



# Qualitative differences between bilingual language control and executive control: evidence from task-switching

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Previous research has shown that highly proficient bilinguals have comparable switch costs in both directions when they switch between languages (L1 and L2), the so-called “symmetrical switch cost” effect. Interestingly, the same symmetry is also present when they switch between L1 and a much weaker L3. These findings suggest that highly proficient bilinguals develop a language control system that seems to be insensitive to language proficiency. In the present study, we explore whether the pattern of symmetrical switch costs in language switching tasks generalizes to a non-linguistic switching task in the same group of highly proficient bilinguals. The end goal of this is to assess whether bilingual language control (bLC) can be considered as subsidiary to domain-general executive control (EC). We tested highly proficient Catalan–Spanish bilinguals both in a linguistic switching task and in a non-linguistic switching task. In the linguistic task, participants named pictures in L1 and L2 (Experiment 1) or L3 (Experiment 2) depending on a cue presented with the picture (a flag). In the non-linguistic task, the same participants had to switch between two card sorting rule-sets (color and shape). Overall, participants showed symmetrical switch costs in the linguistic switching task, but not in the non-linguistic switching task. In a further analysis, we observed that in the linguistic switching task the asymmetry of the switch costs changed across blocks, while in the non-linguistic switching task an asymmetrical switch cost was observed throughout the task. The observation of different patterns of switch costs in the linguistic and the non-linguistic switching tasks suggest that the bLC system is not completely subsidiary to the domain-general EC system.

**Keywords:** bilingualism, executive control, language control, task-switching, language switching

## INTRODUCTION

A remarkable skill of bilingual speakers is the ability to confine speech to one language while preventing interference from the unintended language. The cognitive process underlying this ability is often referred to as bilingual language control (bLC; e.g., Green, 1998; Costa and Santesteban, 2004; Crinion et al., 2006; Abutalebi and Green, 2007; Christoffels et al., 2007). Although there is disagreement regarding the nature of the bLC mechanisms, there is a general consensus that certain aspects of domain-general executive control (EC) functions mediate this ability (Abutalebi et al., 2008). However, it is still unclear whether bLC is completely subsidiary to the domain-general EC system or whether it also involves mechanisms specific to language.

In fact, the relationship between bLC and domain-general EC processes can be characterized in at least two different ways. First, one could think of bLC as a set of processes that are fully subsidiary to the domain-general EC functioning. That is, a bilingual speaker producing language would engage the very same set of EC processes that are involved in other non-linguistic activities requiring EC. Under this hypothesis, when switching language as a function of the interlocutor, individuals would engage the very same

control mechanisms as when they are asked to switch between different non-linguistic tasks in everyday life. Alternatively, the bLC system may be only partially subsidiary to domain-general EC processes. That is, it is possible that the continuous control that bilingual speakers exert over their two languages results in the development of control processes specific to language (Costa and Santesteban, 2004). Although they probably make use of certain aspects of the EC system, additional processes may become specifically engaged in language switch related tasks. From this viewpoint, the crosstalk between the bLC and domain-general EC would still be present, leading to the repeatedly reported bilingual advantages in EC (e.g., Bialystok et al., 2004; Costa et al., 2008, 2009; Hernández et al., 2010). At the same time, however, some aspects of the bLC system would be specific to language and not necessarily related to the EC system.

Here, we set out to gain some initial insights on this issue by exploring a phenomenon observed both in language switching and task-switching, namely, the “asymmetrical switch cost” (see below). By doing this, we hope to shed some light on the crosstalk between the processes involved in bLC and those involved in domain-general EC.

## ON THE FUNCTIONING OF EC SYSTEM IN BILINGUALS AND MONOLINGUALS

A first indication revealing that bilingualism affects the EC functioning can be found in those studies comparing monolinguals and bilinguals performing EC tasks. An increasing body of literature reveals that the continuous use of two languages seems to enhance processes related to domain-general EC such as those put at play in Stroop-like tasks and non-linguistic task-switching. This has been indexed through the observation of reduced Stroop-like interference and switch costs for bilinguals relative to monolinguals (e.g., Bialystok et al., 2004, 2006, 2008, 2010; Colzato et al., 2008; Costa et al., 2008, 2009; Bialystok and Viswanathan, 2009; Hernández et al., 2010). In particular, Prior and MacWhinney (2010) assessed whether bilinguals would show an advantage over monolinguals in non-linguistic task-switching with two sorting rules (sorting by shape or by color). They found that bilinguals had a reduced switch cost compared to monolinguals. Of the multiple components involved in task-switching (e.g., goal shifting, rule activation, etc., see Rubinstein et al., 2001), the authors hypothesized that the bilingual advantage in task-switching might be related to a more efficient goal shifting. The reasoning behind this hypothesis was that bilinguals' lifelong use of language switching may lead to an enhancement of the abilities of goal shifting also in the non-linguistic cognitive control mechanisms<sup>1</sup>.

Other indications of the crosstalk between EC and bLC come from neuroimaging studies comparing monolinguals and bilinguals. Recently, Abutalebi et al. (2011) found differences in the way the dorsal anterior cingulate cortex (ACC) was recruited during conflict resolution in the flanker task. Specifically, bilinguals revealed a smaller activation of this area than monolinguals during conflict resolution. This pattern of brain activation was consistent with the fact that behaviorally bilinguals showed a reduced magnitude of the conflict effect compared to monolinguals. These results suggest that the ACC, one area within the cognitive control network, is engaged to a different extent in bilinguals and monolinguals during EC tasks.

There are also some indications of qualitative differences in brain activation between monolinguals and bilinguals during EC tasks (Garbin et al., 2010). In the study of Garbin et al. (2010), monolinguals and bilinguals completed a task-switching experiment using two sorting rules determined by stimulus color and shape. The authors found that bilinguals recruited brain areas normally engaged during language control (left inferior frontal gyrus), whereas monolinguals did not. This suggests that bilinguals

recruit different neural structures relative to monolinguals in tasks involving the EC system.

Overall, these results indicate that bilingualism has an impact on the development of EC. However, they do not exclude the possibility that bLC involves certain processes that are outside the EC system. One way to explore the crosstalk between bLC and EC is to look at the qualitative difference of performance in tasks that engaged these two systems. Let us explain in more detail these qualitative aspects, specifically the asymmetry of the switch costs in linguistic and non-linguistic task-switching.

