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Where is the bilingual advantage in task-switching?

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ABSTRACT

Based on previous reports of bilinguals' reduced non-linguistic switch cost, we explored how bilingualism affects various task-switching mechanisms. We tested different groups of Spanish monolinguals and highly-proficient Catalan–Spanish bilinguals in different task-switching implementations. In Experiment 1 we disengaged the restart cost typically occurring after a cue from the switch cost itself using two cue–task versions varying in explicitness. In Experiment 2 we tested bilingualism effects on overriding conflicting response sets by including bivalency effects. In Experiment 3 we attempted to replicate the reduced switch cost of bilinguals with the same implementation as in previous studies. Relative to monolinguals, bilinguals showed a reduced restart cost in the implicit cue–task version of Experiment 1 and overall faster response latencies in Experiment 2. However, bilinguals did not show reduced switch cost in any experiment – not even in an omnibus analysis combining the standardized switch cost scores of 292 participants across the three experiments. These results qualify previous claims about bilingualism reducing non-linguistic switch costs.

Introduction

Bilingual speakers typically keep their two languages apart with remarkable efficiency. This ability is known as bilingual language control, which according to some authors shares (at least partially) functional and neuronal mechanisms with domain-general executive control (EC) processes (e.g. Abutalebi & Green, 2007; Abutalebi et al., 2012; Calabria, Hernández, Branzi, & Costa, 2012; Weissberger, Wierenga, Bondi, & Gollan, 2012). This parallelism has led to the hypothesis that bilingualism may lead to differences in the development of EC processes. Indeed, several studies suggest this to be the case (e.g. Bialystok, 2011; Bialystok & Barac, 2012; Bialystok, Barac, Blaye, & Poulin-Dubois, 2010; Bialystok, Craik, & Ruocco, 2006a; Bialystok, Craik, & Ryan, 2006b; Bialystok & Feng, 2009; Bialystok & Martin, 2004; Bialystok & Viswanathan, 2009; Calabria, Hernández, Martin, & Costa, 2011; Carlson & Meltzoff, 2008; Colzato et al., 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008; Hernández, Costa, Fuentes, Vivas, & Sebastián-Gallés, 2010; Hernández, Costa, & Humphreys, 2012; Martin-Rhee & Bialystok, 2008; Treccani, Argyri, Sorace, & Della Sala, 2009).

However, a detailed description of the specific EC processes being affected by bilingualism is still lacking. Identifying those processes is a difficult enterprise, since domain-general EC is a complex set of interactive cognitive processes. Even so, there are studies evidencing the separability of at least some EC processes. For example, Miyake et al. (2000) showed that, although moderately correlated to one another, the EC processes of mental-set shifting,

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task monitoring, and conflicting-response suppression are behaviorally dissociable. Most research on this topic has focused on conflict resolution tasks, which mainly involve the EC processes of suppressing conflicting responses and task monitoring (e.g. Stroop task, flanker task). But little is known about the potential impact of bilingualism on other aspects of EC. The present study aims to explore the impact of bilingualism on a different EC process: task-switching.

Given that bilinguals tend to switch languages rather often, one could readily hypothesize that, to the extent that language switching shares some components with domain-general task-switching, bilingualism should impact task-switching performance. However, up to date, few studies have compared the task-switching performance of bilingual and monolingual adult individuals (Garbin et al., 2010; Paap & Greenberg, 2013; Prior & Gollan, 2011; Prior & MacWhinney, 2010). Here, we report three experiments using different instantiations of the task-switching paradigm that allow us to assess the effect of bilingualism on various task-switching components.

Why would bilingualism affect non-linguistic task-switching?

The main reason one would expect bilingualism to affect the cognitive control processes sustaining task-switching is that bilinguals (in many sociolinguistic contexts) are used to switch between their two languages with remarkable efficiency. Indeed, many studies have made use of language-switching paradigms to explore the mechanisms involved in bilingual language control (e.g. Christoffels, Firk, & Schiller, 2007; Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Jackson, Swainson, Cunnington, & Jackson, 2001; Meuter & Allport, 1999; Philipp, Gade, & Koch, 2007; Philipp & Koch, 2009; Price, Green, & von Studnitz, 1999; Schwieter & Sunderman, 2008; Verhoef, Roelofs, & Chwilla, 2009; Wang, Xue, Chen, Xue, & Dong, 2007). In some form or other, researchers have assumed that some of the processes (if not all) involved in language-switching are the same as those involved in domain-general task-switching. Accordingly, the fact that bilinguals are used to switch between languages regularly may lead to a more efficient (or even qualitatively different) functioning of the task-switching system. This hypothesis about the cross-talk between language-switching and domain-general cognitive systems has been supported by various empirical findings.

First, there are some empirical phenomena similarly occurring in both task-switching and language-switching. For example, the relative difficulty of the two tasks at hand affects the magnitude of the switch costs such that costs are larger for the easier task as compared to the more difficult one (e.g. Martin, Barceló, Hernández, & Costa, 2011; Nagahama et al., 2001; Rubinstein, Meyer, & Evans, 2001; for a review of the different arguments on the origin of this task-difficulty effect in task-switching see Koch, Gade, Schuch, & Philipp, 2010; Schneider & Anderson, 2010). Interestingly, the same asymmetrical pattern is present in language-switching where, at least for low-proficient bilinguals, the magnitude of the switch cost is larger for the dominant language (easy task) in comparison to the non-dominant language (difficult task) (e.g. Meuter & Allport, 1999; but see Calabria et al., 2012). Another example of the similarity between language-switching and domain-general task-switching comes from the so-called $n-2$ repetition cost – slower response latencies returning to a recently performed task after one trial requiring a different task (i.e. ABA sequence) compared to returning to a task not recently performed (CBA sequence) (see Koch et al., 2010; Mayr, 2007; Mayr & Keele, 2000). Philipp and Koch (2009) observed the $n-2$ repetition cost using a picture-naming task implemented in a language-switching paradigm where participants switched among three different languages (German, English, and French) according to a cue. Thus, although indirect, these similarities between language-switching and task-switching are suggestive of underlying common processes.

The second set of evidence comes from the comparison between the performance of bilinguals and monolinguals in task-switching experiments. Early studies comparing bilingual and monolingual children seem to indicate a better ability of bilingual children when switching criteria in a card sorting task (e.g. Bialystok & Martin, 2004). Evidence regarding young adults is provided by three recent studies (Garbin et al., 2010; Prior & Gollan, 2011; Prior & MacWhinney, 2010). We will describe them in some detail below.

Of crucial interest for our purposes is the observation made by Prior and MacWhinney (2010), who compared bilingual and monolingual performance in a task-switching paradigm. In their task, participants had to sort stimuli according to either their color or shape depending on the cue preceding each target. In the mixed-task blocks, the two criteria were randomly presented, and consequently, a given trial required participants to repeat or to switch the sorting criterion. In the single-task blocks, in contrast, only one criterion was used, thus, no switching was required. Mixing costs refer to longer reaction times (RTs) associated to repetition trials in the mixed-task blocks in comparison to trials in the single-task blocks (Los, 1996), and reflect the monitoring processes put at play to perform behavioral adjustments when constant switching is required. Switch costs refer to larger RTs associated with switching trials vs. repeating trials in the mixed-task blocks (Meiran, 1996), and reflect the processes involved in: (a) reactivating the relevant rule (e.g. sorting by color), and (b) reconfiguring stimulus–response (S–R) mappings according to this new rule. Prior and MacWhinney observed a reduced switch cost for bilinguals relative to monolinguals. Mixing costs, in contrast, were not modulated by bilingualism. These results suggest that the ability to reactivate the relevant rule and/or the ability to reconfigure S–R mappings are positively affected by bilingualism.

Relatively consistent results were observed by Prior and Gollan (2011) using the same switch task and comparing the performance of highly-proficient bilinguals (Spanish–English and Mandarin–English) and a group of English monolinguals. The bilingual groups differed in how often they claimed to switch languages on a daily basis, with the Spanish–English bilinguals being more frequent language switchers. The results showed a reduced switch cost (after controlling for socioeconomic variables and overall speed) for Spanish–English bilinguals relative to both Mandarin–English bilinguals and monolinguals. In addition, relative to Mandarin–English bilinguals, Spanish–English bilinguals showed a reduced language-switching cost in a naming task with the same setup as the non-linguistic task. These observations are consistent with the notion that the frequency of language-switching may affect non-linguistic task-switching performance.

