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The supramarginal and angular gyri underlie orthographic competence in Spanish language

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ABSTRACT

Orthographic competence allows automatic word recognition and reading fluency. To elucidate how the orthographic competence in Spanish-speaking adults might affect the neurofunctional mechanisms of visual word recognition, 32 young adults equally divided in two groups (HSS: High Spelling Skills, and LSS: Low Spelling Skills) were evaluated using fMRI methods, while they performed an orthographic recognition task involving pseudohomophones. HSS achieved significantly more correct responses and lower reaction times than LSS. Interestingly, LSS showed greater activation in the left angular and supramarginal regions with increased bilateral activation pattern in the inferior frontal gyrus, and the anterior temporal and posterior parietal regions. In contrast, HSS showed a more left-lateralized pattern over these regions along with higher activation of the anterior cingulated gyrus for misspelled words. Results suggest that the differences found in cortical activation patterns might be explained by the higher degree of specialization for word recognition in HSS, a group of participants that due to their greater orthographic skills require less engagement of processing resources to succeed in the task.

1. Introduction

Spelling can be considered as the ability to represent the unique array of letters that defines a printed word (Vellutino, Scanlon, & Tanzman, 1994). It develops as children learn to read and acquire the skill to automatically recognize words. However, in children with reading difficulties, it has been reported that they have problems in developing the ability to represent orthographic patterns in memory, which impacts reading speed, particularly in transparent orthographies. In dyslexics from Spanish, Finnish, Italian and German, reading accuracy is high, but impairments in reading speed and severe problems in spelling are often observed and persist into adulthood (Bruck, 1993; Landerl & Klicpera, 2009; Nergard-Nilssen & Hulme, 2014).

The development of neural substrates of spelling abilities might be greatly influenced by the orthographic characteristics of the language because orthographic consistency leads to the adoption of different reading strategies across languages. Evidence from studies on transparent languages, such as German, Italian and Polish (Borkowska, Francuz, Soluch, & Wolak, 2014; De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999; Hutzler & Wimmer, 2004) reveals that both the characteristics of the specific language and the type of task are important for detecting spelling disorders and their underlying neural mechanisms.

Research on reading difficulties offers substantial support for the notion that left occipito-temporal reading circuits, comprising the visual word form area, are the origin of persistent impairments of fluent reading (eg. Cohen et al., 2000; Kronbichler et al., 2006); however, few publications have focused on the brain mechanisms that underlie spelling disorders (Borkowska et al., 2014; Gebauer, Enzinger, et al., 2012; Gebauer, Fink, 2012; Richards et al., 2015). Most of those studies show that individuals with isolated spelling disorders tend to exhibit stronger activation over the right hemisphere, particularly in the inferior frontal area and right cerebellum posterior lobe, but also in the left inferior and medial frontal gyri, suggesting the involvement of regions associated with working memory and linguistic processing.

The orthographic word recognition is an automatic and unconscious

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process that cannot be turned on and off and, hence, is not subject to strategic control (Ehri, 2005). Therefore, the phonological similarity between pseudohomophones and words might elicit conflict when an orthographic judgment is made – pseudohomophone effect -. The more automatic is the word recognition process; more evident is the pseudohomophone effect.

In fact, homophone/pseudohomophone effects have been observed on several task types, including lexical decision-making, where response times to pseudohomophones tend to be slower and more prone to error (McCann, Besner, & Davelaar, 1988; Seidenberg, Petersen, MacDonald, & Plaut, 1996; Vanhoy & Van Orden, 2001). Findings in children with isolated spelling deficits, however, show that pseudohomophones are named as quickly as their corresponding words (Moll & Landerl, 2009). Furthermore, regarding the specific homophone effect, a brain activation pattern that includes the inferior frontal gyrus, the inferior parietal lobe and the superior temporal cortex has been described, though activation of the latter might be more closely-related to the number of lexical alternatives (Newman, 2011).

Recently, Braun et al. (2015) used fMRI methods to study lexical decisions in a group of normal, native German-speakers. Hemodynamic activation in the left inferior/superior frontal and middle temporal cortex, left insula, and left superior parietal lobule in response to pseudohomophones was greater than for well-controlled pseudowords. In addition, activation differences were found in the bilateral angular and left supramarginal and bilateral middle temporal gyri for pseudohomophones in low- compared to high-frequency base-words. Based on these findings, the authors proposed that lexical decisions regarding pseudohomophones involve phonology-driven, lexico-semantic activation in response to their base-words that determines the cerebral activation pattern described above.

In our view, the understanding of spelling disorders is still far from complete, particularly in adults, and especially in the context of a transparent language. Spelling has been related to “explicit phonological knowledge and knowledge of orthographic conventions” (see Steffler, 2001, for an extensive review), but the regular orthography of Spanish may impede recognizing pseudohomophonic pseudowords when applying a phonological strategy.

