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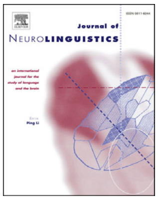

Interference control at the response level: Functional networks reveal higher efficiency in the bilingual brain

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ABSTRACT

The bilingual advantage in interference control tasks has been studied with the Simon task, among others. The mixed evidence from the existing studies has led to contradictions in the literature regarding the bilingual advantage. Moreover, fMRI evidence on the neural basis of interference control mechanisms with the Simon task is limited. Previous work by our team showed that equivalent performance on the Simon task was associated with different activation maps in elderly bilinguals and monolinguals. This study aims to provide a more in-depth perspective on the neural bases of performance on the Simon task in elderly bilinguals and monolinguals, by adopting a network perspective for the functional connectivity analysis. A node-by-node analysis led to the identification of the specific topology that characterized the bilingual and monolingual functional networks and the degree of connectivity between each node across groups. Results showed greater connectivity in bilinguals in the inferior temporal sulcus, which plays a role in visuospatial processing. On the other hand, in monolinguals, brain areas involved in visual, motor, executive functions and interference control were more connected to resolve the same task. In other words, in comparison to the monolingual brain, the bilingual brain resolves visuospatial interference economically, by allocating fewer and more clustered regions. These results demonstrate a larger global efficiency in task performance in bilinguals as compared to monolinguals. Also, the provided evidence filters out the task-specific so-called bilingual advantage discussed in the literature and posits that bilinguals are strategically more efficient in a given performance than monolinguals, thus enhancing our understanding of successful aging.

1. Introduction

Both the early and late acquisition of two or more languages have been related to an enhanced ability to exercise cognitive flexibility during multi-tasking (Ansaldo, Ghazi-Saidi, & Adrover-Roig, 2015; Bak, Vega-Mendoza, & Sorace, 2015; Bialystok,

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2009; Bialystok, Craik, & Luk, 2012; Hilchey & Klein, 2011). Learning two languages also provides building blocks for cognitive reserve and increases functional efficiency at older ages. Different life experiences are crucial for building cognitive reserve, including engaging in leisure activities, education, occupational attainment skills and bilingualism (Bialystok et al., 2012; Bialystok, Abutalebi, Bak, Burke, & Kroll, 2016; Scarmeas & Stern, 2003). Bilingualism is considered to reduce interference from irrelevant stimuli in the environment. Thus, in daily life situations that present a variety of stimuli, a bilingual individual can function effectively by attending to the relevant information and ignoring the irrelevant one. In experimental situations, the successful performance on a given interference task (i.e., Simon, Stroop, go/no-go, tasks) relies upon the establishment of goal representations when beginning the experiment, and upon maintaining them throughout the task (Bialystok et al., 2005; Bialystok, Craik, Klein, & Viswanathan, 2004; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006; Zied et al., 2004).

Lifelong practice at juggling with two or more languages is likely to modulate such goal-directed behavior, resulting in a specific-to-bilinguals expertise, which might lead to a more economical interference control mechanism in this population. From a behavioral perspective, this observation relates to the concept of the “bilingual advantage” and suggests that bilinguals may have more resources than monolinguals for dealing with interference. However, inconsistencies in the behavioral literature and the lack of sufficient neurofunctional evidence to support this claim call for a more in-depth analysis of this issue. The purpose of this work was to provide a network perspective on our previous claims regarding the different underlying neurofunctional bases of interference control observed in elderly bilinguals and monolinguals (Ansaldo et al., 2015).

The bilingual advantage resulting from knowing two or more languages has been studied across the life span (Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok et al, 2004; Costa, Hernández, & Sebastián-Gallés, 2008; Gold, Kim, Johnson, Kryscio, & Smith, 2013; Hilchey & Klein, 2011), in different cognitive-communicative disorders (Alladi et al., 2013; Bialystok, 2007; Craik, Bialystok, & Freedman, 2010), and using different cognitive tasks. The Simon task has often been used to compare interference control mechanisms in bilinguals and monolinguals (Bialystok et al., 2005), as well as within bilinguals (categorized based on age of acquisition, language use or proficiency). The Simon task is based on stimulus-response compatibility and assesses the ability to attend to task-relevant nonspatial information (i.e., the color of the stimuli) and to ignore task-irrelevant spatial information (i.e., the stimuli position on the computer screen). In our study, the colored stimuli (yellow or blue boxes) were presented on either the left or the right side of the computer screen. Each color is assigned a response key on one side of the keyboard that is analogous to the stimulus's position on the computer screen. In congruent trials, the response key for the corresponding color was on the same side as the stimulus position; in incongruent trials, the response key was on the opposite side from the stimulus position.