## QUALITATIVE DIFFERENCES IN SWITCH COSTS BETWEEN LINGUISTIC AND NON-LINGUISTIC TASK-SWITCHING

Abutalebi and Green (2007), in a review of neuroimaging studies, suggested that the same neural regions (the dorsolateral prefrontal cortex, the ACC and the caudate nucleus) are engaged during both language switching tasks (e.g., Price et al., 1999; Hernandez et al., 2000, 2001; for a review see Hervais-Adelman et al., 2011) and non-linguistic task-switching (e.g., Botvinick et al., 1999; Crone et al., 2006). This indirect evidence supports the hypothesis that the mechanisms for language control are subsidiary to those of the domain-general EC.

However, an fMRI study conducted by Abutalebi et al. (2008) may actually be interpreted as going against the claim of functional overlap between bLC and EC. The authors demonstrated the existence of a neural network that is specifically recruited to switch between two different linguistic registers but not between two intra-linguistic tasks. This suggests that some processes at play during bLC are “language-specific” and not recruited for any other switching task.

In this article we further explore the issue of the crosstalk between bLC and EC by assessing qualitative aspects of these two systems (see below). To do so, we employ tasks involving bLC (language switching task) and EC (non-linguistic switching task) to compare the patterns of switch costs observed within the same population of highly proficient bilinguals. These two tasks share many different cognitive components and one can argue that in fact, the language switching task is just a specific instantiation of the more general task-switching paradigm (see for example, Abutalebi and Green, 2008). If so, and according to the first hypothesis put forward above, the pattern of results in the two tasks should be similar. In contrast, if bLC is not fully subsidiary to the EC processes, one could predict that the pattern of results in the two tasks may not be identical. Let us be more specific about the pattern of results we are referring to.

One of the most robust effects in task-switching is the so-called “local switch cost” (e.g., Meiran, 1996; Monsell, 2003; Koch et al., 2010; Schneider and Anderson, 2010; Martin et al., 2011). This cost refers to the observation of slower reaction times (RTs) for trials that require a task-switch in comparison to trials that do not require such a switch. For our present purposes, it is interesting that the magnitude of the local switch cost is not constant for any given task, but rather depends on the relative difficulty of the two tasks at hand during the experiment. Given differences in task difficulty, local switch costs tend to be larger when switching into the easier task than when switching into the more difficult one. For example, consider a switching task where task 1 consists

<sup>1</sup>The question of which EC processes are involved in task-switching is a complex issue that goes beyond the purposes of the present article. Several theories have exemplified how task-switching might be mediated by separable executive control processes [e.g., attention-to-action (ATA) model by Norman and Shallice, 1986; the frontal-lobe executive (FLE) model by Duncan, 1986; and the strategic response-deferment (SRD) model, Meyer and Kieras, 1997]. For a detailed description of such theories see reviews by Rubinstein et al. (2001) and Monsell (2003). Here, we refer to Rubinstein et al.'s (2001) account discussed in Prior and MacWhinney's (2010) study on the bilingual advantage in task-switching. Rubinstein et al. (2001) proposed that at least two processes of the EC system are involved in task-switching, namely “goal shifting” and “rule activation.” “Goal shifting” updates the content of the declarative working memory about the two task-sets; whereas rule activation enables the selection of the current task and disables the rules of the previous one.

in sorting cards by color and task 2 consists in sorting cards by shape, with unpredictable switches from one task (e.g., color) to the other (shape). The switch cost observed when switching to the more difficult task “sorting by shape” are usually smaller than when switching to the easier task “sorting by color” (e.g., Nagahama et al., 2001; Rubinstein et al., 2001; Martin et al., 2011). This phenomenon, often referred to as the asymmetrical switch cost, has received many different explanations in the task-switching literature (for a review see Koch et al., 2010; Schneider and Anderson, 2010). Given the focus of this article, we will only discuss briefly what is, perhaps, the most influential account of this asymmetrical switch cost.

According to Allport et al. (1994), the “task-set inertia hypothesis”, part of the switching cost stems from the need to retrieve a task-set that has been inhibited in the previous trial. Furthermore, the amount of inhibition applied to a given task-set (e.g., sorting by color or shape) depends on the relative strength of the task. That is, the easier task is inhibited more strongly than the more difficult one. Given this imbalance, the asymmetrical switch cost comes about in the following way: when performing the more difficult task (i.e., sorting by shape), the system has to strongly inhibit the task-set corresponding to the easier task (sorting by color). Hence, in the following trial, retrieving the strongly inhibited task-set will incur in a large switching cost. In contrast, when performing the easier task (i.e., sorting by color), the system has to inhibit with less strength the task-set corresponding to the more difficult task (sorting by shape). Consequently, in the following trial, retrieving the not-very-much inhibited task-set will incur in a small switching cost. Therefore, switching from the easier to the more difficult task will incur in a smaller switch cost (from color to shape) than switching from the more difficult to the easier task (from shape to color)<sup>2</sup>.

Similarly, when the task-switching involves two languages, low-proficient bilinguals show asymmetrical switch costs (i.e., larger switch costs when switching into the easier language), which parallels the pattern of the non-linguistic task-switching paradigms. That is, for low-proficient bilinguals switching into the less proficient (and hence, the more difficult task) language (L2) is easier (in terms of RTs and errors) than switching into the more proficient (and hence, the easier task) language (L1; e.g., Meuter and Allport, 1999). This linguistic asymmetrical switch cost can be explained in the same manner as domain-general asymmetrical switching costs. In fact, Meuter and Allport (1999) argued that the magnitude of the inhibition applied to two languages is dependent on the relative strength of the two languages. Therefore, when the less proficient L2 needs to be produced, the more proficient L1 needs to be inhibited more than the other way around. Thus, an asymmetrical switch cost arises because the amount of inhibition that needs to be overcome during the switch into L1 is larger

than when switching into L2. This pattern of asymmetries in low-proficient bilinguals fits very well with the notion that the same control processes involved in bLC are the ones that are also at play in domain-general EC.

The framework described above makes a straightforward prediction: whenever there is a difference in the difficulty of the tasks (or languages) involved in the switching task, there should be an asymmetrical switching cost, being such cost larger when switching into the easier task. Along the same lines, symmetrical switch costs are expected for switching tasks involving tasks of similar difficulty.