In a functional neuroimaging study, Garbin et al. (2010) compared Catalan–Spanish bilingual and Spanish monolingual neural correlates of non-linguistic task-switching. The behavioral results revealed a reduced switch cost for bilinguals in the error rates only. However, a straightforward interpretation of such a behavioral difference is compromised by the fact that bilinguals did not show a switch cost in reaction times. More interesting were the differences at the neural level. Monolinguals recruited the right inferior frontal cortex and the anterior cingulate cortex, replicating previous literature. However, bilinguals were found to recruit a different brain network, consisting in the left inferior frontal cortex and the left striatum, which is typically involved in language processing. Note that strictly speaking, these differences at the neural level are silent regarding the potential advantage of bilinguals in their task-switching ability. Rather, they just provide evidence that bilingualism affects the neural organization of those EC processes implicated in task-switching.

Finally, Soveri, Rodriguez-Fornells, and Laine's (2011) study is also consistent with a bilingual advantage in task-switching, although this time the effect was present only for mixing costs – i.e. negative correlation between language-switching frequency and the mixing cost measured in errors.

Contrasting with Prior and colleagues' studies, Paap and Greenberg (2013) found no bilingual modulation of the switch cost using the same task-switching implementation as those authors. However, Paap and Greenberg did not find the consistently reported bilingual advantage in conflict resolution tasks either, and hence caution needs to be exercised when interpreting such a failure to replicate Prior and colleagues' results.

In sum, previous findings suggest that bilingualism affects the cognitive mechanisms involved in non-linguistic task-switching. However, it is still unclear which specific cognitive mechanisms come into play in this bilingualism effect.

On the different task-switching components potentially affected by bilingualism

To date, the main evidence that bilinguals outperform monolinguals in non-linguistic task-switching is the bilinguals' reduced switch cost observed in Prior and colleagues' studies (Prior & Gollan, 2011 – Spanish–English bilinguals; Prior & MacWhinney, 2010). In the present study we aim at advancing knowledge about the impact of bilingualism on task-switching by exploring what cognitive processes engaged in such task are affected by bilingualism. The fact that the switch cost reflects the complex interaction between multiple cognitive processes (e.g. Kiesel et al., 2010; Logan & Bundesen, 2003; Mayr & Kliegl, 2000; Meiran, 1996; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010; Wylie & Allport, 2000) makes this objective a hard enterprise. In this respect, perhaps the best strategy to approach this question is taking Prior and colleagues' studies as a starting point. To do this we explored the effects of bilingualism in different aspects of task-switching that the particular task implementation used by Prior and colleagues' did not allow to assess independently. In particular, we explored whether bilingualism:

(a) Affects the two components embedded in the switch cost (i.e. S–R reactivation, and S–R reconfiguration).
(b) Only benefits performance if the particular task-switching implementation requires overriding conflicting S–R mappings due to bivalent response sets.

The assessment of these different aspects of task-switching requires specific task-implementations. Therefore, one option to address our questions would be adapting Prior and colleagues' task-implementation to allow the examination of different task-switching aspects. Alternatively, we adopted specific task-implementations from previous literature that have already been specifically developed to assess these different aspects of task-switching. This option helped us to minimize the influence of technical factors on the reliability of the effects.

In the remaining of the Introduction we describe the particular aspects of task-switching assessed in our experiments, why Prior and colleagues' task-implementation does not allow examining them, the particular task-switching implementations we used, and the predictions regarding the impact of bilingualism.

Bilingualism effects on S–R mapping reactivation and reconfiguration

Task-switching always requires reactivating the currently relevant Stimulus–Response association as well as reconfiguring the specific Stimulus–Response mapping according to the new task. The process of reactivating S–R mappings consists of updating the relevant task-set after the presentation of a cue, regardless of whether it instructs to switch or repeat task. The process of reconfiguring S–R mappings is needed to update the appropriate response set in switch trials according to the new task.

Consider for example a card sorting task where participants need to follow the color or shape sorting criteria according to a cue. Every time a cue is presented instructing what sorting criteria to use (e.g. sorting by color), the S–R mappings relevant for the current goal (e.g. right key for red, left key for green) need to be retrieved. This is so independently of whether the specific trial is a repeat or a switch one. That is, even if the preceding trial also required card-sorting by color, the presentation of a cue indicating card-sorting again by color still engages S–R mapping reactivation. Beyond this common process, switch trials require (at least) the additional process of updating the S–R mappings from the previous to the new card-sorting criteria (shape) – e.g. now the right key would need to be associated to the circle shape and the left key to the square shape. The functioning of these two mechanisms (S–R mapping reactivation and reconfiguration) can be told apart only in task-switching implementations in which cues are presented intermittently – after an unpredictable number of target trials (series), a cue signals the need for either switch (e.g. change the card-sorting criterion from shape to color) or keep the same task (continue card-sorting by shape) for the upcoming series. This is because the cost of having to reactivate S–R mappings after a cue cannot be examined in standard task-switching implementations in which every trial is preceded by a cue and, hence, every trial requires reactivating S–R mappings. In contrast, task-switching with intermittent cues allows calculating both the so-called restart and local costs, which in turn permits to disentangle S–R mapping reactivation and S–R mapping reconfiguration respectively. The local cost refers to the longer RTs to the first trial after a switch-cue in comparison to the first trial after a repeat-cue (e.g. sh-sh-sh-"*switch-cue*"-**C-**c-c-c vs. c-c-c-"*repeat-cue*"-**C-**c-c-c; sh = shape and c = color). That is, in a card-sorting task, switching the sorting criterion induces a cost for the first trial of the series. The restart cost refers to the slower RTs for the first trial after a repeat cue (c-c-c-"*repeat cue*"-**C-**c-c-c) than for the second trial after a repeat cue (c-c-c-"*repeat-cue*"-c-**C-**c-c). That is, processing a cue induces a cost for the immediately following trial, even if switching the sorting criterion is not required (e.g. Allport, Styles, & Hsieh, 1994; Allport & Wylie, 2000; Kiesel et al., 2010; Monsell, 2003; Poljac, Koch, & Bekkering, 2009). Interestingly, the processes of S–R mapping reactivation and reconfiguration can be told apart not only behaviorally, but also at neurobiological level by means of electrophysiological recordings (e.g. Barceló, Periáñez, & Nyhus, 2008).

Prior and colleagues' specific task-switching implementation did not allow the separate assessment of these two components, but only the calculation of the local switch cost (switch vs. repeat trials). Since both switch and repeat trials engage S–R reactivation and only switch trials engage S–R reconfiguration, the reduced switch cost associated with bilingualism can only be attributed to a more efficient S–R reconfiguration process. The question now is whether the process of S–R reactivation would also be affected by bilingualism along with the process of S–R reconfiguration.

We explored this question by comparing the performance of bilinguals and monolinguals in an adaptation of the task-switching implementation used in Barceló (2003) that allows independent estimations of both local and restart costs (see Section 'Experiment 1. Bilingualism effects on reactivation vs. reconfiguration of S–R mappings').

In addition, given previous claims about the impact of bilingualism on non-linguistic tasks with different degree of cognitive control demands (e.g. Costa et al., 2009), we also manipulated how much the task taxes cognitive control in two different task versions. In the high-cognitive demand version the cue was implicit – a symbol associated to switch/repeat the immediately preceding card-sorting criteria. In the low-cognitive demand version the cue was explicit – e.g. a cue explicitly reading "sort by color". Previous studies have shown that switch costs tend to be larger with implicit than explicit cues (Periáñez & Barceló, 2008; Saeki & Saito, 2009), and hence, such a manipulation offers the possibility of having a more complete picture of the conditions that have to be met to observe a bilingual advantage in task-switching.

Bilingualism effects on overriding conflicting S–R mappings

A further issue that we address is to what extent the bilingual advantage observed in task-switching stems from a better ability in overriding conflicting S–R mappings, rather than just in a better ability to reconfigure S–R associations. In some task-switching implementations participants not only need to reconfigure S–R associations but also need to override conflicting S–R mappings. Consider for example, Prior and colleagues' implementation where participants had to press the "right key" in response to either the red color or the square shape, and the "left key" in response to either the green color or the circle shape. That is, the same responses (right/left keys) were associated to the two sorting criteria, and hence they are considered bivalent mappings. This is so, even if responses to "color" and responses to "shape" were given with different hands – e.g. they gave a "right key" response with the right hand when sorting by color, but with the left hand when sorting by shape. This is because response bivalency is not only bound to the exact motor response but also to the abstract response meaning. That is, "right" and "left" responses for both criteria (color, shape) are considered bivalent even if the keys are different (and even if responses are given in different modalities – e.g. vocal response for one criterion and manual response for the other; cf. Gade & Koch, 2007; Hübner & Druey, 2006; Schuch & Koch, 2004).

