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Bilingualism modulates dual mechanisms of cognitive control: Evidence from ERPs

Julia Morales [a,*], Carolina Yudes [a], Carlos J. Gómez-Ariza [b], M. Teresa Bajo [a]

[a] Brain, Mind and Behavior Research Center, University of Granada, C/Profesor Clavera s/n, 18071 Granada, Spain
[b] Department of Psychology, University of Jaén, Campus las Lagunillas, 23071 Jaén, Spain

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ABSTRACT

Recent behavioral findings with the AX-Continous Performance Task (AX-CPT; Morales et al., 2013) show that bilinguals only outperform monolinguals under conditions that require the highest adjustment between monitoring (proactive) and inhibitory (reactive) control, which supports the idea that bilingualism modulates the coordination of different control mechanisms. In an ERP experiment we aimed to further investigate the role that bilingualism plays in the dynamic combination of proactive and reactive control in the AX-CPT. Our results strongly indicate that bilingualism facilitates an effective adjustment between both components of cognitive control. First, we replicated previous behavioral results. Second, ERP components indicated that bilingualism influences the conflict monitoring, response inhibition and error monitoring components of control (as indexed by the N2 and P3a elicited by the probe and the error-related negativity following incorrect responses, respectively). Thus, bilinguals exerted higher reactive control than monolinguals but only when they needed to overcome the competing cue-information. These findings join others in suggesting that a better understanding of the cognitive benefits of bilingualism may require consideration of a multi-component perspective.

1. Introduction

Extensive training in one specific domain can transfer to other domains that share related cognitive functions (e.g., Bialystok and Depape, 2009; Schellenberg and Moreno, 2004) and can even modulate their supporting neural networks (for a review, Habib and Besson, 2009). A vast number of studies have demonstrated that bilingualism influences cognitive control, as bilingual speakers surpass monolinguals in a variety of non-verbal tasks that involve conflict resolution (Bialystok et al., 2005; Costa et al., 2009; Costa et al., 2008), inhibitory control (Colzato et al., 2008; Lee Salvatierra and Rosselli, 2010), or task switching (Prior and Gollan, 2011; Prior and Macwhinney, 2010), and they also engage differently the same neural circuits to solve these tasks (Abutalebi et al., 2012; Luk et al., 2012). However, the question of how bilingualism modulates the cognitive mechanisms underlying this advantage is still one of intense debate (for a review, Kroll and Bialystok, 2013). By using both behavioral and electrophysiological (event-related potentials—henceforth ERPs) measures, the present study aims to better understand how bilingual experience influences the dynamics and coordination of different control mechanisms.

The rationale for expecting cognitive advantages in bilinguals comes from the bilinguals' need to coordinate two languages in their minds. Present evidence suggests that bilinguals co-activate their two languages even when only one is in use (for reviews, see Bialystok et al., 2009; Kroll et al., 2006). Consequently, they need to continuously employ language selection mechanisms to avoid intrusions and to reduce interference from the unwanted language. These language control mechanisms are thought to be similar to the ones engaged in conflict resolution in non-linguistic domains (Abutalebi and Green, 2007; Bialystok, 2001; Kan and Thompson-Schill, 2004). Thus bilinguals would more efficiently recruit cognitive control resources, relative to monolinguals, becoming more competent in tasks that tap into similar control processes (i.e., ignoring irrelevant information).

According to influential inhibitory models (Abutalebi and Green, 2007; Dijkstra and van Heuven, 1998, 2002; Green, 1998; Van Heuven et al., 2008), language selection occurs once lexical candidates are activated in both languages by means of inhibitory mechanisms that reduce the level of activation of the unintended language. Inhibition is proportional to the level of competition, so that the stronger the activation of competitors in the unintended language, the stronger the inhibition. Inhibition can be targeted globally to the language when the context clearly signals the

* Corresponding author. Fax: +34 958 246239.
E-mail addresses: mjulia@ugr.es (J. Morales), carolina.yudes@unir.net (C. Yudes), cjgomez@ujaen.es (C.J. Gómez-Ariza), mbajo@ugr.es (M.T. Bajo).

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language in use or it can be applied to specific lexical/semantic representations when they get activated in mixed contexts (De Groot and Christoffels, 2006; Guo et al., 2011). From this perspective, language selection is produced by reactive control, a just-in-time manner of resolving interference after detection of competing information. Hence, bilinguals, relative to monolinguals, would excel in tasks that involve conflict resolution produced by competing alternatives, which is compatible with the smaller interference effects found in bilinguals in interference tasks such as the Stroop (Blumenfeld and Marian, 2011; Martin-Rhee and Bialystok, 2008; Tse and Altarriba, 2012; Zied et al., 2004), flanker (Costa et al., 2009, 2008; Tao et al., 2011) or Simon tasks (Bialystok et al., 2005; Bialystok et al., 2004) and to the lower switching cost for bilinguals in verbal and non-verbal switching procedures (Garbin et al., 2010; Prior and Gollan, 2011; Prior and MacWhinney, 2010).