Crucial for present purposes is the fact that several studies conducted with highly proficient bilinguals have given only partial support to this prediction. Highly proficient bilinguals do not seem to show asymmetrical language switching costs regardless of the difficulty of the languages involved in the task. Let us be more specific and describe the pattern of language switching cost for highly proficient bilinguals in some detail.

As expected, when highly proficient bilinguals are asked to switch between their two proficient languages (hence little difference in difficulty between the two tasks), the switching costs are comparable in both directions (from L1 to L2 and vice versa; Costa and Santesteban, 2004; Costa et al., 2006). However, and crucial for present purposes, when these bilinguals are asked to switch between languages of different difficulties (e.g., switching between their L1 and their L3), the predicted asymmetrical switch cost is not present. In a series of experiments Costa et al. (2006) showed that in highly proficient bilinguals the symmetrical switch cost was present irrespective of the age of acquisition of L2, the similarities of two languages involved in the switching task and language proficiency. Given this pattern, two questions emerge:

- (a) Why highly proficient bilinguals do not show the predicted asymmetrical switch cost when switching between languages of different proficiency, as the low-proficient bilinguals do?
- (b) Would these bilinguals be sensitive to task difficulty when performing a non-linguistic switching task (e.g., would they show asymmetrical switch costs)? Answering this second question is the goal of the present article.

In trying to answer the first question, Costa and Santesteban (2004) hypothesized that highly proficient bilinguals might recruit a qualitatively different bLC when performing the language switching task compared to low-proficient bilinguals. As proposed by Costa and Santesteban (2004), there might be a shift in the type of mechanisms responsible for the selection of the intended language once a certain level of proficiency is attained in an L2. That is, it is possible that at some point highly proficient bilinguals do not make use of inhibition (as low-proficient ones probably do), but instead they make use of a mechanism that restricts lexical competition to the intended language. Importantly, once highly proficient bilinguals develop such a mechanism it would be applied also to other languages (e.g., a weaker L3).

This explanation contains the implicit assumption that bLC might be to some extent different from EC processes in general, and hence the “task-set inertia” hypothesis (Allport et al., 1994) for the performance of highly proficient bilinguals is not granted. Note

<sup>2</sup>Other authors have proposed different accounts based on long-term memory retrieval processes (e.g., Allport and Wylie, 2000; Mayr and Kliegl, 2000; Bryck and Mayr, 2008). One assumption is that the retrieval of irrelevant task traces interferes with selection of the relevant task and that more instances of the more difficult task would be encoded/retrieved into long-term memory than in the case of the easier task. Since the amount of interference is proportional to the number of irrelevant task traces in long-term memory, the interference will be larger when switching into the easier task than into the more difficult one. This leads to a larger switch cost when switching from the more difficult to the easier task than vice versa.

that this hypothesis would predict asymmetrical switch costs when switching from L3 into L1 for highly proficient bilinguals, given that one language (L3) is harder than the other (L1) – similarly to what happens when low-proficient bilinguals switch between L1 and L2. Thus, according to this hypothesis, the difference in the relative strength between L1 and L3 should involve a different amount of inhibition when speaking in one language or the other and therefore produce asymmetries in switch costs as well.

Regardless these explanations, what is relevant here is the potential generalizability of such a lack of asymmetrical switch costs of highly proficient bilinguals to non-linguistic tasks. That is, the question is whether the crosstalk between bLC and EC systems is such that the relative insensitivity of highly proficient bilinguals to task difficulty in the language switching task will also be present in a non-linguistic switching task.

If the bLC system is fully subsidiary to the EC system, it is reasonable to predict that whichever pattern is observed in the language switching task will also be present in a non-linguistic switching task. Hence, we predict that differences in task difficulty should not lead to asymmetrical switch costs in these bilinguals, in the same way that differences in language difficulty do not lead to asymmetrical switch costs for this group. On the other hand, if bLC is governed by processes that are, to some extent, independent of the EC system, then it is possible that the symmetrical switch costs observed for language switching do not generalize to non-linguistic task-switching.

We put these predictions to test by comparing the performance of highly proficient Catalan–Spanish bilinguals in a linguistic and non-linguistic switching paradigm and examining the qualitative pattern of the switch costs. Specifically, we compared the symmetry/asymmetry of the switch costs between tasks differing in their level of difficulty. We used an adaptation of the linguistic switching task previously employed by Costa and Santesteban (2004), through which we expected to replicate the typical symmetrical switch cost of highly proficient bilinguals between L1 and L2 and also between L1 and L3. Note that for the sake of completeness we present two experiments: in Experiment 1 highly proficient bilinguals switched between L1 and L2, and in Experiment 2 between L1 and L3.

Concerning the non-linguistic task, we used a task-switching where participants had to switch between two rule-sets of a card sorting task (color and shape). As previously described, sorting by color is easier than sorting by shape. This effect of task difficulty permitted us to compare the non-linguistic switching task with the language switching task. We defined the non-linguistic switching task such that it did not require changing languages and it did not require explicit verbalization of the response.

To recapitulate, we will examine the issue of the crosstalk between bLC and EC in two ways:

(a) From a qualitative point of view: by examining the pattern of the switch costs in terms of the symmetry/asymmetry in the linguistic and non-linguistic switching tasks. If highly proficient bilinguals show a symmetrical switch cost in the language switching task, the same symmetrical pattern is expected in the non-linguistic switching task if the mechanisms of bLC are completely subsidiary to the EC system.

(b) From a quantitative point of view: by examining any potential correlations between linguistic and non-linguistic switch costs. Significant correlations between switch costs in linguistic and non-linguistic switching tasks could indicate that the bilinguals' behavior in the bLC generalizes to a non-verbal domain, such as domain-general EC.

## PARTICIPANTS

Fourteen bilinguals (mean age = 23.2, range = 18–27 years old) took part in Experiment 1, and 15 bilinguals did it in Experiment 2 (mean age = 20.3, range = 18–23 years old). All participants in both experiments were early and highly proficient Catalan–Spanish bilinguals. All participants had Catalan as L1 and they learned Spanish before the age of 6. Their proficiency in the two languages was tested by means of a questionnaire. Each participant self-rated on a four-point scale the abilities of speaking, comprehension, writing and reading for each language (1 = poor, 2 = regular, 3 = good, 4 = perfect). All the participants were highly proficient in both L1 and L2 (see **Table 1**). In addition, participants in Experiment 2 were low-proficient in English (L3).