In this context, when reconfiguring S–R mappings in switch trials, participants need to overcome the potential conflict elicited by bivalent mappings, and this may involve inhibitory processes. Thus, one could argue that bilingualism confers an advantage not so much in the ability to reconfigure S–R mappings but in the ability to overcome conflict from bivalent mappings. This possibility fits well with reports of bilinguals consistently outperforming monolinguals in tasks requiring overriding conflicting responses by (presumably) engaging more efficient inhibitory processes (e.g. Stroop task, flanker task; Bialystok et al., 2006b; Costa et al., 2008, 2009; Hernández et al., 2010; Hernández et al., 2012).

A way to address this issue is to assess the process of S–R reconfiguration in contexts in which there is no conflict between S–R mappings, that is in so called univalent mappings – e.g. pressing a response key with the right index finger to indicate red color when using the "color" sorting criterion, and pressing an upper response key to indicate circle shape in the "shape" color sorting criteria). Indeed, univalent contexts lead to smaller switch costs than bivalent ones, suggesting that overriding conflicting S–R mappings incurs in an extra cost (Meiran, Chorev, & Sapir, 2000; Monsell, 2003). This seems to be due to the need of "response recoding" (cf. Meiran, 2000; Schuch & Koch, 2003), which leads to a change in the "meaning" of bivalent S–R mappings. In this respect, as Kiesel et al. (2010) pointed out, the fact that bivalent responses activate more than univalent responses those brain regions typically implicated in inhibitory processes (i.e. right lateral prefrontal cortex; e.g. Brass et al., 2003) leads to the hypothesis that "response recoding" engages inhibitory processes to override conflicting S–R mappings.

The question then is whether one could detect the bilingual advantage in S–R reconfiguration in task-switching contexts involving univalent mappings. If this is not the case, and bilinguals only outperform monolinguals in those task-switching conditions where mechanisms to override conflicting S–R mappings are engaged to a larger extent, then we should reconsider the origin of the bilingual advantage in task-switching. This second issue will be explored by comparing the performance of bilinguals and monolinguals in an adaptation of the task-switching implementation used in Crone, Wendelken, Donohue, and Bunge (2006) (see Section 'Experiment 2. Bilingual effects on overriding conflicting S–R mappings').

Description of the monolingual and bilingual samples

All participants (both bilinguals and monolinguals) lived in the same country (Spain), and hence all of them had been exposed to the same socio-cultural context. Bilingual and monolingual participants only differed in their language history. The monolinguals included in the implicit-cue version of Experiment 1 were Psychology undergraduates at the University of La Laguna, Tenerife. The monolinguals included in the explicit-cue version of Experiment 1, and also those of Experiments 2 and 3 were Psychology undergraduates at the University of Murcia. The bilinguals of all experiments were Catalan–Spanish early and highly-proficient bilinguals and were Psychology undergraduates at the University of Barcelona.

Background details of participants are provided in Table 1. Importantly, bilingual and monolingual groups were matched in age in all experiments. Although the gender distribution overall was not balanced, the same distribution was present for bilinguals and monolinguals in all experiments. Specific care was taken to match both groups of participants for general intelligence. General intelligence was assessed by means of the Superior Scale I of the Ravens Advanced Progressive Matrices (Raven, Raven, & Court, 1998), which participants completed after the experimental session. The task was composed by 12 items containing a picture with a missing piece. Participants were asked to indicate which of the 8 possible pieces arranged below the picture completed it correctly. Both groups of participants were comparable on the scores obtained in this task in all experiments. Moreover, all participants had conducted a common mandatory exam to be enrolled at university. The final mark of this exam ranged from 0 to 10, based on the mean of scores on individual assessments for subjects taught in High School (e.g., Mathematics, History, Life Sciences, etc.). No difference between groups of participants was observed in the grades obtained in this exam.

Table 1
Background details of participants.

Task		*N* (M:F)	Age (in years)	Raven (raw score)	Exam
Exp 1. Implicit-cue version	Bil	50 (5:45)	20	10.8	6.6
	Mon	50 (6:44)	19.9	10.5	6.8
Exp 1. Explicit-cue version	Bil	37 (4:36)	20.6	10.5	6.8
	Mon	37 (6:34)	21.2	10.4	6.5
Exp 2	Bil	20 (3:17)	20.4	10.4	6.6
	Mon	21 (3:18)	20.6	10.5	6.6
Exp 3	Bil	38 (6:32)	19.9	10.6	6.3
	Mon	39 (1:38)	19.8	10.3	6.2

Exp = Experiment; Bil = bilinguals, Mon = monolinguals; M = male, F = female; all $Ps \geqslant .25$.

Catalan–Spanish socio-linguistic context

Catalonia is one of the linguistic communities with the privilege of having two co-official languages (Catalan and Spanish) that are used in all day-to-day contexts – both languages are often spoken between the members of a given family; the current education system requires that children are taught the different subjects in both Catalan and Spanish; in Primary and High School some classes are taught in Catalan and others in Spanish (although with a Catalan preponderance); radio and television programs broadcast in Catalan and in Spanish; newspapers contain articles written in Catalan and Spanish; official bureaucracy can be done in either language, etc. Therefore, Catalan–Spanish bilingual conversations are very frequent in private and professional settings, which require switching back and forth between languages depending on the interlocutor. This gives place to a curious socio-linguistic phenomenon: it is often the case that a given interlocutor speaks in Spanish to a particular interlocutor and in Catalan to another within the same conversation, even if all three speakers are highly-proficient Catalan–Spanish bilinguals. That is, even when switching languages is not needed due to all interlocutors being highly proficient in both languages, language-switching occurs naturally (even among members of the same family).

As a result of the particular Catalan–Spanish bilingual context, all our bilingual participants were exposed to two languages at a very early age (before the age of 4) and received their education in the two languages. Information about bilingual language use was obtained by means of a questionnaire administered after the experiment, where scores represent the amount of time participants used each language, indicated on a 7-point scale (1 = *only Spanish*; 7 = *only Catalan*). Mean scores showed that they had used Catalan around 75% of time and Spanish around 25% across their lifespan (Table 2).

Spanish monolingual context

Contrary to what happens in other European countries, Spain does not have a straightforward policy of linguistic immersion so that the population can learn a foreign language (usually English) at a reasonably level of proficiency – bilingual programs in kindergarten (e.g. Spanish–English) are rare, foreign movies are always dubbed into Spanish on TV, and only few theaters screen them in original

Table 2
Language use of the bilingual participants.

Task	Childhood	Adolescence	Adulthood
Exp 1. Implicit-cue	4.8	4.7	4.6
Exp 1. Explicit-cue	4.8	4.6	4.3
Exp 2	5.1	4.9	4.7
Exp 3	4.8	4.8	4.7

Scores represent the percentage of the time using each language by means of a 7-point scale (1 = only Spanish, 7 = only Catalan).

version; only a low proportion of students go abroad under international/European programs and, typically, it is not until the post-graduate phase that this happens. Only those individuals taking degrees such as English Philology, Tourism, or Translation and Interpretation have a proficient English level.

Therefore, our monolinguals were not functionally fluent in any other language despite formal foreign language instruction at school. Importantly, no monolingual reported to currently use or having used in the past any language other than Spanish with relatives (including parents and siblings), partners, friends or in an educational or work setting. In fact, as it is shown in Table 3, monolinguals did not report a high level of proficiency in a foreign language. Participants were asked to rate their skills in oral comprehension, reading, fluency, pronunciation and writing for their native language (Catalan and Spanish for the bilinguals, and only Spanish for monolinguals) as well as for any foreign language they are better at. This rating was based on a 4-point scale, where: 1 = *low*, barely able to understand/express themselves; 2 = *enough*, sufficient to deal with basic activities (e.g. ask directions, order from a menu); 3 = *good*, the speaker has an obviously foreign accent and does not have a good control of grammar but is able to participate in personal and professional conversations with reasonable efficiency; 4 = *very good*, native level or highly-proficient level that allows the speaker to deal with complex social and professional situations.

Experiment 1. Bilingualism effects on reactivation vs. reconfiguration of S–R mappings

In this experiment we explored the question of whether bilingualism benefits both S–R reactivation and S–R reconfiguration by comparing the magnitude of the restart and local costs between bilinguals and monolinguals. To be able to calculate these two components separately, we used a task-switching implementation used in Barceló (2003).

Participants

One hundred and seventy-four participants took part in the experiment. Fifty Catalan–Spanish bilinguals and 50 Spanish monolinguals took part in the implicit-cue version, and 37 Catalan–Spanish bilinguals and 37 Spanish monolinguals in the explicit-cue one.

Design and procedure

Participants were asked to match a choice-card with one out of four key-cards (one red triangle, two green stars, three yellow crosses, and four blue circles) following one of two rules (Fig. 1): matching the color or the shape. Participants had to press as fast as possible one of four key-buttons, the far left button corresponding to the far left key-card and so on. There were 24 choice-cards, which could be unambiguously matched with one of the four key-cards by just one of the sorting criteria (color or shape). The choice-card changed for each trial. The four key-cards were displayed at the top of the screen, always in the same order, and the choice-card below them, for 3000 ms or until the response. Note that we did not test the matching criterion of 'number', but only 'color' and 'shape'. Even so, we kept the original design for the sake of comparability with the original task (Barceló, 2003) regarding the type of stimuli.

