homophones used as stimuli, therefore increasing the N400 amplitude. P600 has been classically associated with recognition and online monitoring and re-analysis [37]. Hence, it seems to be elicited whenever a conflict between "a strong tendency to accept and one to reject a word brings the cognitive system into a state of indecision" ([38], p. 150). The similarity between words and pseudo homophones while performing a lexical decision task in a transparent orthography like Spanish could resemble this conflict, thus eliciting P600.

Based on our results, P600 could be interpreted as related to the orthographic parsing that finally allowed words and pseudo homophones to be distinguished. In this regard, one could expect that stronger visual representations in orthographic memory of the word could correspond to more efficient misspelling detection processes, as occurred in HSS. On the other hand, we expected more significant correlations between ERP' amplitudes and reading speed, especially for the earlier components, but the finding on/of P600 emphasized that higher orthographic competence related to higher reading speed.

Finally, despite the limitations of the present study, the results suggest that differences in orthographic knowledge may reflect extended areas of deficit beyond perceptual recognition that subsequently affect more complex processing steps.

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