## EXPERIMENT 1: LINGUISTIC SWITCHING BETWEEN L1 AND L2 AND NON-LINGUISTIC SWITCHING TASK

### MATERIALS AND PROCEDURE

#### Linguistic switching task

Eight pictures of objects were selected from Snodgrass and Vanderwart (1980). Half of them referred to cognate words [Spanish/Catalan names: “Caracol”/“Cargol” (in English, snail); “Escoba”/“Escombra” (broom); “Martillo”/“Martell” (hammer); “Reloj”/“Rellotge” (watch)], and the other half to non-cognate words [“Calçetín”/“Mitjó” (sock); “Manzana”/“Poma” (apple); “Silla”/“Cadira” (chair); “Tenedor”/“Forquilla” (fork)].

Participants were required to name the picture in Catalan or in Spanish. A Catalan or Spanish flag, which was presented along with the picture, acted as a cue to indicate in which language subjects had to name the picture.

**Table 1 | Language proficiency (mean and SD) of speaking, comprehension, writing, and reading abilities for each language, self-rated on a four-point scale (1 = poor, 2 = regular, 3 = good, 4 = perfect).**

Experiment 1	Catalan, mean (SD)	Spanish, mean (SD)
Speaking	4.0 (0.0)	3.9 (0.3)
Comprehension	4.0 (0.0)	4.0 (0.0)
Pronunciation	4.0 (0.0)	3.9 (0.3)
Reading	4.0 (0.0)	4.0 (0.0)
Writing	4.0 (0.0)	3.9 (0.3)
Experiment 2	Catalan, mean (SD)	English, mean (SD)
Speaking	4.0 (0.0)	2.1 (0.5)
Comprehension	4.0 (0.0)	2.9 (0.7)
Pronunciation	4.0 (0.0)	2.1 (0.7)
Reading	4.0 (0.0)	3.0 (0.4)
Writing	4.0 (0.0)	2.7 (0.5)

There were two types of trials: (a) those in which participants were required to name the picture in the same language as the preceding trial (repeat trial), (b) those in which participants were required to name in a different language with respect to the previous trial (switch trial). There were a total of 320 trials divided in two blocks with 160 trials each. The total distribution of trials was: 128 repeat trials in Catalan, 128 repeat trials in Spanish, 64 switch trials in Catalan, and 64 in Spanish.

Participants were asked to name the picture as fast as possible and they were informed that the language to be used was indicated by a flag, presented on the top of the picture. At the beginning of each series a word cue was presented for 1000 ms indicating in which language participants had to start to name (“CATALÀ,” for Catalan; “ESPAÑOL,” Spanish). Then the picture appeared for 1700 ms and the timeout to respond was 5000 ms. The pictures were presented in a series of three to seven trials and at the end of each series an asterisk appeared and the participants pressed the spacebar to start the next series. The experiment started with a practice session of 80 trials.

**Non-linguistic switching task**

Three shapes (square, circle, and triangle) and three colors (green, blue, and red) were selected for the task. The three shapes were combined with the three colors, resulting in a total of nine colored shapes (e.g., green square, blue square etc.). Participants were presented with an array containing three shapes, two at the top of the screen and one at the bottom. They were instructed to match the shape at the bottom with one of the two at the top of the display according to two possible criteria (shape or color). The criterion was indicated by a cue (“COLOR,” for Color; “FORMA,” for Shape) appearing in the center of the array. As in the linguistic version of the task, there were two types of trials: repeat and switch trials.

At the beginning of each series a word cue was presented for 1000 ms indicating by which rule participants must start matching each item (“COLOR,” for Color; “FORMA,” for Shape). Then the array appeared for 2500 ms and the timeout to respond was 3000 ms.

Participants gave the response by pressing the two keys “M” or “V” according to the position of the matched picture at the top of the array. Specifically, they had to press “M” key when the correct answer was at the top-right part of the array and the “V” key when the correct response was at the top-left part of the array. The experiment started with a practice session of 80 trials.

The experiments were controlled by the software DMDX (Forster and Forster, 2003), which recorded participants’ vocal and manual responses. Responses were analyzed off-line and naming latencies were measured from the onset of the word trough Checkvocal, a program of data analysis of naming tasks in DMDX (Protopapas, 2007). Participants always performed the linguistic switching and then the non-linguistic switching task. The order of the two tasks was not counterbalanced.

**RESULTS**

**Linguistic switching cost**

The variables considered in the analyses were “type of trial” (switch vs. repeat) and “response language” (L1 and L2) which were included as within-subject factors in a repeated-measure ANOVA

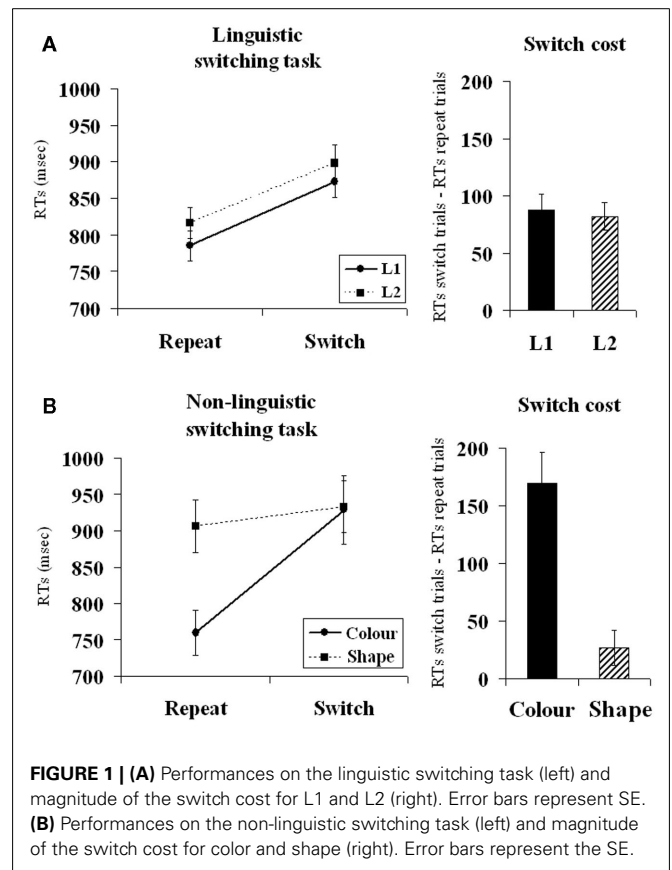
on naming latencies. Naming latencies 3 SD above or below a given participant’s mean were excluded from the analyses. Also the naming latencies in which the participants produced a different name from what was expected were excluded from the analyses.