The experiment started with the color criterion. After an unpredictable number of trials (series), a cue was displayed for 200 ms, indicating either to keep the previous criterion (repeat cue) or switch to the other one (switch cue). The cue–target interval (CTI) between a cue and the first trial of the series varied randomly between 500 ms and 600 ms. The response–stimulus interval (RSI) varied randomly between 800 ms and 900 ms. Participants received feedback for incorrect, delayed, or anticipated responses.

In the implicit-cue version, the cues did not contain any specific information about the matching criterion. Instead,

Table 3
Language skills.

Language skills	Language Group	Spanish	Catalan	Foreign language
Oral comprehension	Bilinguals	4	4	2.3
	Monolinguals	4		2.1
Reading	Bilinguals	4	4	2.5
	Monolinguals	4	–	2.2
Fluency	Bilinguals	4	4	1.8
	Monolinguals	4	–	1.6
Pronunciation	Bilinguals	3.8	4	1.9
	Monolinguals	3.7	–	1.8
Writing	Bilinguals	3.9	4	2.4
	Monolinguals	3.8	–	2.1

Scores represent the level of language proficiency according to a 4-point scale (1 = low, barely able to understand/express themselves; 4 = very good, native or highly proficient level).

they indicated whether participants had to keep using the same criterion as in the preceding series ('∫' keep using the same criterion) or switch the criterion ('∼' switch the criterion). In the explicit-cue version, the cues were explicit about the criterion to be implemented in the next series (COLOR or SHAPE).

There were 354 trials presented in 60 series. To avoid cue anticipation, series varied randomly between 4 and 8 trials. Each version was comprised of 5 series of 4 trials, 23 series of 5 trials, 15 series of 6 trials, 7 series of 7 trials, and 10 series of 8 trials. There were 30 switch series (15 color and 15 shape) and 30 repeat series (15 color and 15 shape).

The local cost was calculated taking the RTs of the first trial of a switch series (first trial after a switch cue) minus the RTs of the first trial of a repeat series (first trial after a repeat cue). The restart cost was calculated taking the RTs of the first trial of a repeat series minus the RTs of the second trial of a repeat series.

The predictions for the Experiment 1 were straightforward:

(a) If bilingualism has a facilitatory impact on the ability to reconfigure S–R mappings, bilinguals should show reduced local costs.
(b) If bilingualism facilitates the reactivation of S–R mappings upon cue presentation, bilinguals should show reduced restart costs.
(c) An effect of bilingualism (if any) should be more evident when the task involves higher cognitive control demands (i.e. in the implicit-cue version).

Results

Matching mistakes and RTs longer than 3000 ms or shorter than 200 ms were scored as errors.

We first performed two analyses of variance (ANOVAs) on RTs and error rates using Language Group (bilinguals vs. monolinguals) and Type of cue (implicit vs. explicit) as between-subject factors, and Switch (switch vs. repeat) and Trial (1 to 7) as within-subject factors. Importantly, no main effect of Language Group was observed (RTs: $F(6,170) = 1.69$, $MSE = 240561.08$, $P < .19$; Error rates: $F < 1$), and the only significant interaction involving the factor Language Group was the three-way interaction in the RT analysis between Trial, Language Group, and Type of cue ($F(6,1020) = 4.89$, $MSE = 9022.51$, $P < .0001$). Given that this three-way interaction could be reflecting between-group differences in the local and/or restart costs, we performed additional ANOVAs assessing potential differences between bilinguals and monolinguals in the magnitude of these two effects.

In the ANOVA regarding the local cost, there were two between-subject factors, Language Group (bilingual vs. monolingual), and Type of cue (implicit vs. explicit), and one within-subject factor, Switch (switch vs. repeat). The Switch factor considers responses to the first trial after a switch and a repeat cue. In the analysis of the restart cost, the same between-subject factors (Language Group, and Type of cue), and one within-subject factor, Restart (first vs. second trial after a repeat cue) were considered (Table 4).

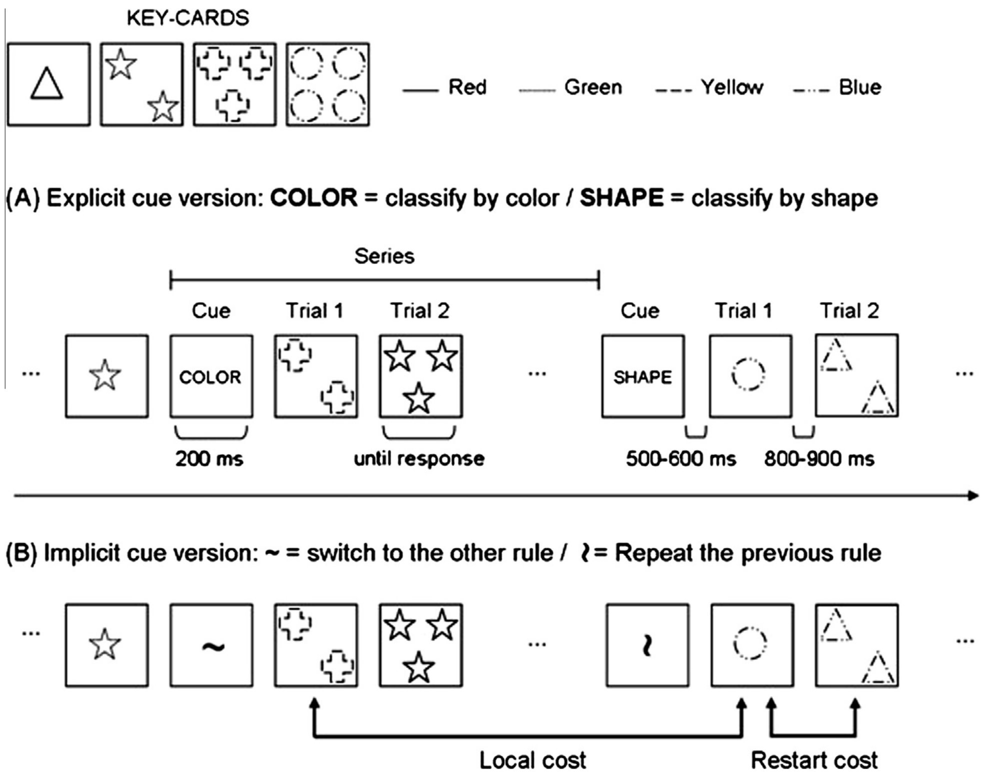

Fig. 1. Schematic examples of one run of the explicit-cue version (Panel A) and the implicit-cue version (Panel B) of Experiment 1.

Local cost (first trial after a repeat cue vs. first trial after a switch cue)

The main effect of Language Group was not significant ($P < .13$). There was a significant main effect of Switch ($F(1,170) = 121.94$, $MSE = 7805.46$, $P < .0001$), with slower RTs when switching than when repeating the matching criterion. RTs were slower in the implicit-cue than in the explicit-cue version ($F(1,170) = 97.85$, $MSE = 78131.34$, $P < .0001$). The magnitude of the local cost was larger in the implicit-cue than in the explicit-cue version (Switch × Type of cue interaction: $F(1,170) = 47.66$, $MSE = 7805.46$, $P < .0001$).

Importantly, neither the two-way interaction between Switch and Language Group nor the three-way interaction between Switch, Language Group, and Type of cue were significant, indicating that the magnitude of the local cost was the same for monolinguals and bilinguals in both cue task versions ($Fs < 1$).

The interaction between Language Group and Type of cue was significant ($F(1,170) = 6.93$, $MSE = 78131.34$, $P < .009$), showing faster RTs for bilinguals in the implicit-cue version ($F(1,98) = 7.95$, $MSE = 100210.19$, $P < .006$) but not in the explicit-cue version ($F < 1$), probably due to the bilingual modulation of the restart cost being embedded in switch trials as well (see Section 'Restart cost (first trial after a repeat cue vs. second trial after a repeat cue)').

The error rates followed the pattern of the RTs regarding the Switch factor. Since there was no interaction involving the factor Language Group, errors were not analyzed further.

