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Neural bases of language switching in high and early proficient bilinguals

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ABSTRACT

The left inferior frontal cortex, the caudate and the anterior cingulate have been proposed as the neural origin of language switching, but most of the studies were conducted in low proficient bilinguals. In the present study, we investigated brain areas involved in language switching in a sample of 19 early, high-proficient Spanish–Catalan bilinguals using a picture naming task that allowed contrasting switch and non-switch trials. Compared to the non-switching condition, language switching elicited greater activation in the head of the left caudate and the pre-SMA/ACC. When the direction of the switching was considered, the left caudate was more associated with forward switching and the pre-SMA/ACC with backward switching. The discussion is focused on the relevance of these brain structures in language control in early, high-proficient bilinguals, and the comparison with previous results in late bilinguals.
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1. Introduction

The neural implementation of a bilingual's two languages has been the focus of an important amount of research (Abutalebi, 2008; Indefrey, 2006 for two extensive reviews). However, neuroimaging data on this issue have often lacked information regarding the age of acquisition, the degree of proficiency, and the degree of exposure to a given language of the tested sample, possibly creating confounds in the interpretation of the results (Abutalebi, Tettamanti, & Perani, 2009). It is the aim of the present study to bring new experimental evidence about the neural substrates of language control in speech production in early and high-proficient bilinguals.

High-proficient bilinguals are able to produce and understand complex sentences in a language different from their own mother tongue. In early bilinguals, this ability develops since early childhood, and can be retained and practiced during adulthood. Furthermore, in some sociolinguistic contexts such as the Spanish communities, where Catalan is spoken, there are often bilingual conversations, in which the two languages are concomitantly used according to the interlocutor. This situation leads to a life-long experience with language switching in individuals with a high proficiency in both languages, an activity that it is at the core of language control. The sample of bilinguals explored in our study corresponds to this sort of speakers, namely, individuals that have been exposed to two languages very early in life, use the two of them on everyday basis, and have a very good command in both of them.

The issue of the neural underpinnings of language control has captured the attention of quite a few studies (Crinion et al., 2006; Price, Green, & von Studnitz, 1999; see Abutalebi, 2008, for a review). When considering these studies, irrespective of whether they involve comprehension or production processes, it appears that the language control network involves frontal and prefrontal areas, left inferior and superior parietal cortices, ACC, and the caudate nucleus. These areas have been shown to support general executive control processes (Dehaene & Changeux, 1991; Desimone & Duncan, 1995; Miller & Cohen, 2001). Beyond this general approach, it is important to asses how this general network may be differentially engaged during comprehension or production processes. This is because the involvement of the speaker in language switching in production and comprehension is very different. In production, the speaker is the one that decides whether or not (and when) to switch languages, and hence the switching performance is mostly pro-actively driven. In contrast, in comprehension the listener is a passive receptor of language switching, and hence the switching performance is mostly re-actively driven. In the present study we focus on the bilingual language control system in speech production.

Perhaps the most used paradigm to explore the cognitive mechanisms behind bilingual language control in speech production is

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the language switching paradigm (Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006; Gollan & Ferreira, 2009; Meuter & Allport, 1999), where participants are asked to name pictures in both of their two languages in an intermixed fashion. The language in which a given stimulus has to be named is prompt by a cue; leading to two types of trials: (a) trials in which a response has to be given in the same language as in the immediately preceding trial (non-switch trials) and (b) trials in which the language of the response is different from the one used in the immediately preceding trial (switch trials). The difference in performance between switch and non-switch trials is commonly referred to as the language switch cost. From the behavioural aspect of this research, an important difference associated with language proficiency arises: while low proficient bilinguals show asymmetrical switching costs (a larger cost when switching into L1 – backward switching – than when switching into L2 – forward switching–), early and high-proficient bilinguals show symmetrical switching costs (the same cost when switching into L1 or L2) (Costa & Santesteban, 2004; Costa et al., 2006). This different pattern of switching costs (symmetrical vs. asymmetrical) has been interpreted as revealing a qualitative shift in the cognitive mechanisms responsible for bilingual language control, linked to an increase in proficiency in the non-dominant language (but see: Christoffels, Firk, & Schiller, 2007).

The qualitatively different performance in the language switching task of low and high-proficient bilinguals prompts the hypothesis that the neural circuits sustaining language control in speech production might also be influenced by second language proficiency. Present data, however, do not allow us to answer this issue. This is because most of the research on the neural basis of language switching either involved L2 learners (or late proficient bilinguals; e.g., Abutalebi et al., 2008; Crinion et al., 2006; Price et al., 1999) or made use of language comprehension tasks. Hence, we lack the necessary set of data informing us about whether language proficiency affects the neural substrates of bilingual language control in speech production. It is the goal of the present study to provide some of this data.

