CORTEX 49 (2013) 905–911

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Note

# Language proficiency modulates the engagement of cognitive control areas in multilinguals

*Jubin Abutalebi* [a,b], *Pasquale A. Della Rosa* [a], *Guosheng Ding* [c], *Brendan Weekes* [b], *Albert Costa* [d] and *David W. Green* [e,*]

[a] *Vita-Salute San Raffaele University and San Raffaele Scientific Institute, Milan, Italy*
[b] *Division of Speech and Hearing Sciences, University of Hong Kong, Hong Kong*
[c] *State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, China*
[d] *Universitat de Pompeu Fabra & ICREA, Barcelona, Spain*
[e] *Cognitive, Perceptual and Brain Sciences, University College London, United Kingdom*

ARTICLE INFO

*Article history:*
Received 29 March 2012
Reviewed 15 June 2012
Revised 3 July 2012
Accepted 22 August 2012
Action editor Roberto Cubelli
Published online 1 September 2012

*Keywords:*
Bilingual
Cognitive control
Language control
Multilingual
Language switching

ABSTRACT

Language proficiency should modulate the regions involved in language control in predictable ways during language switching. However, prior studies reveal inconsistent effects on the regions involved in language monitoring [pre-Supplementary Motor Area/Anterior Cingulate Cortex (pre-SMA/ACC)] and language selection (left caudate) conceivably because variations in relative proficiency are confounded with other between-group differences. We circumvented this problem in an fMRI (functional Magnetic Resonance Imaging) study of overt picture naming in trilingual participants. In this case, the difference between a high-proficient and a low-proficient further language can be assessed within subjects with no between-group confound. We also used a monolingual group to assess the neural correlates of switching between two categories of response within the same language.

We report a novel result: relative language proficiency dissociates response of the pre-SMA/ACC and left caudate during language switching. Switching between languages increased pre-SMA/ACC response regardless of proficiency differences. By contrast, left caudate response did vary with proficiency differences. Switching from the most to the least proficient language increased the response. Within-language switching, as contrasted with between-language switching, elicited a comparable increase in pre-SMA/ACC response but a decrease in left caudate response. Taken together, our data support a wider role of pre-SMA/ACC in task monitoring and establish the critical role of the left caudate in the selection of the less proficient language in language switching.



## 1. Introduction

Language use and cognitive control are intimately related in bilingual language processing. For successful communication bilinguals have to control their two languages in order to select the correct language for use and to avoid unwanted interference from the language not in use. Bilinguals achieve this feat by engaging brain areas closely related to cognitive

* *Corresponding author*. Cognitive, Perceptual and Brain Sciences, University College London, Gower Street, London WC1E 6BT, UK.
E-mail address: d.w.green@ucl.ac.uk (D.W. Green).
0010-9452/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cortex.2012.08.018

control such as the pre-Supplementary Motor Area/Anterior Cingulate Cortex (pre-SMA/ACC), prefrontal cortex and the left caudate (Abutalebi and Green, 2007). The relative demand on each region relates to its cognitive function. The pre-SMA/ACC is important for monitoring the language context, for detecting conflict and for avoiding errors that may arise during language selection. Prefrontal regions are implicated in the top-down control required for selecting the correct language and eventual error correction (Hernandez, 2009) whereas the left caudate is more specifically implicated in selecting the intended language (Crinion et al., 2006). Indeed, lesions to the left caudate and the prefrontal regions may lead to errors in language selection such as pathological language switching in bilinguals (Abutalebi et al., 2000).