Restart cost (first trial after a repeat cue vs. second trial after a repeat cue)

There was no main effect of Language Group ($P < .27$). There was a main effect of Restart ($F(1,170) = 651.92$, $MSE = 9738.64$, $P < .0001$), revealing slower RTs for the first than for the second trial after a repeat cue. The main effect of Type of cue was significant ($F(1,170) = 20.97$, $MSE = 50329.70$, $P < .0001$), revealing slower RTs in the implicit-cue version than in the explicit-cue one. The magnitude of the restart cost was larger for the implicit-cue than for the explicit-cue version (Restart × Type of cue interaction: $F(1,170) = 130.55$, $MSE = 9738.64$, $P < .0001$). Importantly, the three-way interaction between Language Group, Restart, and Type of cue was significant ($F(1,170) = 4.96$, $MSE = 9738.64$, $P < .03$).

Separate ANOVAs for each version revealed a main effect of Language Group only in the implicit-cue version ($F(1,98) = 4.79$, $MSE = 59905.13$, $P < .03$; explicit-cue: $F < 1$), bilinguals being faster than monolinguals. Also, the crucial interaction between Restart and Language Group, indexing differences between monolinguals and bilinguals on the magnitude of the restart costs, was present only in the implicit-cue version (implicit-cue: $F(1,98) = 6.34$, $MSE = 13013.22$, $P < .01$; explicit-cue: $F < 1$).

The errors followed the pattern of the RTs, except for the lack of any interaction involving the factor Language Group (all $Ps < .26$).

Exploring the restart cost embedded in switch trials. As discussed in the Introduction, both switch and repeat trials engage S–R mapping reactivation, hence both type of trials should involve restart costs. Typically, however, the restart cost is calculated considering repeat trials only (i.e. first trial after a repeat cue vs. second trial after a repeat cue) to avoid potential confounding effects from the processes of S–R reconfiguration that are also involved in switch trials.

Here, for the sake of completeness, we examined whether bilingualism impacts the magnitude of the restart cost in the implicit cue version regardless of the type of

Table 4
Mean reaction times (Panel A) and error rates (Panel B) for Trial 1 after a switch cue and Trials 1 and 2 after a repeat cue (Trial 1 switch; Trial 1 repeat; Trial 2 repeat), as a function of Language Group (bilinguals; monolinguals) and Type of cue (implicit; explicit) in Experiment 1. Values in brackets refer to standard deviations. Panel A also displays local and restart cost values as a function of Language Group and Type of cue, as well as the cost differences between Bilinguals and Monolinguals (values in bold). Bil = Bilinguals; Mon = monolinguals.

	Implicit cue			Explicit cue		
	Bil	Mon	*Bil – Mon*	Bil	Mon	*Bil – Mon*
Panel A: Mean reaction times (ms)						
Trial 1 switch	1306	1442	*−136*	1026	990	*36*
	(218)	(259)		(193)	(134)	
Trial 1 repeat	1144	1260	*−116*	983	953	*30*
	(227)	(231)		(183)	(134)	
Trial 2 repeat	789	824	*−35*	825	809	*16*
	(129)	(155)		(140)	(119)	
Local cost (T1 switch – T1 repeat)	162	182	***−20***	43	37	**6**
Restart cost (T1 repeat – T2 repeat)	355	436	***−81***	158	144	**14**
	Implicit cue			Explicit cue		
	Bil	Mon		Bil	Mon	
Panel B: Error rates (%)						
Trial 1 switch	11.4	12.7		7.6	5.1	
	(9.5)	(11)		(6.7)	(6)	
Trial 1 repeat	9.8	8.6		3.1	3.2	
	(8)	(7.5)		(4.1)	(3.8)	
Trial 2 repeat	4.8	4.2		3.2	3	
	(4.7)	(4.4)		(3.5)	(3.8)	

trial (switch, repeat). We performed an ANOVA including Switch (switch vs. repeat) and Trial (first vs. second trial after a cue) as within-subject factors, and Language Group (bilingual vs. monolingual) as a between-subject factor. If bilingualism reduces the restart cost regardless of the type of trials, bilinguals should show faster response latencies than monolinguals to the second relative to the first trial after a cue in both switch and repeat series. This would be confirmed by a two-way interaction between Language Group and Trial in the absence of a three-way interaction between Language Group, Trial, and Switch.

The results showed a main effect of Switch ($F(1,98) = 221.57$, $MSE = 7124.93$, $P < .0001$) reflecting slower response latencies for switch (1129 ms) than repeat (1004 ms) trials. The main effect of Trial ($F(1,98) = 811.51$, $MSE = 24046.48$, $P < .0001$) reflected slower response latencies for the first trials after a cue (1288 ms) relative to the second trials after a cue (846 ms). There was also a main effect of Language Group ($F(1,98) = 5.658$, $MSE = 120565.43$, $P < .019$) indicating that bilinguals (1026 ms) were overall faster than monolinguals (1108 ms). The two-way interaction between Switch and Trial ($F(1,98) = 35.47$, $MSE = 6037.74$, $P < .0001$) revealed that the difference in RTs between the first and second trial after a cue was larger in the switch series (488 ms) than in the repeat series (396 ms). The two-way interaction between Language Group and Trial ($F(1,98) = 7.93$, $MSE = 24046.48$, $P < .006$) revealed that faster response latencies of bilinguals relative to monolinguals were more evident in first trial after a cue (bilinguals = 1225 ms, monolinguals = 1351 ms; $t(97) = 2.65$, $P < .009$) than in the second trial after a cue (bilinguals = 827 ms, monolinguals = 867; $t(97) = 1.37$, $P < .17$). The lack of a three-way interaction between Switch, Trial, and Language Group indicated that bilinguals were faster than monolinguals in the first trial after a cue in both repeat and switch series (Fig. 2).

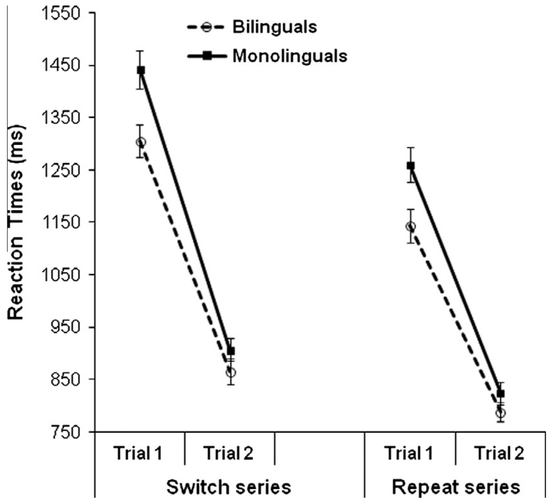

Fig. 2. Response latencies (in ms) broken by Switch (switch vs. repeat), Trial (first vs. second after a cue) and Language Group (bilinguals vs. monolinguals) in the implicit version of Experiment 1. Error bars represent standard error.

Discussion

In this experiment we aimed at assessing the impact of bilingualism on the S–R reactivation and S–R reconfiguration in task-switching, by asking participants to perform an intermittent switch task that allows disentangling these two components. As argued above, we took the magnitude of the local cost to reflect the reconfiguration of S–R mappings involved when switching tasks, and the magnitude of the restart cost to reflect the reactivation of S–R mappings. Furthermore, we assessed the magnitude of these two effects in two versions of the switch task involving different amounts of cognitive load. These versions made use of either implicit or explicit cues.

Several relevant results were obtained in this experiment.

(a) Reliable restart and local costs were detected in the two groups of participants.
(b) Local costs were similar in bilinguals and monolinguals.
(c) Restart costs were larger for implicit than for explicit cues, and for monolinguals than for bilinguals when the cue was implicit.

The last two results are probably the most interesting in the present context. Note that our experimental setting led to a sizable local cost (about 180 ms) and was sensitive enough to detect modulations of such an effect when comparing the different types of cues. Thus, it is unlikely that the lack of a bilingual effect in the magnitude of the local cost can be attributable to a lack of sensitivity of the design. We defer further discussion of this issue to the 'General discussion'.

The lack of modulation of the restart cost in the explicit-cue version fits well with our prediction that any effect of bilingualism should be more evident in the task version involving higher cognitive control demands (i.e. in the implicit-cue task version).

Together these results suggest that under high cognitive control demands (implicit cues) bilingualism facilitates the ability to reactivate the currently relevant S–R mappings after an interruption with a cue (as indexed by the larger magnitude of restart costs for monolinguals). In contrast, bilingualism does not seem to exert any effect on the ability to reconfigure the S–R mappings according to the new matching criterion (as indexed by the similar magnitude of local costs for bilinguals and monolinguals).

Experiment 2. Bilingual effects on overriding conflicting S–R mappings

In this experiment we explored whether bilingualism benefits performance on task-switching only if mechanisms to override conflicting S–R mappings are engaged – i.e. in contexts of bivalent S–R mappings. To explore this question we used an adaptation of Crone et al.'s (2006) task-switching implementation that allows assessing the switch cost in different S–R valence conditions.

