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Language and task switching in the bilingual brain: Bilinguals are staying, not switching, experts

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ABSTRACT

Bilinguals' ability to control which language they speak and to switch between languages may rely on neurocognitive mechanisms shared with non-linguistic task switching. However, recent studies also reveal some limitations on the extent control mechanisms are shared across domains, introducing the possibility that some control mechanisms are unique to language. We investigated this hypothesis by directly comparing the neural correlates of task switching and language switching. Nineteen Spanish–English bilingual university students underwent a functional magnetic resonance imaging (fMRI) study employing a hybrid (event-related and blocked) design involving both color-shape switching and language switching paradigms. We compared the two switching tasks using within-subject voxel-wise *t*-tests for each of three trial types (single trials in single blocks, and stay and switch trials in mixed blocks). Comparing trial types to baseline in each task revealed widespread activation for single, stay, and switch trials in both color-shape and language switching. Direct comparisons of each task for each trial type revealed few differences between tasks on single and switch trials, but large task differences during stay trials, with more widespread activation for the non-linguistic than for the language task. Our results confirm previous suggestions of shared mechanisms of switching across domains, but also reveal bilinguals have greater efficiency for sustaining the inhibition of the non-target language than the non-target task when two responses are available. This efficiency of language control might arise from bilinguals' need to control interference from the non-target language specifically when *not* switching languages, when speaking in single- or mixed-language contexts.

1. Introduction

During natural conversation, bilinguals appear to effortlessly manage activation of two languages, fluently switching between them at will without any obvious difficulty. A current debate in the literature on bilingualism concerns how bilinguals manage to accomplish this skill so seamlessly. Some general consensus has emerged that bilinguals recruit at least some non-linguistic mechanisms of executive control to manage dual-language activation and language switching (Abutalebi and Green, 2007; Gollan and Ferreira, 2009; for review, Bialystok et al., 2009; Hernandez, 2009), but the extent to which non-linguistic mechanisms of executive control are used remains uncertain. While some results suggest completely overlapping control mechanisms across domains, others suggest at least partially unique and specialized mechanisms for language control (e.g., Abutalebi et al., 2008; Prior and Gollan, 2013; Weissberger et al., 2012). The goal of the present study was to investigate this question by comparing the neural underpinnings of linguistic and non-linguistic control using functional magnetic resonance imaging (fMRI) techniques with an eye towards identifying differences between domains that might signal the existence of specialized language control mechanisms.

Evidence that non-linguistic executive control mechanisms are recruited to achieve bilingual language control comes from a growing literature documenting bilingual advantages on non-linguistic tasks of executive function (for review see Bialystok et al. (2009); though recent literature reviews have called this into question, see Paap (2014)). For example, bilinguals exhibited

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reduced Stroop interference effects (e.g., Bialystok et al., 2008) and were faster to resolve response conflict in the Simon Task (Bialystok et al., 2004) and the Attentional Network Task (Costa et al., 2009, 2008) when compared to matched monolinguals.

A topic of particular interest in investigating bilingual language control, and the possible role of executive control, is switching. Non-linguistic task switching is more transparently linked to bilingual language switching than other tasks that have shown bilingual advantages (e.g., Flanker Task). Supporting the notion of a shared "switch mechanism", studies of bilingual switching ability reveal explicit relationships between task switching and language switching (e.g., Prior and Gollan, 2011; Weissberger et al., 2012). In switching paradigms, there are single task blocks (in which participants perform just one task), and mixed task blocks (in which participants are cued to switch between tasks from trial to trial). Within mixed blocks, there are trials in which the individual is cued to switch tasks (switch trial) and trials in which the individual is cued to perform the same task as the preceding trial (stay trial). Studies implementing these paradigms report robust switching costs (comparing switch to stay trials) and mixing costs (comparing stay trials to single-task trials) for both linguistic and non-linguistic tasks (Christoffels et al., 2007; Meuter and Allport, 1999; Rubin and Meiran, 2005), and studies comparing bilinguals to monolinguals on non-linguistic task switching have found a significant reduction in switching, but not mixing costs, for bilinguals (e.g., Prior and Gollan, 2011; Prior and MacWhinney, 2010).

Follow-up studies directly comparing task to language switching suggest some overlap but also some differences in control mechanisms across linguistic and non-linguistic domains (Calabria et al., 2012; Prior and Gollan, 2011; Weissberger et al., 2012). For example, Weissberger et al. (2012) found both similarities and differences between tasks by examining aging effects across the two tasks. Suggestive of shared control mechanisms, a subset of older bilinguals was unable to complete the task switching paradigm at better than chance levels of performance, and these same bilinguals also exhibited greater switching costs during the language switching paradigm than matched controls. However, in support of unique control mechanisms, there was a crossover interaction between age and task such that aging effects appeared to be far greater for non-linguistic than for linguistic switching; whereas young bilinguals responded more slowly on language than on task switching, the reverse was true for older bilinguals.

