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Neural differences between monolinguals and early bilinguals in their native language during comprehension

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ABSTRACT

Research has shown that semantic processing of sentences engages more activity in the bilingual compared to the monolingual brain and, more specifically, in the inferior frontal gyrus. The present study aims to extend those results and examines whether semantic and also grammatical sentence processing involve different cerebral structures when testing in the native language. In this regard, highly proficient Spanish/Catalan bilinguals and Spanish monolinguals made grammatical and semantic judgments in Spanish while being scanned. Results showed that both types of judgments recruited more cerebral activity for bilinguals in language-related areas including the superior and middle temporal gyri. Such neural differences co-occurred with similar performance at the behavioral level. Taken together, these data suggest that early bilingualism shapes the brain and cognitive processes in sentence comprehension even in their native language; on the other hand, they indicate that brain over activation in bilinguals is not constrained to a specific area.

1. Introduction

A substantial proportion of the world population is bilingual and speaks more than one language fluently. Bilingual speakers routinely produce and understand sentences belonging to two (or more) languages without difficulty. Therefore, understanding how two languages coexist in one brain, with little conflict or interference between both codes, is an issue of great theoretical and applied interest.

One important question during the last years has focused on whether a bilingual brain processes linguistic information in the same manner as a monolingual brain. More specifically, there is an ongoing debate as to whether an early and/or continued exposure to more than one language yields changes in the pattern of brain activity during language processing. It has been extensively demonstrated that many early childhood experiences can permanently influence brain organization (Fine, Finney, Boynton, & Dobkins, 2005; Neville & Bavelier, 2001; Ohnishi et al., 2001; Petersson, Reis, Askelof, Castro-Caldas, & Ingvar, 2000) and in the linguistic domain, some early experiences result in persistent behavioral and neurological changes (Lenneberg, 1967; Mayberry & Eichen, 1991; Neville et al., 1997; Newman, Bavelier, Corina, Jezzard, & Neville, 2002; Petitto et al., 2000; Roder, Stock, Bien, Neville, & Rosler, 2002). The early acquisition of a second language seems to play an important role in neural organization regardless of the level of proficiency (Pakulak & Neville, 2011) and an increasing number of neuroimaging studies in bilingualism have shown that also late experience with more than one language lead to structural and functional modifications in the brain (Kroll, Bobb, & Hoshino, 2014).

Functional differences in the brain between bilinguals and monolinguals have been observed in word comprehension and production. Rodríguez-Fornells and colleagues observed increased activation in the left inferior frontal gyrus (lIFG) and superior temporal cortex (STC) in Spanish–Catalan bilinguals compared to monolinguals in a lexical decision task (Rodríguez-Fornells, Rotte, Heinze, Nösselt, & Münte, 2002). However, a study by Parker-Jones et al. showed increased brain activation for bilinguals compared to monolinguals in tasks requiring speech production (reading or naming) but not during the semantic decision tasks in either their native or their second language (Parker-Jones et al., 2012). Specifically, these authors observed a higher blood oxygen level dependent (BOLD) signal response for bilinguals in the lIFG (pars triangularis and opercularis), superior temporal gyrus (STG), planum temporale and dorsal precentral gyrus when a task required retrieving and articulating words in both their

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native and second language (L2). Since this group of regions is classically associated with language processing, they considered that increased recruitment in bilinguals arose because word retrieval is more demanding due to the co-activation of two languages. Palomar-García et al. (2015) reached a similar conclusion. These authors mirrored the production-only differences in a study in which early balanced bilinguals of Spanish/Catalan and Spanish monolinguals carried out listening and naming tasks in their native language. However, cerebral regions that mediated production in bilinguals were posterior (right STG and posterior cingulate cortex). It is important to highlight three aspects of their study that should maximize similarities in cognitive and neural processing between bilinguals and monolinguals: (1) the sample in their study was early balanced bilinguals; (2) their participants were tested in one language only, therefore reducing the need of language co-activation (e.g. Elston-Gütler, Gunter, & Kotz, 2005); and, finally, (3) the language of testing was their native language. Despite all this, bilinguals and monolinguals presented a different pattern of neural activation.

Also, studies on sentence comprehension have observed differences between bilinguals and monolinguals in the brain. Kovelman, Baker, and Petitto (2008) performed an fMRI study comparing brain activations of English monolinguals and early Spanish/English bilinguals. Participants had to judge whether visually presented sentences were plausible or not. The sentences varied in their syntactic complexity and were presented in each language in separated blocks for bilingual speakers. For monolinguals, only English sentences were presented. Results showed that bilinguals and monolinguals yielded similar speed and accuracy at the behavioral level, but their brain activations presented some differences in English sentence processing. Neuroimaging analyses revealed that bilinguals had – similar to word processing research – a significantly greater activation in the lIFG (particularly within BA 44/45) than monolinguals. According to Kovelman and colleagues, this activation difference in the lIFG provided evidence suggesting a possible "neural signature" for bilinguals as a consequence of an early exposure to two languages. On the other hand, a greater activation of some cortical areas in the frontal lobe could be indicative that sentence processing in highly proficient bilingual speakers is more effortful for them than for monolingual speakers (Bialystok, Craik, Green, & Gollan, 2009), since some regions in the frontal cortex are associated with cognitive control (i.e. conflict monitoring, interference resolution, and selection of information when both languages are co-activated). In a recent fNIRS study using the same task and materials as Kovelman et al., Jasinska and Petitto (2013) observed that differences between bilingual and monolingual adults appeared in the right STG, but not in the IFG regardless the type of sentence.