Participants

Forty-one participants took part in the experiment (20 Catalan–Spanish bilinguals, and 21 Spanish monolinguals).

Design and procedure

In this task, participants had to respond to a picture (stimulus) according to previously learnt S–R mappings indexed by a cue. There were four experimental picture stimuli (a chair, a tree, a butterfly, and a jacket). The cue, presented before the picture and never displayed along with it, could be a circle, a triangle, a star, or a bidirectional arrow. The pictures of a "chair" and a "tree" could be presented after the circle cue, the triangle cue, or the star cue, but never the bidirectional arrow cue. The pictures of a "butterfly" and a "jacket" were always presented following only the bidirectional arrow cue (Fig. 3). The S–R mappings for each cue were set in the following manner.

Circle:	Respond with a right-key press to chair
	Respond with a left-key press to tree
Triangle:	Respond with a right-key press to tree
	Respond with a left-key press to chair
Bidirect. arrow:	Respond with a right-key press to butterfly
	Respond with a left-key press to jacket
Star:	Respond by pressing once the up-key to chair
	Respond by pressing twice the up-key to tree

Each single stimulus was always preceded by a cue. A given trial preceded by a trial with the same cue was considered a "repeat trial" (e.g. a trial with a circle cue preceded by another trial with a circle cue). A given trial preceded by a trial with a different cue was considered a "switch trial" (e.g. a trial with a circle cue preceded by a trial with a triangle cue). This allowed the calculation of the switch cost (switch vs. repeat trials), which indexes the process of S–R mapping reconfiguration that is always engaged in switch but never in repeat trials.

Accordingly, there were six combinations leading to three types of "repeat" (RP) trials and three types of "switch" (SW) trials.

Repeat trials:

(a) "Repeat bivalent" trials (RP_Bi): Bivalent trials preceded by bivalent trials (trials with a circle cue preceded by trials with a circle cue, and trials with a triangle cue preceded by trials with a triangle cue).
(b) "Repeat univalent" trials (RP_Uni): Univalent trials (bidirectional arrow) preceded by univalent trials (bidirectional arrow).
(c) "Repeat semi-bivalent" trials (RP_semi-Bi): Semi-bivalent trials (star cue) preceded by semi-bivalent trials (star cue).

Switch trials:

(d) "Switch to bivalent" trials (SW to Bi): Bivalent trials (circle cue or triangle cue) preceded by univalent (bidirectional arrow cue), semi-bivalent trials (star

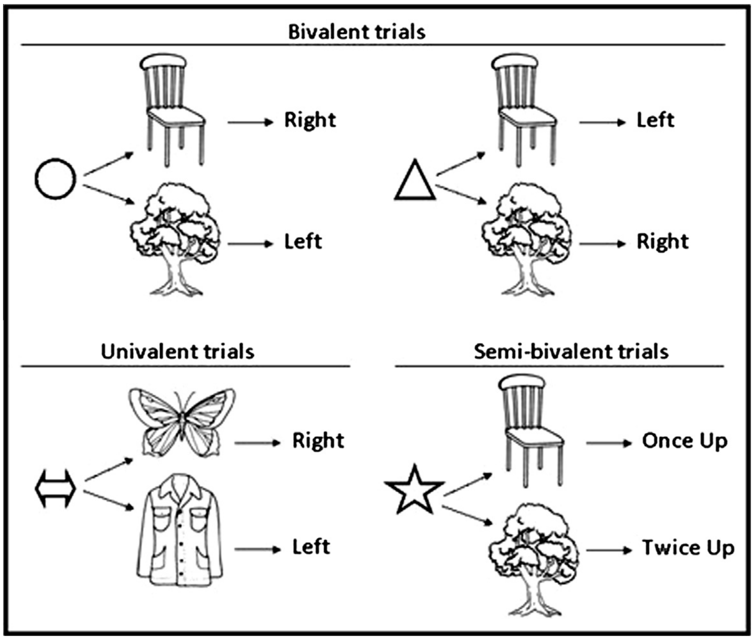

Fig. 3. Schematic illustration of the four types of cue (circle, triangle, bidirectional arrow and star) that, in combination with the stimuli pictures (chair, tree, butterfly and jacket) and with the response-set (right, left, once up, and twice up), gave three types of trials (bivalent, univalent, and semi-bivalent) in Experiment 2.

cue), or bivalent trials with the opposite cue (circle cue preceded by triangle cue or the other way around).

(e) "Switch to univalent" trials (SW to Uni): Univalent trials (bidirectional arrow cue) preceded by bivalent (circle cue, a triangle cue) or semi-bivalent trials (star cue).

(f) "Switch to semi-bivalent" trials (SW to semi-Bi): Semi-bivalent trials (star cue) preceded by bivalent (circle cue, a triangle cue) or univalent trials (bidirectional arrow cue).

Regarding the procedure, participants were asked to learn with no time-limit the associations between the visual cues and the specific set of S–R mappings. Subsequently, there was a consolidation phase in which the S–R mappings were practiced for each type of cue separately, in short blocks of 10 trials for each type of cue. The consolidation phase was performed twice. Then, participants performed a practice block of 80 trials (20 trials for each type of cue – circle, triangle, bidirectional arrow and star) that were pseudo-randomly mixed. After this practice session, the actual experiment started, which was composed of two blocks of 160 trials. In each block, 40 trials for each type of cue were presented in a pseudo-randomly mixed order. The number of occasions in which current trials with a given type of cue (e.g. trials with a circle cue) were preceded by trials with any type of cue (e.g. circle, triangle, bidirectional arrow, star) was equal. For example, out of the 40 trials with a circle cue in every block, ten of them were preceded by the same cue (circle), other ten by a triangle cue, other ten by a bidirectional cue, and the remaining ten by a star cue. Therefore, across the whole experiment there were 80 repeat trials (40 bivalent, 20 univalent, and 20 semi-bivalent) and 240 switch trials (120 into bivalent, 60 into univalent, and 60 into semi-bivalent).

Trials had the following structure: after the presentation of a fixation cross for 800 ms a visual cue was presented for 1000 ms, followed by a 500 ms delay (blank screen), and then the target. The target was present on the screen until participants responded or up to 1700 ms.

The predictions for the Experiment 2 were as follows:

(a) If bilingualism helps to override conflicting S–R mappings, bilinguals should show a reduced cost when switching into bivalent trials (and possibly also a reduced cost when switching into semi-bivalent trials since, despite not opposite, the different response set associated to the same stimuli may create conflict).

(b) If bilingualism exerts a facilitatory impact on the ability to reconfigure S–R mappings, bilingualism should reduce the switch cost in all types of trials.

(c) If bilingualism exerts a facilitatory impact on both abilities (reconfiguring S–R mappings and overriding conflicting S–R mappings), bilingualism should reduce the switch cost in all types of trials, the size of this reduction being significantly larger when switching into bivalent trials.

Results

Responses either faster or slower than 2.5 *SD* relative to every participant's mean within each type of trial were excluded from the analyses. This led to the loss of 2.54% trials (bilinguals: 2.53%, monolinguals: 2.55%). In the ANOVAs there were two within-subjects factors, Switch (switch

Table 5

Mean reaction times (Panel A) and error rates (Panel B) as a function of Language Group (bilinguals; monolinguals), Switch (switch vs. repeat) and Type of cue (bivalent, univalent, and semi-bivalent). Values in brackets refer to standard deviations. Panel A also displays the switching cost value as a function of Language Group and Type of cue, as well as the cost differences between bilinguals and monolinguals (values in bold). Bil = Bilinguals; Mon = monolinguals.

	Switch trials			Repeat trials		
	Bil	Mon	*Bil − Mon*	Bil	Mon	*Bil − Mon*
Panel A: Mean reaction times (ms)						
Bivalent trials	648	758	*−110*	573	687	*−114*
	(162)	(143)		(143)	(137)	
Univalent trials	509	608	*−99*	501	595	*−94*
	(93)	(123)		(81)	(126)	
Semi-bivalent trials	502	612	*−110*	479	579	*−100*
	(122)	(113)		(102)	(105)	
Switch into bivalent trials (SW_Bi − RP_Bi)	75	71	***4***			
Switch into univalent trials (SW_Uni − RP_Uni)	8	13	*−**5***			
Switch into semi-bivalent trials (SW_semi-Bi − RP_semi-Bi)	23	33	*−**10***			

	Switch trials		Repeat trials	
	Bil	Mon	Bil	Mon
Panel B: Error rates (%)				
Bivalent trials	5.83	5.83	3.12	2.02
	(2.51)	(3.22)	(2.55)	(2.45)
Univalent trials	1.08	0.71	1.75	0.24
	(1.81)	(0.71)	(2.93)	(1.09)
Semi-bivalent trials	0.67	1.35	0.25	1.9
	(0.99)	(1.79)	(1.12)	(2.49)

vs. repeat), and Type of cue (bivalent, univalent, and semi-bivalent), and one between-subject factor, Language Group (bilingual vs. monolingual) (Table 5).