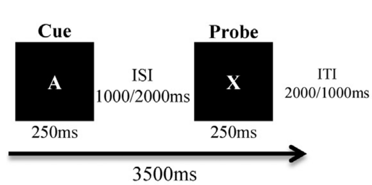
However, superior performance on cognitive control tasks has not always been replicated (see Blumenfeld and Marian, 2013; Hernández et al., 2013; Hilchey and Klein, 2011; Paap and Greenberg, 2013; Tao et al., 2011, for recent reviews) and differences between bilinguals and monolinguals have sometimes been evident in non-inhibitory tasks (e.g., Bialystok et al., 2004; Bialystok et al., 2006; Bialystok and Martin, 2004; Hommel et al., 2011; Kharkhurin, 2010; Luo et al., 2013; Marzecová et al., 2013; Ricciardelli, 1992). These findings bring into question the notion that inhibition is the only mechanism responsible for language control and selection (or, at least, that the use of inhibition in language control transfers to other cognitive domains) and suggest that bilingualism may affect other cognitive processes beyond inhibition.

Recent proposals suggest that monitoring and goal maintenance might also underlie the superiority of bilinguals in attentional tasks (Colzato et al., 2008; Costa et al., 2009). According to this view, proactive control processes (Braver et al., 2007; Braver, 2012) would help bilinguals to cope with interference before it occurs. The selection of the intended language would involve context monitoring for cues to successfully select the proper language for comprehension, production, and maintenance of the intended language until new cues induce a language switch (Costa et al., 2006, 2006; Finkbeiner et al., 2006, 2006; Philipp et al., 2007).

A more integrative view proposes that control might be exerted by a dynamic combination of proactive and reactive executive mechanisms rather than by a single process that would be modulated by demands of the situation (Costa et al., 2006; De Groot and Christoffels, 2006; Festman and Münte, 2012; Green and Abutalebi, 2013; Kroll and Bialystok, 2013; Morales et al., 2013). As recently argued by the adaptive control hypothesis (Green and Abutalebi, 2013), interactive bilingual contexts require that different cognitive control processes act collaboratively to achieve successful communication. Within this framework, individual differences in cognitive control may be better understood by examining the interplay between proactive and reactive control, rather than by proposing simpler hypotheses concerning each of these modes of control.

Accordingly, Morales and colleagues (2013) recently found differential dynamics between proactive and reactive control in early bilinguals and monolinguals, revealed from a modified version of the Continuous Performance Task (CPT, Rosvold et al., 1956), the AX-CPT (see Fig. 1a). This task requires participants to respond YES to every *X* probe preceded by an *A* cue, and to respond NO to any probe that breaks that rule (i.e., BX, AY or BY trials). The AX combination occurs at a very high frequency (70% of the trials), so participants prepare to respond YES after seeing an *A* cue, motivated by proactive control mechanisms. The AX-CPT constitutes an excellent tool to investigate the interactions between proactive and reactive control because, to keep errors to a minimum, it is crucial to adjust both processes according to the task demands by detecting and solving the conflict produced by the unexpected stimulus (Y) that invalidates the previous contextual information (A). Morales and colleagues found that both

a



CUE	PROBE	%	RESPONSE	CONDITION
A	X	70%	Yes	Target trials
A	Y	10%	No	Errors due to **Proactive Control** (cue prepares to «yes» responses)
B	X	10%	No	Errors due to failures in **Reactive Control** (probe induces «yes» responses)
B	Y	10%	No	Control trials (no bias from cue or probe)

b

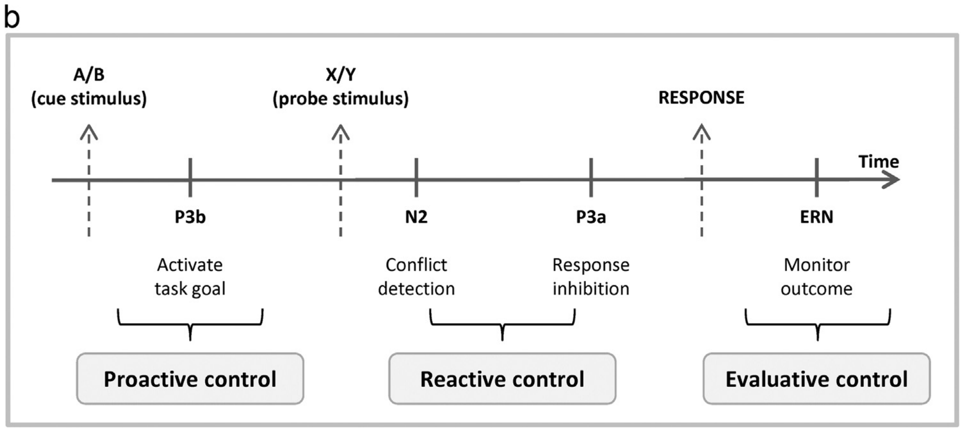


Fig. 1. (a) Schematic representation of the AX-CPT procedure and the four types of trials that conform the task. (b) Schematic overview of the control processes involved in the AX-CPT and their associated ERP components.