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Brain potentials predict language selection before speech onset in bilinguals

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ABSTRACT

Studies of language production in bilinguals have seldom considered the fact that language selection likely involves proactive control. Here, we show that Chinese-English bilinguals actively inhibit the language not-to-be used before the onset of a picture to be named. Depending on the nature of a directive cue, participants named a subsequent picture in their native language, in their second language, or remained silent. The cue elicited a contingent negative variation of event-related brain potentials, greater in amplitude when the cue announced a naming trial as compared to when it announced a silent trial. In addition, the negativity was greater in amplitude when the picture was to be named in English than in Chinese, suggesting that preparation for speech in the second language requires more inhibition than preparation for speech in the native language. This result is the first direct neurophysiological evidence consistent with proactive inhibitory control in bilingual production.

1. Introduction

Even when bilinguals function in one language, lexical representations of the other language are simultaneously active (Miwa, Dijkstra, Bolger, & Baayen, 2014; Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011; Thierry & Wu, 2007; Wu & Thierry, 2010a, 2010b). However, the cognitive mechanism that enables bilinguals to keep their languages functionally separate and operate in a seemingly monolingual fashion has not yet been elucidated. One hypothesis, the Inhibitory Control Model, poses that, in order to prevent cross-language interference, a control mechanism in the bilingual brain inhibits activation of non-target language representations allowing representations of the target language to reach the critical levels of activation required for speech production (Green, 1998). Evidence for such cross-language competition comes from picture-word interference studies in which bilinguals are generally asked to name a picture superimposed with a printed word. Indeed, when the word is semantically related to the picture but presented in a different language from that of the production language, naming latency is delayed (Costa & Caramazza, 1999; Hermans, Bongaerts, de Bot, & Schreuder, 1998). Also, when bilinguals switch between their two languages during a naming task, it takes longer to switch into their more dominant than into their less dominant language (Meuter & Allport, 1999). Both sources of evidence suggest that lexical representations of the non-target language are actively inhibited to resolve competition between the two languages (as is the case in picture-word interference) or to deliver monolingual production in the target language (as is the case in language-switching).

Consistent with this hypothesis, functional neuroimaging studies of bilingual language production have repeatedly highlighted increased activation in left dorsolateral prefrontal cortex (DLPFC), anterior cingulate cortex (ACC), caudate nucleus, and bilateral supramarginal gyri (Abutalebi & Green, 2007; Abutalebi et al., 2008; Crinion et al., 2006), that is, in brain regions critically involved in domain-general executive function such as response selection and inhibition (Aron, 2008; Grahn, Parkinson, & Owen, 2008) and conflict monitoring (Botvinick, Cohen, & Carter, 2004).

In the same vein, event-related brain potential (ERP) studies have provided evidence in support of parallel lexical access during bilingual language production (Hoshino & Thierry, 2011; Rodriguez-Fornells et al., 2005; Spalek, Hoshino, Wu, Damian, & Thierry, 2014; Wu & Thierry, 2011) and inhibitory control (Kroll, Bobb, Misra, & Guo, 2008; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006). Rodriguez-Fornells et al. (2005), for example,

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reported a negative-going ERP variation in fluent bilinguals performing a tacit naming task (i.e., judging whether a picture name begins with a vowel or a consonant), which the author interpreted as a correlate of the interference caused by the activation of the non-target language. The temporal characteristics and topography of this effect were comparable to that of the N200, a peak of ERPs classically modulated by executive control demands (Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Kopp, Rist, & Mattler, 1996) and associated with activation of the anterior cingulate cortex in relation to response suppression (Huster, Westerhausen, Pantev, & Konrad, 2010; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). These results are overall consistent with the hypothesis that language production in bilinguals involves the inhibition of unintended language representations via a cognitive control mechanism probably shared with generic executive control systems.

However, unlike reading and listening, speaking is primarily intentional and likely involves greater top-down control driven by conceptualization (i.e., the state of the semantic system) and proactive language selection (e.g., Strijkers & Costa, 2016a; Strijkers, Holcomb, & Costa, 2011). In real life circumstances, bilinguals arguably select the language to speak on the basis of non-linguistic, contextual variables (e.g., the interlocutor's preferred language) and implement speech production in a goal-oriented rather than a bottom-up fashion. Nevertheless, previous studies investigating the cognitive mechanisms underlying language production in bilinguals have mostly focused on linguistic or meta-linguistic tasks such as picture naming, language-switching, and translation (Morales, Yudes, Gómez-Ariza, & Bajo, 2015; Runnqvist et al., 2011; Strijkers, Baus, Runnqvist, FitzPatrick, & Costa, 2013). Some of these studies have measured brain and/or behavioural responses after a stimulus is presented (e.g., Branzi, Della Rosa, Canini, Costa, & Abutalebi, 2016; Hervais-Adelman, Moser-Mercer, Michel, & Golestani, 2015), giving surprisingly little attention to the fact that the human brain not only functions reactively but also proactively and is indeed prone to prediction and anticipation (Federmeier & Kutas, 1999; Martin et al., 2013; Strijkers, 2016).

