Brain and Language 175 (2017) 57–63

Contents lists available at ScienceDirect

Brain and Language

journal homepage: www.elsevier.com/locate/b&l

Anterior cingulate cortex sulcation and its differential effects on conflict monitoring in bilinguals and monolinguals

Arnaud Cachia[a,b,c,d], Nicola Del Maschio[e], Gregoire Borst[a,b,c], Pasquale Anthony Della Rosa[e], Christophe Pallier[f], Albert Costa[g], Olivier Houdé[a,b,c], Jubin Abutalebi[e,*]

[a] Laboratory for the Psychology of Child Development and Education, Sorbonne, CNRS UMR8240, Paris, France
[b] Paris Descartes University, Sorbonne Paris Cité, Paris, France
[c] Institut Universitaire de France, Paris, France
[d] Biomarkers of Brain Development and Disorders, Center of Psychiatry and Neurosciences, INSERM UMR894, Paris, France
[e] Centre for Neurolinguistics and Psycholinguistics, University Vita-Salute San Raffaele and Scientific Institute San Raffaele, Milano, Italy
[f] Cognitive Neuroimaging Unit, CEA DSV/I2BM, INSERM, Université Paris-Sud, Université Paris-Saclay, NeuroSpin Center, Gif-sur-Yvette, France
[g] Universitat de Pompeu Fabra, Barcelona & ICREA, Spain

ARTICLE INFO

Keywords:
Bilingualism
Cognitive control
MRI
ACC
Sulcal pattern
Paracingulate sulcus
Neurodevelopment

ABSTRACT

The role of the anterior cingulate cortex (ACC) in modulating the effect of bilingual experience on cognitive control has been reported at both functional and structural neural levels. Individual differences in the ACC sulcal patterns have been recently correlated with cognitive control efficiency in monolinguals. We aimed to investigate whether differences of ACC sulcation mediate the effect of bilingualism on cognitive control efficiency. We contrasted the performance of bilinguals and monolinguals during a cognitive control task (*i.e.*, the Flanker Task) using a stratification based on the participants' ACC sulcal features. We found that performance of the two groups was differentially affected by ACC sulcation. Our findings provide the first evidence that early neurodevelopmental mechanisms may modulate the effect of different environmental backgrounds – here, bilingual vs monolingual experience – on cognitive efficiency.

1. Introduction

Monitoring cognitive conflicts induced by distracting information from either external or internal sources is a core executive function required by everyday life. The anterior cingulate cortex (ACC) has been indicated as a key structure in the neural circuit mediating domain-general cognitive control processes such as goal maintenance, conflict monitoring, error detection and response inhibition (Botvinick, Cohen, & Carter, 2004; Carter, Botvinick, & Cohen, 1999; Petersen & Posner, 2012).[1] The demand for monitoring conflicting information is also evident in bilingual individuals, who must select one language for communication avoiding interference from the language not in use (Abutalebi & Green, 2007). The study of bilingual language processing thus provided a chance to test whether the neural mechanisms mediating language control are shared with more general cognitive control functions. Functional neuroimaging investigations have shown that the ACC is recruited when bilinguals perform both linguistic and non-linguistic conflict tasks, indicating the ACC as a critical component of the neural network underpinning conflict monitoring, whether in verbal or non-verbal domains (Abutalebi et al., 2012; Branzi, Della Rosa, Canini, Costa, & Abutalebi, 2016; Crinion et al., 2006; Hernandez, 2009). It has been suggested that bilinguals may have a so-called "cognitive advantage" over monolinguals on tasks that require attention, memory and cognitive control in terms of differences in response times (RTs) (see Valian, 2015, for a review). For instance, faster RTs for bilingual speakers have been reported on the Attention Network Test (ANT) (Costa, Hernández, & Sebastián-Gallés, 2008; Luk, De Sa, & Bialystok, 2011), the Simon task (Bialystok, Craik, Klein, & Viswanathan, 2004; Linck, Hoshino, & Kroll, 2008), the Stroop (Bialystok, Craik, & Luk, 2008; Heidlmayr et al., 2014) and other conflict-related tasks (see Bialystok, Craik, & Luk, 2012, for a review). These effects tend to be more robust in children and seniors although

* Corresponding author at: Centre for Neurolinguistics and Psycholinguistics, University Vita-Salute San Raffaele and Scientific Institute San Raffaele, Via Olgettina 60, 20132 Milano, Italy.
E-mail address: abutalebi.jubin@hsr.it (J. Abutalebi).