While Kovelman et al. and Jasinska and Petitto used semantic judgment tasks, Wartenburger and collaborators used two types of tasks on sentences in an fMRI study with Italian–German bilinguals: one based on a semantic judgment and one based on a grammatical judgment. They found quite a different pattern of brain activity depending on the nature of the task (Wartenburger et al., 2003). Participants were bilinguals with a variable age of acquisition and variable proficiency level of their L2. Data showed that brain organization underlying semantic processing is more influenced by proficiency level in L2, whereas age of L2 acquisition had a more pronounced effect on the neural representation of grammatical processes. Indeed, Wartenburger et al.'s fMRI study was the first to demonstrate that age of L2 acquisition is crucial for grammatical processing (Perani & Abutalebi, 2005). However, since they did not include a sample of monolingual speakers, this study could not address the question of whether or not bilingual and monolingual brain activations differ during grammatical processing. Rüschemeyer, Fiebach, Kempe, and Friederici (2005) did compare native speakers of German to late learners. They presented auditory sentences that were semantically or syntactically violated and non-violated. Syntactically correct and incorrect sentences elicited increased activation in the pars opercularis of the lIFG and bilaterally in the head of the caudate in late L2 learners compared to native speakers. No differences appeared in the semantic condition. This pattern is similar to event-related potentials (ERPs) research (e.g. Ojima, Nakata, & Kakigi, 2005), in which highly proficient late L2 learners show native-like ERPs in response to semantic information (a negativity around 400 ms or N400) but differences in syntactic processing (absence of a left anterior negativity [LAN] in the complex LAN/P600).

To sum up, there is evidence that semantic processing presents a native-like neural pattern in late highly proficient bilinguals, when in contrast grammatical processing in bilinguals entails differences compared to monolinguals. Since Wartenburger et al. found that age of acquisition has a larger impact on grammatical rather than semantic processing, it is particularly important to explore how early bilingualism affects sentence processing compared to monolinguals. Research indicates that differences in neural patterns between monolinguals and bilinguals are modulated not only by age of acquisition (Jasinska & Petitto, 2013) but, as explained above, by those conditions that minimize interference between languages (e.g. monolingual context, processing of the native language, etc.; Palomar-García et al., 2015). Therefore, in the present work, we explore neural differences between bilinguals and monolinguals for semantic and grammatical processing in a native-like setting; monolinguals are compared to bilinguals that: (1) have acquired their second language early in life, (2) are balanced in both languages, (3) are tested only in their native, dominant language and, therefore, the experimental setting is monolingual; and, finally, (4) we use simple sentences. The use of simple sentences is important for our goal in two ways. On one hand, complex sentences (as those used in Kovelman et al.'s and Jasinska & Petitto, 2013) involve increased cognitive control demands (Ye & Zhou, 2009). Since executive control functions/engagement seem to differ between monolinguals and bilinguals in linguistic (e.g. Rodríguez-Fornells, de Diego Balaguer, & Münte, 2006) and non-linguistic tasks (e.g. Colzato et al., 2008), even under similar behavioral performance (Rodríguez-Pujadas et al., 2013), the recruitment of executive control might be a crucial difference between monolinguals and bilinguals in language processing (Abutalebi, 2008). In terms of neural substrates, syntactic complexity and increased demands of executive control are both related to changes in the IFG (Fiebach, Vos, & Friederici, 2004; Just, Carpenter, Keller, Eddy, & Thulborn, 1996). It is desirable, thus, to lessen differences in terms of the cognitive demands that a task places on each group to reveal differences in linguistic processing per se. On the other hand, simple sentences are acquired earlier in life (see Clark, 2009) and consequently processing of simple sentences may be more prone to show steady changes in terms of neural markers. Clahsen and Felser (2006), for example, stated that although the native language and L2 processing can become more similar, however, even highly proficient bilinguals present differences in processing complex syntax. Friederici, Steinhauer, and Pfeifer (2002) suggested that in using artificial languages, late learners could use native-like neural correlates in settings with few rules and words, which resemble simple sentences (Pakulak & Neville, 2011). Taken into consideration simultaneous bilinguals (early learners), research shows that they are exposed to a lesser extent to each of their languages in relation to monolinguals – whether referring to the lexicon (Bialystok, Luk, Peets, & Yang, 2010), or syntactical structures. This is because they are in contact with an increased diversity of words for each concept and with a diversity of linguistic structures (MacLeod, Fabiano-Smith, Boegner-Pagé, & Fontolliet, 2013). The use of simple sentences