The main effect of Language Group was significant ($F(1,39) = 8.81$, $MSE = 75864.98$, $P < .005$), indicating that bilinguals (535 ms) were overall faster than monolinguals (640 ms). There was a significant main effect of Switch ($F(1,39) = 48.92$, $MSE = 1729.42$, $P < .0001$), with slower RTs for switch (606 ms) than repeat (569 ms) trials. The main effect of Type of cue was also significant ($F(2,78) = 71.28$, $MSE = 5414.62$, $P < .0001$). Pair-wise comparisons revealed that responses to bivalent trials were slower than both univalent ($t(40) = 9.45$, $P < .0001$) and semi-bivalent ($t(40) = 10.1$, $P < .0001$) trials, which, in turn, did not differ ($t < 1$).

There was a two-way interaction between Type of cue and Switch ($F(2,78) = 18$, $MSE = 1154.17$, $P < .0001$) indicating an effect of bivalency. Post-hoc analyses showed that switching into bivalent trials was more costly than switching into both univalent ($F(1,39) = 28.37$, $MSE = 1371.26$, $P < .0001$) and semi-bivalent trials ($F(1,39) = 14.17$, $MSE = 1448.28$, $P < .001$). In turn, switching into semi-bivalent trials was more costly than switching into univalent trials ($F(1,39) = 4.58$, $MSE = 642.96$, $P < .04$), reflecting that a milder bivalency effect arises whenever the same stimuli are associated with different but not opposite response sets. Crucially, however, the interaction between Type of cue, and Language Group was not significant ($F < 1$), indicating that the effect of bivalency was of a comparable magnitude for bilinguals and monolinguals. Neither the interaction between Switch and Language Group ($F < 1$), or the interaction between Switch, Type of cue, and Language Group ($F < 1$) were significant, indicating no differences between bilinguals and monolinguals in the magnitude of the local cost across all type of cues.

In the error analysis, the main effect of Language Group was not significant ($F < 1$). However, the interaction between Type of cue and Language Group ($F(2,78)=4.89$, $MSE = 5.26$, $P < .01$) was significant. Pair-wise comparisons showed that monolinguals' proportion of errors in semi-bivalent trials was higher than that of bilinguals (mean difference: 0.93% errors, $t(39) = 2.33$, $P < .02$), and that the proportion of errors in the other two types of trials was similar for bilinguals and monolinguals (bivalent: $t(39) < 1$; univalent: $t(39) = 1.43$, $P < .16$). The rest of the main effects and interactions followed the pattern of the RTs. Note that these results ruled out the possibility that overall faster response latencies of bilinguals were due to a trade-off effect.

Discussion

In this experiment we aimed at assessing whether bilingualism reduces switch costs when mechanisms to override conflicting S–R mappings need to be engaged. With this aim, we compared bilinguals' and monolinguals' performance on a task-switching implementation containing various conditions varying in the need of overriding conflicting S–R mappings: bivalent, semi-bivalent, and univalent conditions.

This experiment led to the following main results in the present context.

(a) Switch costs were present for all type of trials.
(b) Bivalent stimuli led to slower RTs than univalent and semi-bivalent stimuli.
(c) Switch costs were larger for bivalent stimuli than for the other two types of stimuli, and also for semi-bivalent relative to univalent.
(d) Bilinguals were overall faster than monolinguals.
(e) The magnitude of the switch cost and the bivalency effect was similar in bilinguals and monolinguals.

The first three observations replicated previous results by Crone et al. (2006), and revealed that our experiment was sensitive to a wide range of variables. The extra processing cost (in terms of overall RTs and larger switch costs) of bivalent trials in comparison to univalent and semi-bivalent trials, indexes the process of overcoming the interference from conflicting S–R mappings afforded by bivalent trials. In addition, the milder bivalency effect observed when comparing the switch costs of semi-bivalent and univalent trials indicates that overcoming different but not opposite S–R mappings also incurs an extra processing cost.

More important for our present purposes is the observation that bilingualism does not affect the magnitude of the switch cost, even in conditions in which participants have to overcome previous strongly conflicting S–R mappings (bivalent trials). This result is at odds with previous reports (Prior & Gollan, 2011-Spanish–English group; Prior & MacWhinney, 2010), where bilingualism reduced the magnitude of the switch cost in a task-switching with bivalent S–R mappings. However, the lack of modulation of the switch cost by the bilingual status is consistent with the observations of Experiment 1 in which the local cost was unaffected by bilingualism.

In addition, bilinguals' overall faster response latencies revealed that in this experiment bilinguals were more efficient than monolinguals at performing the task in all conditions (bivalent, semi-bivalent, univalent) and type of trials (repeat, switch). This observation is consistent with previous studies comparing bilinguals and monolinguals in conflict resolution tasks where bilinguals showed faster response latencies regardless of the type of trials (conflicting, non-conflicting) (e.g. Bialystok, 2006; Costa et al., 2008, 2009; Hernández et al., 2012; Martin-Rhee & Bialystok, 2008).

Interim summary

Building on previous observations of reduced switch costs for bilinguals, in the previous experiments we aimed at exploring the contribution of S–R reactivation, S–R reconfiguration, and conflict resolution processes to such effect.

In Experiment 1, we assessed whether bilingualism impacts S–R reactivation and S–R reconfiguration by means of exploring the magnitude of restart and local switch costs. The pattern of results observed in the two cue–task versions replicated the presence of independent restart and local costs:

(a) Restart costs were present when comparing the first and second trials on repeat series.
(b) Local costs were present when comparing the first trial in repeat and switch series, being such effect larger with implicit cues.

Importantly, differences between bilinguals and monolinguals were observed only for restart costs in the most cognitively demanding context, that is, when the cues were implicit. This revealed that bilingualism affected the process of reactivating S–R mappings. Also, the lack of a bilingual modulation of local costs suggests that the processes involved in S–R reconfiguration are not affected by the bilingual status of the participants.

In Experiment 2 we assessed whether a potential bilingual advantage in task-switching stems from a better ability to resolve conflict between conflicting S–R mappings. Hence, we explored bilinguals' and monolinguals' task-switching performance on univalent and bivalent (conflicting) response set mappings. We replicated previous observations regarding bivalency effects – slower RTs were observed when switching into bivalent, relative to univalent/semi-bivalent trials. However, the magnitude of the switch costs for bilinguals and monolinguals was comparable irrespective of the S–R mapping valence. Nevertheless, bilinguals appeared to be faster in all types of trials.

Together these results reveal that the bilingualism effect in task-switching is more constrained than previously thought. In particular, we failed to observe any modulation of local switch costs in Experiments 1 and 2, even in conditions in which conflicting S–R mappings were involved. Hence, to the extent that local switch costs index the processes behind S–R mapping reconfiguration, we could tentatively conclude that bilingualism does not affect such processes. However, caution needs to be exercised when drawing strong conclusions at this point, since the present set of results conflicts with previous reports. Recall that Prior and colleagues reported a reduced switch cost for bilinguals relative to monolinguals. This inconsistency between the results of our Experiments 1 and 2 and Prior and colleagues' casts doubts on the particular experimental conditions that have to be met to find a modulation of the switch cost associated with bilingualism.

Given these experimental inconsistencies, it is necessary to gather more information about the potential effect of bilingualism on S–R mapping reconfiguration, and hence, on the local switch costs. Perhaps the most reasonable step to take is to assess a bilingual effect in an experiment that uses the same instantiation of the task-switching paradigm that has already been shown to be sensitive to the bilingual status of the participants (Prior & Gollan, 2011; Prior & MacWhinney, 2010) (see Section 'Experiment 3. Attempt of a direct replication of Prior and colleagues').

Also, we performed an omnibus analysis combining the standardized switch cost scores for every bilingual and monolingual across the three experiments (see Section 'Omnibus analysis: Switch cost across the three experiments').

Seeking bilingualism effect on S–R reconfiguration

Experiment 3. Attempt of a direct replication of Prior and colleagues

In Experiment 3, we used the same instantiation of the task-switching paradigm as in Prior and Gollan (2011), and Prior and MacWhinney (2010) (see also Rubin & Meiran, 2005). Participants had to sort stimuli according to their color (red or green) or shape (circle or triangle). The sorting criterion used in each trial was determined by a preceding cue. In the mixed-task blocks, the cues unpredictably indicated to switch the criterion of classification from trial to trial. In the single-task blocks, the cues indicated the same classification criterion – thus, no switches were required. This design allows the assessment of both switch costs (i.e. larger RTs associated with switch trials vs. repeat trials in the mixed-task blocks) and mixing costs (i.e. longer RTs associated to repeat trials in the mixed-task blocks vs. trials in the single-task blocks). In this setting, the switch cost reflects the process of S–R mappings reconfiguration according to the new rule. The mixing cost is supposed to index the functioning of the monitoring system.