[1] Cognitive control may be characterized as a multi-componential construct comprising a range of mechanisms that support flexible, goal-directed behavior by representing task-relevant information in order to guide thought and action (Yeung, 2013). Following common practice in the literature, we will use the terms "cognitive control", "executive control" and "executive function" interchangeably.

http://dx.doi.org/10.1016/j.bandl.2017.09.005
Received 10 February 2017; Received in revised form 13 September 2017; Accepted 25 September 2017
0093-934X/

they are not exclusive to these groups (Zhou & Krott, 2016). One popular account of the putative bilingual advantage is that the simultaneous management of multiple languages provides bilinguals with enhanced executive control abilities, due to continuous monitoring for potential cross-linguistic interference (Kroll & Bialystok, 2013). However, it should be underlined that evidence on bilingual advantage has been challenged in recent years, as an increasing number of behavioral studies reported null or negative differences in executive control performance between bilingual and monolingual speakers (e.g. Antón et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2014; see, for a review, Hilchey & Klein, 2011). These inconsistent findings have led some to question the veracity of the bilingual advantage (Paap, Johnson, & Sawi, 2015), which is currently the basis of a lively debate in the field of bilingual studies (Bak, 2016; Bialystok, Kroll, Green, MacWhinney, & Craik, 2015; De Bruin, Treccani, & Della Sala, 2015). Mixed results across studies may be due to a range of different factors. For instance, Prior and Gollan (2011) claim that language background variability of bilingual speakers makes the bilingual advantage elusive, while Valian (2015) argues the bilingual advantage may depend on age and notes that it is more common in seniors (see also Bialystok et al., 2004; Zahodne, Schofield, Farrell, Stern, & Manly, 2014). On the other hand, one factor that has never been considered is the role of individual cortical fold patterns such as ACC sulcal patterns in modulating the effect of bilingualism on conflict monitoring. ACC sulcation is an indirect marker of early brain development determined in utero and not affected by neuroplastic processes like brain maturation (Cachia et al., 2016) or cognitive training (e.g. forced use of the right hand in left handers, see Sun et al., 2012). The effects of ACC sulcation on conflict monitoring in bilingual and monolingual speakers will be tested in the present study. In addition to functional activation during cognitive control tasks, the role of the ACC in conflict information processing has been suggested by the identified relationship between differences in adults' cognitive control efficiency and inter-individual variation in the ACC's quantitative morphology, as measured by structural brain imaging (cortical thickness: Westlye, Grydeland, Walhovd, & Fjell, 2011; cortical surface area (CS): Fjell et al., 2012; gray matter volume (GMV): Takeuchi et al., 2012). For instance, Abutalebi et al. (2012) combined functional and structural neuroimaging to examine whether bilingualism induces beneficial neuroplasticity both at a functional and structural level. When compared to monolinguals on a cognitive control task (*i.e.* the Flanker task), less activity in the dorsal ACC was detected for the bilingual group, suggesting that bilinguals used ACC more efficiently than their monolingual peers to monitor nonlinguistic cognitive conflicts. Interestingly, although bilinguals activated the ACC less than monolinguals already in the first session of the Flanker task, in the second session they showed a radical decrease in signal in the dorsal ACC, while the monolingual group did not. This activation pattern correlated with the conflict effect scores observed in behavioral data, indicating that bilinguals adapted better to conflicting situations than monolinguals. Moreover, a negative correlation was detected in bilinguals between ACC activity and local GMV, as increased gray matter in the dorsal ACC was significantly associated with lower ACC activation. These findings have been interpreted as a result of the beneficial neuroplastic effects induced by life-long bilingual experience. However, quantitative measures of cortex anatomy like thickness and GMV are known to be affected by brain maturation (Giedd & Rapoport, 2010) and learning (Draganski et al., 2004, 2006; Hyde et al., 2009) both during the course of development and later in life. Accordingly, these state markers cannot provide information on the potential role played by early neurodevelopmental characteristics in modulating the effect of bilingual experience on conflict monitoring. Such information, on the other hand, can be provided by the cortical sulcation, a qualitative anatomical feature which is stable from childhood to adulthood irrespective of brain maturation and experience-related factors (Cachia et al., 2016; Sun et al., 2012). Individual differences in the ACC sulcal pattern have been recently correlated with cognitive control efficiency both in monolingual children (Borst et al., 2014; Cachia et al., 2014) and adults (Huster et al., 2009). Interference scores from a Stroop task performed by participants with symmetrical vs asymmetrical ACC sulcal patterns showed a significant cognitive advantage for participants, either children or adults, with asymmetrical ACC sulcal patterns (*i.e.* lower RT scores in participants with asymmetrical ACC sulcation). If these results seem to underscore the critical role of neurodevelopmental factors assessed by qualitative features of brain anatomy on human executive abilities, the possible interaction with experience in terms of learning/training effects on cognitive control efficiency remains incompletely understood.

