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Earlier and more distributed neural networks for bilinguals than monolinguals during switching

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ABSTRACT

The present study investigated processing differences between young adults who were English monolinguals or English-French bilinguals on a task- and language-switching paradigm. The mechanisms responsible for task switching and language switching were investigated using electrophysiological (EEG) measures. In nonverbal task switching, monolinguals and bilinguals demonstrated equivalent behavioral mixing (pure vs. repeat) and switching (repeat vs. switch) costs, but bilinguals were more accurate in the mixed blocks. Bilinguals used a more distributed neural network than monolinguals that captured the nonverbal mixing effect and showed earlier discrimination for the switching effect in the ERPs. In language switching, more distributed networks for bilinguals than monolinguals were found for the switching effect. The scalp distributions revealed more overlap between task switching and language switching for bilinguals than monolinguals. For switch costs, both groups showed P3/LPC modulations in both tasks, but bilinguals showed extended activation to central regions for both switching tasks. For mixing costs, both groups revealed modulations of the N2 but only bilinguals showed extended activation to the occipital region. Overall bilinguals revealed more overlapping processing between task- and language-switching than monolinguals, consistent with the interpretation of integration of verbal and nonverbal control networks during early visual processing for bilinguals and later executive processing for monolinguals.

1. Introduction

Language selection is arguably at the core of bilingual language use and is a key part of the linguistic processing that is unique to bilinguals. As such, processes involved in language selection may be ultimately responsible for the domain-general processing differences found between monolinguals and bilinguals on a range of executive function tasks (for review, see Bialystok, 2017; for meta-analysis on working-memory span, see Grundy and Timmer, 2016). Bilinguals activate the lexical representations of both languages, even in environments in which only one is relevant (Colomé, 2001; Costa et al., 1999; Finkbeiner et al., 2006; Hermans et al., 1998; Martin et al., 2009; Spivey and Marian, 1999; Thierry and Wu, 2007; Timmer et al., 2014a, 2014b; Timmer and Schiller, 2014; Wu and Thierry, 2012), yet they rarely speak in the unintended language (Gollan et al., 2011; Poulisse, 1999). Therefore, bilinguals are able to selectively attend to the target language in the context of the jointly-activated and competing alternatives (Bialystok et al., 2012). To achieve this, a control system is necessary to select the target language without intrusion from the non-target language (Green, 1998), a process that over time leads to enhanced attentional processing for bilinguals (Bialystok, 2015). These attentional and control processes required for language selection are potentially the basis of executive function performance advantages in bilinguals (Bialystok, 2017). Thus, understanding the relation between language control and nonverbal executive control is essential for identifying the mechanisms by which bilingualism is associated with improved outcomes on executive function tasks.

A switching paradigm is ideal for comparing language and nonverbal control processes because the paradigm can be set up in the same manner for both domains with the only difference being the stimulus and response outputs. The current study examined bilinguals and functional monolinguals who had only rudimentary knowledge of a second language, performing both nonverbal and language switching while EEG was recorded. The inclusion of a functional monolingual group offers the opportunity to investigate monolingual-bilingual processing differences in these tasks, and ERPs provide time-sensitive data to identify potential processing differences between language groups and tasks. Evidence from fMRI research with bilinguals indicates that

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Table 1
Summary table of predictions and results.

Task	Condition	Component	Literature	Present study
Nonverbal task switching	Switch cost	N2	Greater N2 for repeat than switch trials	Greater N2 for repeat trials through central to occipital regions in bilinguals. No significant effects for monolinguals (Fig. 4).
		P3/LPC	Greater P3 for switch than repeat trials	Greater P3/LPC for switch trials at central, parietal, and parietal-occipital regions for both groups (Fig. 4).
	Mixing cost	N1	Not discussed in previous literature.	Greater N1 for pure than repeat trials through parietal and occipital region for both groups. This is extended to the frontal region for bilinguals only (Fig. 7).
		N2	Not discussed in previous literature.	Greater N2 for pure than repeat trials through frontal region for both groups. Greater N2 for repeat than pure trials through occipital region for bilinguals (Fig. 7).
		P3/LPC	Greater P3 for pure than repeat trials	Greater P3/LPC for pure than repeat trials through frontal, parietal, and occipital regions for bilinguals. Evident only at occipital regions for monolinguals (Fig. 7).
Language switching	Switch cost	N2	Inconsistent findings in literature	No significant effects (Fig. 9).
		P3/LPC	Greater P3/LPC for switch than repeat trials	Greater P3/LPC for switch trials throughout parietal-occipital regions for both groups but extended to central regions for bilinguals (Fig. 9).
	Mixing cost	N2	Greater N2 for repeat than pure trials	Greater N2 for repeat than pure trials for both groups (Fig. 12).
		P3/LPC	Not discussed in previous literature	Greater P3/LPC for pure than repeat trials throughout parietal-occipital regions for monolinguals. No significant effects for bilinguals (Fig. 12).