**Reaction times.** Overall participants were slower in switch trials (886 ms) compared to repeat trials [801 ms;  $F(1, 13) = 55.11$ ,  $MSE = 1822.67$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.81$ ], and faster to name in L1 (829 ms) than in L2 [857 ms;  $F(1, 13) = 4.81$ ,  $MSE = 2318.88$ ,  $p = 0.05$ ,  $\eta_p^2 = 0.27$ ]. But the cost to switch to L1 (87 ms) and to L2 (82 ms) was the same, as indexed by a non-significant “type of trial” × “response language” interaction [ $F(1, 13) = 0.15$ ,  $MSE = 741.59$ ,  $p = 0.70$ ; see **Figure 1A**]. That is, there was a symmetrical switch cost.

**Accuracy.** No difference in accuracy was found between switch and repeat trials [Type of trial:  $F(1, 13) = 2.29$ ,  $MSE = 9.65$ ,  $p = 0.15$ ] and between L1 and L2 [Response language:  $F(1, 13) = 0.40$ ,  $MSE = 22.76$ ,  $p = 0.54$ ]. The interaction between type of trial and response language was not significant either [ $F(1, 13) = 0.19$ ,  $MSE = 6.64$ ,  $p = 0.66$ ; see **Table 1**].

**Non-linguistic switching cost**

The variables considered in the analysis were “type of trial” (switch vs. repeat) and “sorting criteria” (color and shape), which were included as a within-subject factor in a repeated-measure ANOVA using RTs as a dependent variable.



**FIGURE 1 | (A)** Performances on the linguistic switching task (left) and magnitude of the switch cost for L1 and L2 (right). Error bars represent SE. **(B)** Performances on the non-linguistic switching task (left) and magnitude of the switch cost for color and shape (right). Error bars represent the SE.

**Reaction times.** Overall participants were slower in switch trials (931 ms) compared to repeat trials [833 ms;  $F(1, 13) = 38.42$ ,  $MSE = 3505.52$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.75$ ], and faster to sort by color (843 ms) than to sort by shape [920 ms;  $F(1, 13) = 40.32$ ,  $p < 0.0001$ ,  $MSE = 2011.41$ ,  $\eta_p^2 = 0.76$ ]. In this case the switch cost interacted with “type of trial” [ $F(1, 13) = 19.88$ ,  $MSE = 3592.72$ ,  $p = 0.001$ ,  $\eta_p^2 = 0.61$ ]. That is, participants showed a cost when they switched from shape to color [169 ms,  $F(1, 13) = 37.57$ ,  $MSE = 5353.39$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.74$ ], but not from color to shape [27 ms,  $F(1, 13) = 2.85$ ,  $MSE = 1744.86$ ,  $p = 0.11$ ; see **Figure 1B**].

**Accuracy.** There was a tendency toward lower accuracy for switch trials (91.25%) over repeat ones [94.75%; Type of trial:  $F(1, 13) = 3.64$ ,  $MSE = 17.80$ ,  $p = 0.08$ ]. Also, participants were less accurate in sorting by shape (90.0%) than by color [94.7%;  $F(1, 13) = 14.22$ ,  $MSE = 22.40$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.52$ ; see **Table 2**].

To summarize, we found that bilingual participants showed symmetrical switch costs in the linguistic task-switching, but in the non-linguistic one we found asymmetrical switch costs since only switching into color resulted in a cost.

**EXPERIMENT 2: LINGUISTIC SWITCHING BETWEEN L1 AND L3 AND NON-LINGUISTIC SWITCHING TASK**

As advanced in the Introduction, one could argue that the symmetrical switch costs between L1 and L2 of highly proficient bilinguals are due to both tasks (naming in L1 and naming in L2) being equally easy for highly proficient bilinguals. In other words, we

would have a difference in difficulty between color and shape in the non-linguistic task-switching but not between L1 and L2 in the language switching task. Thus, in this experiment, bilinguals (who were still highly proficient in both Catalan and Spanish) conducted the language switching task between their L1 (Catalan) and L3 (English) for which they were low-proficient.

**MATERIALS AND PROCEDURE**

The procedure for the linguistic and non-linguistic switching tasks was the same as that reported for the Experiment 1. The only difference with Experiment 1 was that participants were required to name in Catalan and English, instead of Catalan and Spanish in the language switching task. The material was the same as in Experiment 1.

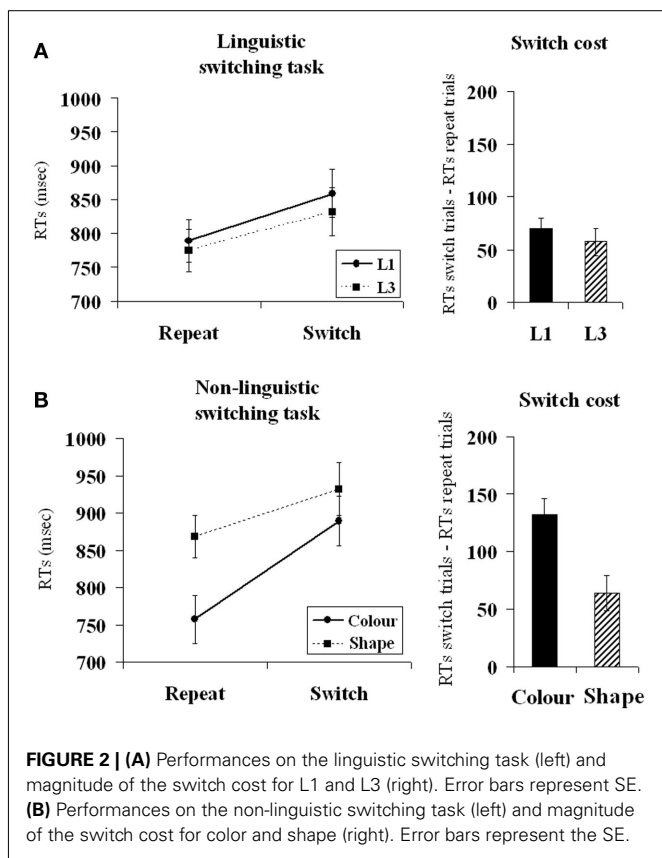
**RESULTS**

**Linguistic switching cost**

The variables considered in the analyses were “type of trial” (switch vs. repeat) and “response language” (L1 and L3), which were included as within-subject factor in a repeated-measure ANOVA on naming latencies.