In this context, the present study uses high resolution magnetic structural imaging (MRI) to investigate whether the ACC sulcation modulates the effects of bilingual experience on conflict monitoring. The behavioral and structural MRI data used in this study are from Abutalebi et al. (2012). However, a different set of analyses was performed on existing data in order to assess new factors.

2. Material and methods

2.1. Participants

Thirty-one healthy right-handed participants from Abutalebi et al. (2012) were included in the study. Participants comprised 17 highly-proficient German–Italian bilinguals (all females; mean age: 23.35, standard deviation [SD] ± 4.59) and 14 Italian monolinguals (all females; mean age: 26.55, SD ± 4.15) with a comparable educational and socio-economical background. Individuals with a history of psychiatric care, neurological disease or head injury were excluded. Bilinguals came from South Tyrol, a bilingual region in Italy in which German and Italian are official languages. For all bilinguals German was the first and dominant language (*i.e.*, L1), whereas Italian was the second language (*i.e.*, L2) acquired at kindergarten age and regularly spoken in the bilingual environment of South Tyrol. Participants' language proficiency was assessed with translation tasks (see Abutalebi et al., 2012, for details and results). Monolingual participants were from mainland Italy.

The study was approved by the University Vita-Salute San Raffaele Research Ethics Committee and carried out in compliance with their guidelines. Written informed consent was obtained from all participants.

2.2. Behavioral assessment

All participants (bilinguals and monolinguals) performed a revised version of the Flanker Task (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) divided into two sessions to investigate adaptive changes in each group. Participants performed the task on a computer screen using an external mouse. A fixation point appearing at the center of the screen for 400 ms was followed by a target, *i.e.* a central arrow presented foveally on the screen for 1700 ms, pointing to left or right. Targets were presented in congruent, incongruent or neutral conditions, *i.e.* with additional arrows flanked to the same direction as the target (→→→→→), with additional arrows flanked to the opposite direction of the target (←←→←←) or with additional neutral lines (– – → – –). Participants were instructed to press the left or the right button of the mouse as quickly as possible depending on whether the target pointed to left or right, respectively. Accuracy and RTs were recorded. Whereas the neutral lines surrounding the target typically bias neither the correct nor the incorrect response, the incongruent flankers represent conflicting information with the correct response and are generally associated with decline in performance, *i.e.* lower accuracy and increasing RTs. By contrast, congruent flankers favor the correct response and are generally associated with better performance, *i.e.* higher accuracy and lower RTs. Target stimuli appeared either above or below a fixation cross that remained at the center of the screen during the whole trial and could be preceded or not by visual cues (no