Another source of evidence comes from fMRI studies, which suggest shared mechanisms between non-linguistic and linguistic control. Such studies reveal apparent overlapping neural circuits responsible for both types of control, though direct comparisons are limited. For example, imaging studies of monolinguals performing task switching, Stroop, and Simon tasks show activation in the dorsal executive system including the prefrontal cortex (PFC), dorsolateral PFC, anterior PFC, parietal cortex, the anterior cingulate cortex (ACC), and the left caudate nucleus (e.g., Braver et al., 2003; Corbetta and Shulman, 2002; Digirolamo et al., 2001; Dosenbach et al., 2006; Fan et al., 2003; Hyafil et al., 2009; Jimura and Braver, 2010; Liu et al., 2004; Lungu et al., 2007; MacDonald et al., 2000; Peterson et al., 2002; Sohn et al., 2000). Imaging studies of bilingual language switching reveal activation in similar brain regions (Abutalebi and Green, 2007; Abutalebi et al., 2012; Crinion et al., 2006; Hernandez, 2009; Hernandez et al., 2001; Hernandez et al., 2000; Hosoda et al., 2012; Rodriguez-Fornells et al., 2005; Wang et al., 2007, 2009; for review, see Hervais-Adelman et al. (2011)) and support the notion that linguistic control is accomplished through general mechanisms of executive control.

To date, few imaging studies have examined language control and non-linguistic executive control within the same study and the few studies that do this have evidence for both shared and unique mechanisms of control (Abutalebi et al., 2008, 2012; Hosoda et al., 2012). For example, Abutalebi et al. (2012) reported evidence for shared mechanisms of control across domains using a flanker task to measure non-linguistic control and a picture-naming task to measure linguistic control. A conjunction analysis that extracted regions of overlap between the two tasks revealed the anterior cingulate cortex to be active in both tasks. However, Abutalebi et al. (2012) also found greater activation during the flanker task in certain regions that were not recruited during the language task, suggesting the presence of some unique control mechanisms for switching across domains. Another study that compared bilingual performance on a within-language task (name the picture or a related verb in the same language) and a between-language task (name pictures in either language) revealed the left caudate and anterior cingulate cortex were active during the between-language paradigm, but not during the within-language paradigm, suggesting these regions were recruited to manage between-language competition (Abutalebi et al., 2008). However, follow-up studies reported anterior cingulate and left caudate involvement during non-linguistic executive control tasks (e.g., Abutalebi et al., 2012; Wang et al., 2012) and raise questions regarding the degree to which these regions are domain-specific.

Thus, to date, there is both behavioral and neuroimaging evidence supporting the proposal of shared mechanisms for linguistic and non-linguistic control as well as evidence supporting at least partially non-overlapping control mechanisms across domains. However, methodological differences across studies, and sometimes tasks used within the same study, leave a critical gap in this comparison and may account for the contrasting findings in the literature. The present study aimed to close this gap by comparing linguistic and non-linguistic task switching in the same group of bilinguals while minimizing methodological differences between tasks, with the goal of identifying both similarities and differences in control mechanisms across domains.

Following Prior and Gollan (2011, 2013) we tested bilinguals on color-shape switching and language switching paradigms behaviorally and in the scanner to investigate neural mechanisms underlying single, stay, and switch trial-types. Imaging studies that have investigated language switching in bilinguals have not decomposed single, stay, and switch trial-types in the way that is commonly done in the behavioral literature. This is due to the limitation of using either a blocked design that only allows for between block comparisons (non-mixed block versus mixed block) or an event-related design that eliminates single blocks and allows for only between-trial comparisons in a mixed block (stay trials versus switch trials). Thus, to decompose the regions of activation associated with switch and stay trials of mixed blocks, and single trials within single blocks, we implemented a hybrid event-related and blocked fMRI design (see Braver et al. (2003) for use of this design with task switching) that more closely mirrors the design in behavioral studies. We opted to focus on between-task comparisons separately for each trial type, rather than comparing tasks on switch and mix costs as is typically done for response time data, since it is not clear what the neural instantiation of mix and switch costs really reflect. Decomposing trial-types provides greater transparency of the neural substrates underlying components of language and task switching. Given previously reported bilingual advantages in switching and other connections between language and task switching (Prior and MacWhinney, 2010; Prior and Gollan, 2011; Weissberger et al., 2012), we predicted that differences between tasks would be smallest on switch trials and relatively greater on stay trials within the mixed task block. Alternatively, similarities and differences between tasks might be found on both switch and stay trials, given reported associations between tasks in the size of mixing costs (Prior and Gollan, 2013),