Nevertheless, we do have some information about the neural correlates of language switching in speech production in low proficient bilinguals. In Wang, Xue, Chen, Xue, and Dong (2007) study, language switching (irrespective of the switch direction) yielded activations in the left superior and medial prefrontal cortex, and the right caudate. However, there were instructive differences associated with the switching direction. Activations in the left ACC and medial prefrontal areas were associated with forward switching (from L1 to L2), whereas increases of activity in right parahippocampus, left cerebellum, and thalamus were observed for backward switching (from L2 to L1). In a subsequent study, Wang, Kuhl, Chen, and Dong (2009) were able to confirm the involvement of the left superior and medial prefrontal cortex in language switching. However, they failed to detect any involvement of subcortical structures, rendering the role of the caudate in language control in speech production controversial.

Beyond this controversy, our knowledge of what are the specific processes sustained by each brain area during language control is still limited (see Abutalebi & Green, 2007; Wang et al., 2009, for a discussion of this issue). In this respect, it is useful to bring up the distinction between sustained and transient control processes. According to a recent study by Wang et al. (2009) (see also Christoffels et al., 2007) sustained language control, as indexed by the difference in naming situations in which one language is only used and those in which the two languages are at play, would involve bilateral frontal executive regions. In contrast, transient language control, as indexed by the difference between switch and non-switch trials, would involve a more left lateralized fronto-parietal executive network. In the present study, we are interested in evaluating the brain circuits involved in this transient language control, in early and high-proficient bilinguals. Consequently, we will use a design in which the two languages are intermixed in the same testing session, therefore avoiding any effects of sustained language control.

To recapitulate, our study intends to complement and extend Wang et al.'s results by exploring the language control system put at play during the production of speech by early and very high-proficient bilinguals with wide experience in both languages from birth. We do so by analysing the neural correlates associated with language switching in overt speech production. Given that this type of bilinguals, in comparison to late and low proficient bilinguals, exhibit a different pattern of behavioural switching costs (symmetrical vs. asymmetrical), it is reasonable to expect differences in the brain networks associated with language control in the two populations. In particular, we hypothesize that the large differences observed by Wang et al. (2007) between forward and backward switching, will be different in the case of high and very early proficient bilinguals.

2. Methods

2.1. Subjects

A total of 19 right-handed university students at the University Jaume I of Castelló were selected for this study: 7 males (mean age 20.3 years, s.d. 2.3, range 18–23) and 12 females (mean age 20.3, s.d. 2.4, range 17–24). The subjects gave written informed consent to the experiment, according to the ethical protocol of the University. Participation in this experiment was monetarily rewarded. All candidates underwent a preliminary interview to ensure they had no physical or psychological impairments, and were asked to answer a questionnaire regarding their personal and familiar language history, followed by an interview on the same topic. Language proficiency and age of acquisition of the two languages (Spanish and Catalan) was evaluated using self-reported measures and personal interviews.

Age of acquisition was derived from a self-reported questionnaire that contained questions regarding the frequency of use of each language at various ages starting from early life (1 = only Spanish, 7 = only Catalan). This questionnaire was structured into four main categories and three sub-categories: before primary school, primary school age (at school, home, free time), secondary school age (at school, home, free time), adult age (at work/university, home, free time), and the corresponding questions were intended to assess the extent of early and continuous practice with Catalan and Spanish. All participants had learned both languages and had sufficient experience with them during the first four years of life: 11 bilinguals learned one language at home and the other in kindergarten (started before 18 months), whereas the rest of the bilinguals spoke in one language to their mother and in the other to their father. Despite this early and continued exposure participants showed preferences for one of their languages. We took their preferences to establish the L1 (or dominant) and L2 (or non-dominant) of the participants (11 participants preferred Catalan and 8 Spanish).

Subjects self-rated their language proficiency on a four-point scale (1 = "very non-proficient," 4 = "very proficient") in four different domains: listening, reading, speaking and writing. Given the very extensive and early bilingual experience, participants rated 4 on all these domains in both Spanish and Catalan. It is important to note that these participants received bilingual schooling for at least 13 years. This bilingual schooling does not mean that Catalan (or Spanish) was taught as a foreign language. Rather, what it means is that different topics (e.g., maths, social sciences,

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