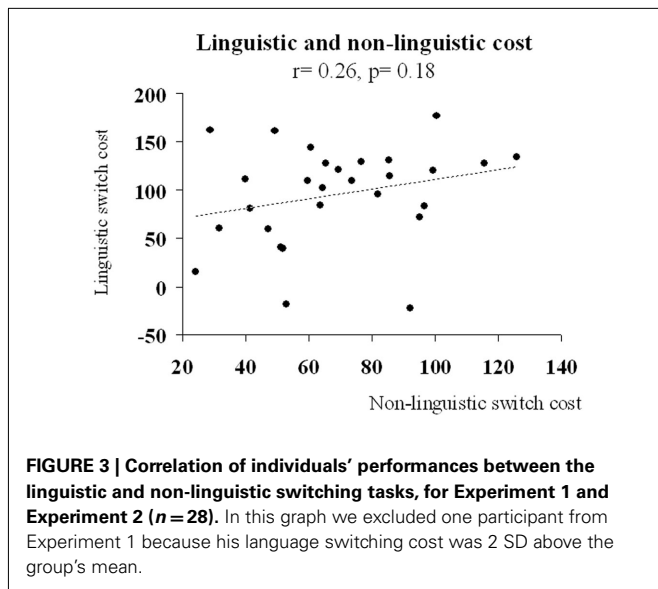
**Reaction times.** Overall participants were slower in switch trials (846 ms) compared to repeat trials [783 ms;  $F(1, 14) = 75.85$ ,  $MSE = 799.13$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.84$ ], but there was no difference in naming latencies between L1 (824 ms) and L3 [804 ms;  $F(1, 14) = 2.12$ ,  $MSE = 2914.51$ ,  $p = 0.17$ ]. The cost to switch to L1 (70 ms) and to L3 (57 ms) was equivalent, as indexed by a non-significant effect of “type of trial” × “response language” interaction [ $F(1, 14) = 0.56$ ,  $MSE = 1211.89$ ,  $p = 0.47$ ; see **Figure 2A**], revealing a symmetrical switch cost.

**Accuracy.** No difference in accuracy was found between switch and repeat trials [Type of trial:  $F(1, 14) = 2.81$ ,  $MSE = 11.99$ ,  $p = 0.12$ ] and between L1 and L3 [Response language:  $F(1, 14) = 0.59$ ,  $MSE = 10.92$ ,  $p = 0.46$ ]. The interaction between type of trial and response language was not significant either [ $F(1, 14) = 0.09$ ,  $MSE = 13.93$ ,  $p = 0.77$ ; see **Table 3**].



**Table 2 | Accuracy (%) and SE in the linguistic and non-linguistic versions of the task-switching broken for trial types for the Experiment 1.**

Experiment 1	Accuracy (%)	SE	Accuracy (%)		SE
			L1	L2	
<b>LINGUISTIC VERSION</b>					
Repeat	97.8	0.5	97.3	0.6	0.6
Switch	96.8	1.0	95.7	1.5	1.5
Total	97.3	0.7	96.5	1.0	1.0
	<b>Color</b>		<b>Shape</b>		
<b>NON-LINGUISTIC VERSION</b>					
Repeat	96.0	0.6	90.9	0.8	0.8
Switch	93.5	1.0	89.0	1.9	1.9
Total	94.7	0.8	90.0	1.3	1.3



**Table 3 | Accuracy (%) and SE in the linguistic and non-linguistic versions of the task-switching broken for trial types for the Experiment 2.**

Experiment 2	L1		L3	
	Accuracy (%)	SE	Accuracy (%)	SE
<b>LINGUISTIC VERSION</b>				
Repeat	94.5	1.1	93.4	2.1
Switch	92.6	2.1	92.2	2.1
Total	93.4	1.6	92.4	2.1
	Color		Shape	
<b>NON-LINGUISTIC VERSION</b>				
Repeat	96.0	0.8	91.2	0.8
Switch	92.2	1.5	91.7	1.3
Total	93.6	1.1	91.9	1.2

**Non-linguistic switching cost**

The variables considered in the analysis were “type of trial” (switch vs. repeat) and “sorting criteria” (color and form), which were included as within-subject factors in a repeated-measure ANOVA on the RTs.

**Reaction times.** Overall participants were slower in switch trials (911 ms) compared to repeat trials [812 ms;  $F(1, 14) = 69.38$ ,  $MSE = 2104.36$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.83$ ], and faster sorting by color (823 ms) than sorting by shape [900 ms;  $F(1, 14) = 42.81$ ,  $p < 0.0001$ ,  $MSE = 2085.37$ ,  $\eta_p^2 = 0.75$ ]. In this case the switch cost interacted with “type of trial” [ $F(1, 14) = 14.11$ ,  $MSE = 1221.76$ ,  $p = 0.002$ ,  $\eta_p^2 = 0.50$ ]. That is participants showed a larger cost when they switched from shape to color [132 ms,  $F(1, 14) = 82.34$ ,  $MSE = 1600.58$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.85$ ], than from color to shape [64 ms,  $F(1, 14) = 18.22$ ,  $MSE = 1725.55$ ,  $p = 0.001$ ; see **Figure 2B**].

**Accuracy.** Participants were less accurate in switch trials (91.9%) than in repeat trials [93.6%; Type of trial:  $F(1, 14) = 7.59$ ,  $MSE = 5.54$ ,  $p = 0.01$ ,  $\eta_p^2 = 0.35$ ], and less accurate to sort by shape (91.4%) than by color [94.1%;  $F(1, 14) = 9.44$ ,  $MSE = 11.58$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.40$ ]. A significant interaction between “type of trial” and “sorting criteria” [ $F(1, 14) = 7.38$ ,  $MSE = 9.34$ ,  $p = 0.02$ ,  $\eta_p^2 = 0.34$ ], indicated an increase of errors when participants switched from shape to color [ $F(1, 14) = 12.76$ ,  $MSE = 8.57$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.47$ ] but not from color to shape [ $F(1, 14) = 0.26$ ,  $MSE = 6.31$ ,  $p = 0.62$ ; see **Table 2**].