The Simon effect – namely the difference between response times for the congruent and incongruent conditions of the Simon task – has been shown to be smaller in bilinguals than monolinguals (Bialystok et al., 2004, 2005; Blumenfeld & Marian, 2014; Yow & Li, 2015), and this difference is even larger for older adults than for younger adults (Bialystok et al., 2004). However, some studies have reported no differences between bilinguals and monolinguals on the Simon task (Ansaldo et al., 2015; Kirk, Scott-Brown, & Kempe, 2013; Paap & Greenberg, 2013; Prior & MacWhinney, 2010). Similar results – namely either a bilingual advantage or bilingual equivalence in terms of behavioral response time cost – have also been observed with the Stroop task (Bialystok, Craik, & Luk, 2008; Duñabeitia et al., 2015) and the Flanker task (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa et al., 2008). Moreover, functional neuroimaging studies on the neural correlates of the purported bilingual benefits in interference control are limited (Abutalebi et al., 2012, 2015) and sparse regarding the Simon task.

fMRI studies on the Simon task have demonstrated a lack of consensus about the brain areas involved in task performance. Activity has been reported in the anterior cingulate cortex (ACC), the middle frontal gyrus, the inferior parietal cortex, and various frontal and temporal areas (Kerns, 2006; Maclin, Gratton, & Fabiani, 2001; Peterson et al., 2002). The variability of the neural areas related to Simon task performance can be attributed to the confounding variables across populations. Nevertheless, many studies provide only limited information on participant selection, namely number and type of languages known by the participants, socioeconomic status, etc. (Forstmann, Van den Wildenberg, & Ridderinkhof, 2008; Kerns, 2006; Lee, Dolan, & Critchley, 2008; Maclin et al., 2001; Peterson et al., 2002), all of which have been shown to influence cognitive processing. For example, in an fMRI study, Peterson et al. (2002) examined the performance of young bilingual adults (M = 26.5 years) on the Simon task with participants from different ethnic backgrounds (Caucasian, Asian-Americans) who had English as their native language. However, no information was reported on the type and level of the second languages spoken by participants or their socioeconomic status. The fMRI data showed that performance on the Simon task significantly activated the dorsolateral prefrontal cortex (BA 46), the ACC (BA 24 and 32), the supplementary motor area (BA 6), the visual association area (BA 19), the inferior temporal area (BA 37), and parietal (BA 40) and frontal areas (BA 44). Forstmann et al. (2008) reported quite different areas of activation for the Simon task, namely the superior parietal lobe, the middle occipital gyrus, the inferior parietal lobe, the inferior precentral sulcus, the superior temporal gyrus and sulcus calcarinus. Like in the Peterson's et al. study, no information was provided on the participants' linguistic background. Unlike the mentioned previous studies, Kerns (2006) highlighted the role of the ACC, the inferior parietal cortex and the middle frontal gyrus in the Simon task by observing the effect of a conflict in the previous trial on performance in the current trial. Thus, Kerns highlighted the global effect of cognitive control by post-trial adjustments induced by the ACC, which triggers the prefrontal cortex to minimize conflict. In distinguishing between the Stroop and Simon tasks using fMRI paradigms, several authors have highlighted the role of preprogrammed and hard-wired visuospatial-motor circuitry (Liu, Banich, Jacobson, & Tanabe, 2004; Peterson et al., 2002). In particular, Liu et al. (2004) account for the specific role of posterior processing regions in the middle occipital and inferior temporal cortices in attentional control. The only study carried out on bilinguals' performance on the