Luk, Green, Abutalebi, and Grady (2012) put forward the hypothesis that early activation in response to a cue may be sufficient to trigger proactive control in bilinguals. More recently, a few studies have reported evidence in support of multiple processing components being engaged, but the corresponding stage of processing and the mechanisms by which inhibition is applied to the non-target language remain to be defined (Branzi, Martin, Abutalebi, & Costa, 2014; Guo, Liu, Misra, & Kroll, 2011; Hanulová, Davidson, & Indefrey, 2011; Kroll, Gollan, Goldrick, Ferreira, & Miozzo, 2014; Misra, Guo, Bobb, & Kroll, 2012; Mosca & Clahsen, 2016; Strijkers & Costa, 2016a; Strijkers et al., 2013; Van Assche, Duyck, & Gollan, 2013). Nevertheless, evidence for inhibition has already been obtained in bilingual comprehension (Martin, Molnar, & Carreiras, 2016).

It thus remains mostly unknown how bilingual speakers prepare for language production. In order to investigate this issue, we examined pre-stimulus electrophysiological activity leading to real-time, overt speech production in bilinguals asked to name pictures. A group of late Chinese-English bilinguals named pictures in Chinese, English, or remain silent depending on the nature of a cue presented one second before the onset of each picture. ERP analysis was focused on the period of time between the onset of the visual cue and that of the stimulus picture. Following the presentation of the cue, we anticipated to observe a progressive negative shift of brain potentials indexing mental anticipation, the so-called contingent negative variation (CNV; (Jacobson & Gans, 1981; Walter, Cooper, Aldridge, McCallum, & Winter, 1964). If language production involves an inhibitory control mechanism that is generic and thus stimulus-independent, we should expect the CNV to index the relative intensity of the inhibition required to control the activation levels of the native and the second language, respectively. This is because, due to differences in proficiency and familiarity between the two languages, inhibiting native language representations likely requires greater processing resources (i.e., executive control) than inhibiting second language ones.

2. Materials and methods

2.1. Participants

Twenty (10 female) Chinese students from Bangor University, UK, aged between 18 and 23 years gave written consent to take part in the experiment that was approved by the ethics committee of Bangor University. They received financial compensation for their time. All participants were right-handed, had normal or corrected-to-normal vision, and reported no neurological problems or language impairments. All participants spoke Mandarin Chinese as their native language and knew no other language apart from English (i.e., they were late Chinese-English bilinguals). They started to learn English at the age of 12 (in secondary school) in a classroom context. Before coming to the UK, they had never stayed in an English-speaking country for any significant period of time. At the time of testing, they had lived in the UK for an average of 25 (±4.5) months and they were using English daily in both their private and academic lives. Their English proficiency, measured by the International English Language Testing System (IELTS) (www.ielts.org/test_takers_information/what_is_ielts.aspx), was 6.5, which is the entrance requirement for most UK institutions as a non-native English student. The IELTS covers four fundamental language skills (i.e., reading, listening, writing, and speaking) and scores can vary between 0 and 9.

2.2. Stimuli

One hundred pictures of common and highly imaginable objects were selected from the stimuli used in Wu and Thierry (2010a, 2010b). None of these pictures were semantically related or rhymed with another picture, either in Chinese or in English. They were controlled for basic visual characteristics such as size, contrast and resolution, and all pictures were presented on a white background. However, they were highly variable in terms of viewpoint, shape, and colour to minimise risk of a systematic bias due to inter-stimulus variance (Thierry, Martin, Downing, & Pegna, 2007). No cultural stereotype was featured to avoid a differential bias between Chinese and English naming (see examples in Fig. 1). No picture was repeated in the experiment.

2.3. Procedure

At the beginning of the experiment, verbal instruction was given to participants who sat on a chair about 100 cm away from a 19″ CRT monitor in a sound-attenuated room with dimmed lighting. Each trial began with a cue presented in the centre of the screen for 500 ms followed by a blank screen for another 500 ms. The visual cues were nonverbal symbols ('+', 'o', and '⊕') that have no specific ties to either of the languages of the participants. The cross and the circle each cued a particular language (English or Chinese), while the combined cue '⊕' indicated that no naming preparation was required (i.e., pictures were suppressed to eliminate potential anticipation or planning of naming in one or the other language). The cue-language correspondence was counterbalanced between participants. Trial order was pseudorandomized and different from one participant to the next. In the naming trials, a pic-