To summarize, we found that bilingual participants showed symmetrical switch costs in the linguistic version of the task, but asymmetrical switch costs in the non-linguistic version, as we did in Experiment 1.

**Individuals' differences in performance: correlations**

Additionally, we used a correlation analysis (Pearson's coefficient) to compare the magnitude of the switch cost between the linguistic and non-linguistic switching tasks.

In fact, if we assume that the switch cost reflects to some extent the efficiency of the BLC and EC in the same way, we may expect that the magnitude of the two switch costs (linguistic and non-linguistic) varies in the same manner in participants.

First, we obtained the correlation coefficient of the total switch cost between the linguistic task and the non-linguistic task (collapsing language in one case and the sorting criteria in the other case). In order to gain more statistical power we ran the analysis with participants of both experiments resulting in a total number of 28 (one participant from Experiment 1 was excluded because his performance was 2 SD above the group means). The switch costs of the two tasks were not significantly correlated ( $r = 0.26$ ,  $p = 0.18$ ; see **Figure 3**).

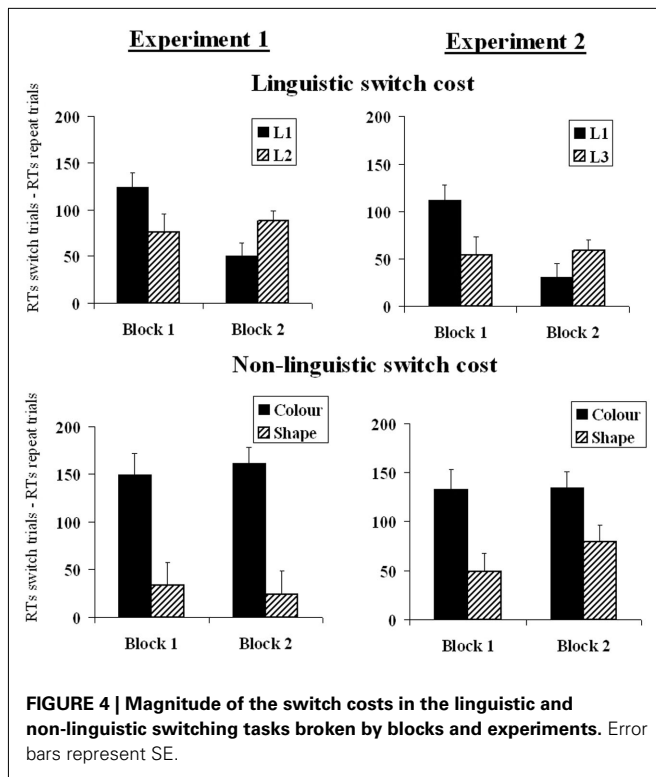
Then, we tested whether the cost of switching into the easier language (L1) correlated with the cost of switching into the easier sorting criteria (i.e., color), and whether the cost of switching into the difficult language (L2/L3) correlated with the cost of switching into the more difficult sorting criteria (shape). Neither the correlation between the cost of switching to L1 and to color ( $r = 0.16$ ,  $p = 0.42$ ), nor the correlation between the cost of switching to L2/L3 and to shape ( $r = -0.15$ ,  $p = 0.44$ ) were significant.

**Exploratory analysis of the switch costs across blocks**

Considering the overall results, we found that the switch cost was symmetrical in the linguistic switching task and asymmetrical in the non-linguistic switching task. In a further analysis we explored the pattern of the switch costs across the two experimental blocks with the aim of assessing any potential differences in task adaptation.

To do so we calculated the switch costs separately for the two blocks of the two tasks (linguistic and non-linguistic), containing 160 trials each. In the non-linguistic switching task-switch costs were asymmetrical in both blocks<sup>3</sup> (i.e., switching into color

<sup>3</sup>Non-linguistic switching task. In Experiment 1, the switch costs were 149 ms for color and 34 ms for shape in block 1; 162 ms for color and 24 ms for shape in block 2 [Type of trial × Block interaction:  $F(1, 13) = 0.34$ ,  $p = 0.57$ ]. In Experiment 2, the switch costs were 133 ms for color and 49 for shape in block 1; 134 ms for color



was more costly than switching into shape; see **Figure 4**). However, in the linguistic switching task we found a more puzzling result. In the first block, switching into L1 was more costly than switching into L2 or L3, but this pattern reversed in the second block. Interestingly, the cost of switching into L2 or L3 was constant across both blocks, whereas the cost of switching into L1 decreased in the second block. Even though this interaction renders the interpretation of the results more complex, the interesting point here is that it suggests that there are differences between the two types of task-switching also in what regards adaptation to the task.

## DISCUSSION AND CONCLUSION

In the present study we examined the relationship between the bLC and EC system. We did so by comparing the pattern of switch costs across linguistic and non-linguistic tasks within a set of highly proficient bilinguals.

We assessed the presence of the symmetrical switch cost in the linguistic task as a starting point, and then we looked at the pattern of switch cost in a non-linguistic switching task. In both experiments, bilinguals showed an asymmetrical non-linguistic switch cost: switching from shape to color was more costly than switching from color to shape. That is, switching from the more

difficult task (sorting by shape) to the easier one (sorting by color) resulted in a larger switch cost than vice versa. Additionally, participants committed more errors when they sorted by shape than by color, suggesting that the shape criterion was the most difficult of the two – a finding congruent with previous studies (e.g., Koch, 2001; Martin et al., 2011). In contrast, the same participants showed a symmetrical switch cost in the linguistic task (as previously reported by Costa and Santesteban, 2004; Costa et al., 2006). That is, there seems to be a qualitative difference in the way highly proficient bilinguals perform linguistic and non-linguistic task-switching.

The relationship between the two tasks was also explored by examining the magnitude of the switch costs in the two task versions. The idea behind this analysis was to see whether the efficiency of the bLC abilities could, to some extent, be transferred to the domain-general EC system. Specifically, bilingual individuals that have developed more efficient bLC will probably show relatively small switch costs in the language switching task compared to individuals with less developed bLC. If indeed the bLC functioning depends completely on the EC system, one would expect to find smaller switch costs also in the non-linguistic task. We did not find significant correlations between the linguistic and non-linguistic switch costs, neither between L1 and color nor between L2/L3 and shape. Thus, quantitatively, the magnitude of the switch cost suggests that there is no generalizability from the bLC to the EC system.