Since evidence seem to support the notion that increasingly automatized orthographic processing is accompanied by a decline in the use of slow and effortful process of phonological recoding (Ehri, 2005; Grainger, Lété, Bertrand, Dufau, & Ziegler, 2012; Wolf, 1991), we aimed to examine the behavioral and neurophysiological differences in young adult native Spanish-speakers with distinct orthographic abilities when asked to distinguish between words and pseudohomophones. In this regard, we hypothesized that native Spanish-speaking subjects with lower orthographic knowledge would depend excessively on phonological strategies to decode words– as compared with orthographic strategies-, and so would have fewer correct responses and/or prolonged response times compared to their peers, while distinguishing between words and pseudohomophones. In addition, and in light of previous findings by Braun et al., we expected to find greater activation in theinferior frontal, temporal, occipital and angular regions in the participants with lower orthographic knowledge, as a probable expression of a less-automatized, orthography-specific functional tuning of brain reading networks that depends primarily on the transparency of the language.

2. Methods

2.1. Participants

A total of 32 (11 females) healthy, right-handed, monolingual, native Spanish-speaking young adults (aged 18–24) participated. Experimental procedures were approved by the Ethics Review Board (ERB) of the *Instituto de Neurociencias* and the Committee on Bioethics at the *Instituto de Neurobiología*. All participants read and signed the ERB-approved informed consent form prior to any experimental procedure.

The sample was obtained from a pool of 470 students in the final year of high school (public) or the first semesters at a public university. Participants were divided into two groups according to their performance on four orthographic-knowledge tasks from the *Batería de Conocimiento Ortográfico* (BCO: Orthographic-knowledge tests; Gómez-Velázquez et al., 2014). These tasks involved: (1) *Word completion*: participants were told that they would see a list of 36 words with letters missing, and had to fill in the blanks to make complete words by choosing between two or three possible homophone letters (eg. *no_ivo, **c**-s-**z***); (2) *Text dictation*: participants were instructed to write down a narrative text in the form of a letter as it was read aloud; the document had 196 words adapted from a text found in a primary school textbook; (3) *Word dictation*: subjects had to write down a list of 40 words as they were spoken; each word contained 2 or 3 syllables and all were susceptible to pseudohomophone errors; and, (4) *Text correction*: in an expository text of 276 words, 22 were replaced by pseudohomophonic errors (eg. ***b**acterias* × ***v**acterias*). Participants were instructed to detect the orthographic errors in the text. The BCO is a 4-test battery validated for Mexican High School students. It has a Cronbach’s internal consistency reliability of $\alpha = 0.859$, and a construct validity analysis showed that all tests contribute to a single construct that explains 71% of total variability.

The two experimental groups were formed as follows: High Spelling Skills (HSS: 15 participants (6 females) with fewer errors than those corresponding to the 10th percentile of standardized BCO scores); and Low Spelling Skills (LSS: 14 participants (3 females) with a number of errors above the 90th percentile). Due to the strong relationship found between spelling difficulties and low reading fluency (González-Garrido, Gómez-Velázquez, & Rodríguez-Santillán, 2014; Holmes, Malone, & Redenbach, 2008), we sought to explore whether LSS also manifested problems in reading accuracy or speed. Consequently, all participants were asked to read aloud an expository text of 504 words while researchers measured the following parameters: (a) reading speed; (b) number of misread words; and, (c) text comprehension. Finally, all subjects had a global estimated IQ ≥ 90 according to a short version -Vocabulary and Block Design subscales- of the Wechsler Intelligence Scale III (Wechsler, 2003).

The groups were matched according to age and educational level. All participants underwent an extensive clinical interview and none had any personal or family history of psychiatric, neurological or degenerative illness, nor diagnoses of ADHD, emotional disturbances or behavioral disorders, according to the DSM-IV criteria (American Psychiatric Association, 2004). Table 1 presents the demographic characteristics and reading test performance of all participants.

2.2. Stimuli and task procedure

Spanish words (W), pseudohomophones (PH: the same set of word

Table 1
Descriptive statistics for both groups of participants.

	HSS	LSS	Group comparison		
	Mean (SD)	Mean (SD)	t	df	*p*
Age	19.7 (3.4)	19.8 (3.4)	−0.041	27	0.960
Years of education	12.9 (1.3)	12.1 (2.1)	0.708	27	0.435
Estimated IQ	113.8 (8.5)	107.9 (8.4)	1.879	27	0.071
Total errors in BCO	4.3 (1.8)	40.2 (8.9)	−14.691	**13.98**	**0.000**
Reading speed	168.5 (16.9)	152.5 (22.6)	2.169	**27**	**0.039**
Misread words	2.2 (1.5)	6.8 (4.4)	−3.719	**15.72**	**0.002**
Reading comprehension	8.3 (1.2)	7.6 (1.2)	1.410	27	0.169

HSS: High Spelling Skills group. LSS: Low Spelling Skills group. IQ (intelligence quotient). SD: Standard Deviation. BCO: *Batería de Conocimiento Ortográfico* (orthographic knowledge 4-test battery). Reading speed is shown in words per minute. df: degree of freedom.