similar brain regions are employed during language and nonverbal control (Abutalebi et al., 2013; Abutalebi and Green, 2007; De Baene et al., 2015; Garbin et al., 2010; Kong et al., 2014; Luk et al., 2012). The present study extends these results by including monolingual participants and using ERPs to compare the temporal profiles for processing these tasks for the two language groups.

Central to the examination of performance in switching paradigms is the distinction between switch costs and mixing costs. *Switch costs* are the slower responses for switch trials than repeat trials in a block in which two types of decisions are intermixed (e.g., color and shape decisions for task switching or English and French naming for language switching). *Mixing costs* are the slower responses for repeat trials during a mixed block that includes two decision types than for the same trials in a single task block (for review see Meiran, 2010). Research focusing on differences between monolinguals and bilinguals on nonverbal switching tasks has mainly revealed a smaller switch cost for bilinguals than monolinguals (Garbin et al., 2010; Houtzager et al., 2017; Prior and Gollan, 2011; Prior and Macwhinney, 2010), although some studies have reported reduced mixing costs for bilinguals (Hillman et al., 2006; Wiseheart et al., 2016). Moreover, some studies have shown a relation between frequency of language switching in daily life and accuracy on pure and repeat trials (Soveri et al., 2011). Not all studies have found differences between monolinguals and bilinguals during nonverbal task switching (e.g., Paap et al., 2017; Paap and Greenberg, 2013), but more sensitive measures than reaction time are often needed in populations of young adults who are at ceiling performance (Grundy et al., 2017b). Because of its high temporal resolution, electroencephalography (EEG) is an ideal method to capture processing differences between groups.

The task switching literature explains switch costs in terms of reactivation of decision rules and reconfiguration of the appropriate stimulus-response (S-R) mappings for the new decision rule (Periáñez and Barceló, 2009). Thus, switch costs reflect attending to the cue and remembering the associated rule. If a new rule is activated, the S-R mappings need to be reconfigured to execute the appropriate response (Hernández et al., 2013; Jost et al., 2008; Meiran, 2010; Prior and Macwhinney, 2010).

For language switch costs, several explanations have been proposed. One influential explanation is the inhibitory control model (Green, 1998). This view suggests that every time a concept is named its lexical representation receives a language tag. Lexical representations from the opposite language are then inhibited, increasing the threshold for accessing those representations. On a switch trial, the inhibited language needs to be reactivated, creating a delay in naming. Other explanations do not assign a role to inhibition (Costa et al., 1999; Finkbeiner et al., 2006; La Heij, 2005; Roelofs, 1998; Verhoef et al., 2009). For example, La Heij (2005) suggested that the target language receives additional activation without inhibition of the other language. However, none of these explanations is able to account for all reported results (for review see Declerck and Philipp, 2015). Hence, it is likely that switch costs do not reflect a single process, such as inhibition, but rather indicate several processes that may be different for variants of a switching task (such as language switching and nonverbal switching) and for individuals with different language backgrounds (such as monolinguals and bilinguals). Therefore, to obtain a more complete description of performance on these tasks, we examined the ERP components involved in switching.

ERP studies for switch costs in task switching reveal an N2 component (Moulden et al., 1998; Periáñez and Barceló, 2009; Rushworth et al., 2002) and P3 component (Periáñez and Barceló, 2009). The N2 shows greater negativity for repeat than switch trials, consistent with studies showing greater negativity for less effortful trials as in the repetition of a cue. Cue repetition is a form of sensory priming which can lead to an enduring memory trace for the repeated stimulus (Moulden et al., 1998; Periáñez and Barceló, 2009; Rushworth et al., 2002). In contrast, the P3 shows greater positivity for switch trials than repeat trials and reflects greater working memory required for switch trials