Similar results of uncorrelated performance between linguistic and non-linguistic tasks were reported in a study by Bialystok et al. (2008). These authors correlated the performance of bilingual speakers in two language production tasks (fluency and picture naming) with their performance in EC tasks. They did not find any correlation and concluded that their results leave open the possibility that the mechanisms responsible for bLC and those of domain-general EC may have different causes.

Further evidence about differences between the patterns of results in the two versions of the task-switching comes from the different adaptation patterns across the experiment. In the non-linguistic switching task, asymmetrical switching costs (larger switch cost for the easier task) were consistently observed across the whole experiment. However, this was not the case in the language switching task, where a puzzling result was observed. The switch cost for L1, both in Experiment 1 and 2, decreased from block one to block two, whereas the switch cost for L2 and L3 remained constant across blocks. That is, while there is a modulation of the switch cost for the easier task (L1) across the experiment, switch costs for the more difficult task (L2 and L3) remain the same. An interpretation of the L1 adaptation is premature, and future studies need to replicate it. However, our observations highlight the need of exploring language switching costs across the experimental blocks. Besides any kind of interpretation, the interesting point here is that in the two versions of task-switching we found different patterns of switch costs also over time. To some extent, these results indicate that some properties of bLC, for instance a certain degree of flexibility to adapt the behavior, are peculiar to the linguistic domain and they do not transfer to other domains. Once again, this might be evidence for the fact that bLC processes are not fully subsidiary to those

and 79 ms for shape in block 2 [Type of trial  $\times$  Block interaction:  $F(1, 14) = 0.92, p = 0.35$ ]. Linguistic switching task. In Experiment 1, the switch costs were 124 ms for L1 and 76 ms for L2 in block 1; 50 ms for L1 and 88 ms for L2 in block 2 [Type of trial  $\times$  Block interaction:  $F(1, 13) = 19.72, p = 0.001$ ]. In Experiment 2, the switch costs were 112 ms for L1 and 54 for L3 in block 1; 31 ms for L1 and 59 ms for L3 in block 2 [Type of trial  $\times$  Block interaction:  $F(1, 14) = 12.96, p = 0.003$ ].



of the EC system and that there is no transfer from bLC to the domain-general EC system.

Before going into the implications of the results reported here, it is important to note a potential caveat of our study. We have argued that the instantiation of the language switching task in Experiment 2 involves languages of different difficulty, since we compared L1 and L3. In principle, the difference in proficiency between the two languages should be enough to reveal asymmetrical switch costs, as has been shown previously with low-proficient bilinguals (Costa and Santesteban, 2004). However, we do not have any independent evidence that guarantees this difference in proficiency. Indeed, one may be tempted to take the fact that L1 is slower than L3 as an indication against our assumption. However, such interpretation is not without problems. This is because in previous studies we observed a similar pattern of RTs for participants for which we did have independent evidence that L1 was much stronger than L3 (Costa and Santesteban, 2004; Costa et al., 2006). At any rate, we acknowledge that the lack of independent information about the differences in strength between the two languages is a shortcoming of the present study.

The results of the present study suggest that the set of processes engaged in bLC are not fully subsidiary to the domain-general EC processes. That is, a bilingual speaker producing language will not engage the very same set of EC processes that are involved in any other non-linguistic activity in which the executive system is required. As discussed in the Introduction, most of the available evidence from neuroimaging studies is indirect. That is, it is a result of comparing different groups of participants performing either language switching tasks (e.g., Abutalebi and Green, 2007, 2008) or non-linguistic switching tasks (Garbin et al., 2010). One exception is the study of Abutalebi et al. (2011) in which the same group of bilinguals performed a language switching task and a non-linguistic conflict resolution task. The analysis of the brain networks involved in the two tasks showed an overlap over a set of brain areas along the mesial surface, comprising the ACC (BA 32) and the pre-SMA (BA 6). However, some additional areas were recruited during the conflict resolution task that were not active during the language switching task. Thus, the general conclusion from the neuroimaging literature is that some brain areas of the bLC and EC overlap, but the small amount of direct evidence (e.g., the same group of participants tested both on linguistic and non-linguistic tasks involving EC) precludes us from drawing strong conclusions about the extent of this overlap.

Our results fit well with data on brain-damaged individuals. Studies testing bilingual aphasics have reported double dissociations between language control and domain-general control (e.g., Green et al., 2010; see also Abutalebi et al., 2000; Mariën et al., 2005). For example, in Green et al. (2010) found a relatively

different impairment of language control and the EC system as a result of the brain lesion, indicating that the brain areas implicated in language control are not totally subsidiary to those implicated in EC and vice versa.

Before concluding, it is worth mentioning the lack of a correlation observed between the magnitudes of the switch costs in the linguistic and non-linguistic tasks. This also points to the direction that one cannot equate the processes involved in bLC with those involved in domain-general EC system. This approach, in which the crosstalk between bLC and EC is assessed in the same group of bilinguals by comparing the magnitude of switch costs, has started to receive some attention. Recently, Prior and Gollan (2011) looked at this issue by testing whether the bilingual advantage in EC was to some extent related to the cost of language switching. They found that those bilinguals who showed less cost in task-switching were also those who showed less cost in language switching. But this was true only for those bilinguals who reported to switch quite often in their everyday life. Second, no direct correlations of the switch costs between the two tasks were performed within the group of participants. Therefore, only based on the results of Prior and Gollan (2011) it is premature to conclude that the mechanisms underlying bLC are fully subsidiary to the EC system. And, in fact, if anything our results indicate otherwise.

To conclude, in this study we found different patterns of switch costs between a language switching task and a non-linguistic switching task. These results suggest that even if there is crosstalk between bLC and domain-general EC, there are some aspects of the bLC system that are specific to the domain of language and not necessarily related to the EC system. The relevance of our results is that they represent an attempt to investigate the crosstalk between the bLC and EC in the same group of participants. Further research is needed to investigate the exact mechanisms underlying the bLC and EC systems in bilinguals in order to eventually gain knowledge about their functional and neural relationship.

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