The activation of the regions in the language control network might be expected to vary as a function of language proficiency. This issue can be addressed in the language switching paradigm in which participants name pictures in each of their two languages in an intermixed fashion contingent on a specific cue (see for review, Luk et al., in press). In this paradigm we would expect that switching into a less proficient language would increase demand on the left caudate and so increase its activation. If ACC activation reflects conflict or error avoidance then it too would show an increase on switching to the less proficient language. Alternatively if the region monitors language context, activation would increase on a switch trial but not as a function of language proficiency. However results to date using this paradigm present an inconsistent picture. One reason is that differences in relative language proficiency are confounded by other between-group differences. In a study with highly proficient Spanish–Catalan bilingual speakers, Garbin et al. (2011) reported that switching into the first language (L1) elicited greater activation only in the pre-SMA/ACC complex, while switching into the second language (L2) engaged the left caudate. In contrast, in a study with low proficiency Chinese–English bilingual speakers, Wang et al. (2007) recorded no engagement of the caudate and ACC activation only when bilinguals switched into the low-proficient L2.

In this study, we aimed to achieve a better characterization of the response of critical regions in the language control network during language switching. Instead of using bilinguals, we studied language switching in early multilingual speakers. With such participants, we can investigate within subjects how a difference in relative proficiency for the two further languages alters the response of these regions. We compared the neural response to switching to a high-proficient L2 relative to L1 and the response to switching to a lower-proficient third language (L3) relative to L1. Moreover, we also compared neural response to language switching in our multilinguals with the neural response to a within-language switching task in a group of monolinguals. This comparison allowed us to explore the selectivity of neural response to between-language switching.

## 2. Materials and methods

Participants in the study comprised 14 healthy right-handed multilinguals (German–Italian–English) and 14 healthy right-handed Italian speaking monolinguals matched for socio-economic background, education and age (mean = 23.35 years, SD = 4.5). All were female with normal or corrected-to-normal vision. All multilinguals were from South Tyrol. They learned German from birth as their L1. They attended school from age six and were taught in German and Italian and so they learned Italian from age six. All participants also had a reasonable mastery of English (L3) which they learned at around the age of eight. We investigated language proficiency with translation tasks (see Abutalebi et al., 2007). For L1 and L2, subjects translated 81.1% of words correctly from L1 into L2 and 74.2% of words correctly from L2 to L1. Translation from L1 into L3 and L3 to L1 yielded lower accuracy rates of 64.8% and 69.2%, respectively. Hence, L2 was classified as a high-proficient and L3 as a medium-proficient language (see Supplemental material for demographic data). There was no significant correlation between AoA (Age of acquisition) and test performance for translation into L2 ($R = -.223$; $p = .444$) or into L3 ($R = -.328$; $p = .252$).

The investigation was approved by the Ethics Committee of the University San Raffaele and informed consent was obtained from participants.

### 2.1. Task and procedures

Participants (multilinguals and monolinguals) performed an overt picture-naming task (see Fig. 1A for details) with two runs for each naming context. For the multilinguals the order of presenting the two contexts (L1–L2 and L1–L3) was counterbalanced over participants. For all languages, 32 different pictures (8.5 × 8.5 cm) were selected from the Snodgrass and Vanderwart (1980) set. Each picture was repeated three times for each language across the conditions, totaling 96 stimuli in each of the two contexts for multilinguals and the single context for monolinguals. Four pre-randomized lists were created defining the order in which the stimuli appeared. All stimuli were checked for frequency and syllable length in each language, based on the norms for each of the languages (German: Genzel et al., 1995; Italian: Laudanna et al., 1995; English: Leech et al., 2001). Pictures with cognate names were excluded.

Each picture was displayed for 2 sec, followed by an ISI (Inter-Stimulus Interval) of 1880, 3550, or 4950 msec for the purposes of optimizing statistical power.

Trials could be switch trials or non-switch trials. For the multilinguals, these were defined by the language required on the prior trial. It was a switch trial if a picture-to-be-named was preceded by one named in a different language and a non-switch trial if a picture-to-be-named was preceded by one named in the same language. In total there were 48 switch trials (for each language) and 48 non-switch trials (for each language) in each experimental context. Switch trials could occur in an unpredictable manner.

For monolinguals, switch and non-switch trials were defined by whether the same or a different category of naming response (noun or verb) was required on the current compared to the preceding trial. Again there were 48 switch and 48 non-switch trials. Our analysis concerned trials on which pictures were named with a noun (noun naming trials) to match the response of multilingual speakers in their L1.