There are two predictions on the potential influence of bilingualism in this experiment:

(a) If bilingualism exerts a facilitatory impact on the ability to reconfigure S–R mappings, it should reduce the switch cost.
(b) If bilingualism exerts a facilitatory impact on the ability to monitor the need to switch, it should reduce the mixing cost.

In the present context, the first prediction is of especial interest, given our previous failure to observe any difference between monolinguals and bilinguals in S–R reconfiguration.

Participants

Seventy-seven participants took part in the experiment (38 Catalan–Spanish bilinguals, and 39 Spanish monolinguals).

Design and procedure

Participants were asked to indicate either the color (red or green) or shape (circle or triangle) of a target according to a cue. The size of each shape was $2.8^\circ \times 2.8^\circ$ for the circle, and $2.3^\circ \times 2.3^\circ$ for the triangle. The cue instructing participants to indicate the color of the targets was a color gradient, and the cue instructing them to indicate the shape of the targets was a row of small block shapes with a size of $4.5^\circ \times 0.8^\circ$. In every trial, a cue indicated what criterion (color or shape) to follow. Participants responded as fast as possible with their index and middle fingers. They used the right hand for one criterion (color or shape; counterbalanced across participants) and the left hand for the other criterion. Each trial started with a fixation cross presented for 350 ms, followed by a delay (blank screen) of 150 ms. Then the cue was presented for 250 ms and remained on the screen when the target appeared. Both cue and target remained on the screen until participants responded or up to 4000 ms. Participants received feedback for incorrect responses through use of a 100 ms beep. There was an 850 ms delay between trials.

In each block half of the trials required a right-press key and the other half a left-press key. In single-task blocks participants were required to respond following only one criterion (color or shape). Single-task blocks were composed of 8 practice trials followed by 36 experimental trials. In mixed-task blocks both the color and the shape criteria were pseudo-randomly mixed. Thus, in mixed-task blocks there were two types of trials (repeat and switch). Any trial preceded by a trial with the same criterion (e.g. a trial with a color cue preceded by a trial with a color cue) was considered "repeat" trial. Any trial preceded by a trial with the other criterion (e.g. a trial with a color cue preceded by a trial with a shape cue) was considered "switch" trial. Each mixed-task block included 48 trials, half of which were "repeat" and the other half "switch". Trials were pseudo-randomly mixed so that there were no more than four consecutive trials of the same type (repeat or switch). There were always two dummy trials at the beginning of each mixed-task block. First, participants completed two single-task blocks, one including only the "color" criterion and the other the "shape" criterion (counterbalanced across participants). Then, participants performed a 16-trial practice for the mixed-task blocks, followed by three experimental mixed-task blocks. Finally, other two single-task blocks were administered, one including only the "color" criterion and the other the "shape" criterion (counterbalanced across participants).

Results

Responses that were either faster or slower than 2.5 *SD* relative to every participant's mean within each type of trial were excluded from the analyses (total 2.8% trials – bilinguals: 2.7%, monolinguals: 2.9%). Only trials from mixed-task blocks (repeat and switch) were considered in the analyses exploring the switch cost. Analyses that looked at the mixing cost included repeat trials of mixed-task blocks and trials of single-task blocks. Following the same procedure as Prior and MacWhinney (2010), two separate ANOVAs were carried out to explore the switch and the mixing costs (Table 6).

Switch cost (switch vs. repeat trials in mixed-task blocks). Language Group (bilingual vs. monolingual) was included as a between-subject factor, and Switch (switch vs. repeat) as a within-subjects factor in the ANOVA.

There was a significant main effect of Switch ($F(1,75) = 321.98$, $MSE = 3253.02$, $P < .0001$), with slower RTs for switch (785 ms) than repeat (620 ms) trials. Neither the main effect of Language Group ($F < 1$) nor the interaction between Switch and Language Group ($F < 1$) were significant. Thus, there were no differences between bilinguals and monolinguals in the magnitude of the switch cost.

The error rates followed the pattern of the RTs regarding the Switch factor, and since there was no interaction involving the factor Language Group, errors were not analyzed further.

Table 6
Mean reaction times (Panel A) and error rates (Panel B) as a function of Language Group (bilinguals; monolinguals) and Type of trial (switch, repeat and single) in Experiment 3. Values in brackets refer to standard deviations. Panel A also displays the switching cost and mixing cost values as a function of Language Group, as well as the cost differences between Bilinguals and Monolinguals (values in bold). Bil = Bilinguals; Mon = monolinguals.

	Bil	Mon	*Bil* – *Mon*
Panel A: Mean reaction times (ms)			
Mixed-task blocks: Switch	790 (123)	779 (110)	*11*
Mixed-task blocks: Repeat	626 (88)	614 (90)	*12*
Single-task blocks	483 (67)	484 (70)	*−1*
Switch cost (switch – repeat)	164	165	***−1***
Mixing cost (repeat – single)	143	130	***13***

	Bil	Mon
Panel B: Error rates (%)		
Mixed-task blocks: Switch	10.38 (5.24)	12.04 (3.55)
Mixed-task blocks: Repeat	5.74 (3.89)	6.55 (3.82)
Single-task blocks	3.11 (3.2)	3.31 (2.5)

Mixing cost (repeat trials in mixed-task blocks vs. trials in single-task blocks). Language Group (bilingual vs. monolingual) was included as a between-subject factor, and Mixing (repeat vs. single) as a within-subjects factor in the ANOVA.

There was a significant main effect of Mixing ($F(1,75) = 359.28$, $MSE = 2000.11$, $P < .0001$), with slower RTs for repeat trials in mixed-task blocks (620 ms) than trials in single-task blocks (484 ms). Neither the main effect of Language Group ($F < 1$) nor the interaction between Mixing and Language Group ($F < 1$) were significant, indicating that bilinguals and monolinguals performed similarly in repeat trials in mixed-task blocks and trials in single-task blocks. Thus, there were no differences between bilinguals and monolinguals in the magnitude of the mixing cost.

The error rates followed the pattern of the RTs regarding the Mixing factor, and since there was no interaction involving the factor Language Group, errors were not analyzed further.

Discussion

The main aim of this experiment was to assess the extent to which switch costs were affected by the bilingual status of the participants. Given the conflicting results in respect to this issue between our Experiments 1 and 2 and those obtained by Prior and collaborators, we tested this issue under the same experimental conditions as Prior et al.'s studies.

This experiment led to the following main result: There were robust switch and mixing costs, and their magnitudes were independent of the status of the participants (bilingual or monolingual).

This observation revealed that although the experiment was sensitive and revealed quite large switch and mixing costs, these effects were not affected by bilingualism. The lack of a bilingual modulation of the switch cost fits well with the results of our two previous studies and with the outcome of Prior and Gollan (2011) in the Mandarin–English bilingual group. However, it is in contrast with Prior and MacWhinney's (2010) as well as with the outcome of Prior and Gollan (2011) in the Spanish–English group.

Thus, this experiment failed to replicate previous observations. However, and in order to gather further insights about potential differences between bilinguals and monolinguals in the magnitude of the switch cost (or its distribution across participants), we performed an omnibus analysis looking for a bilingualism effect across our three experiments.

Omnibus analysis: Switch cost across the three experiments

We combined the three experiments in an omnibus analysis including 292 participants (145 bilinguals and 147 monolinguals). For this analysis we used the local cost of Experiment 1, the switch cost of Experiment 2 collapsing all valence conditions (bivalent, semi-bivalent, and univalent), and the switch cost of Experiment 3. Since the magnitude of the switch costs was different across the three studies due to the different instantiations of the task-switching paradigm, we standardized such magnitudes by converting them into *z*-scores. This standard score was calculated by subtracting the population mean (i.e. the mean of the bilingual and monolingual samples combined) from an individual raw score and dividing the difference by the standard deviation of that population, for each experiment separately. The resulting score indicated how many standard deviations a particular data-point was above or below the mean (that is 0). Thus, these *z*-scores allowed us to examine the distribution of the switch cost of all participants – if the switch cost was smaller for bilinguals relative to monolinguals, we should observe a left-shifted distribution of bilingual *z*-scores. That is, overall bilingual *z*-scores should be below the mean to a larger extent than monolingual *z*-scores. However, as it can easily be appreciated in Fig. 4, where we plotted the *z*-scores of all 292 participants, the bilingual and monolingual *z*-score distributions are very similar. In addition, the chi-square test comparing bilinguals and monolinguals in the number of *z*-scores that fell in every 1 *SD*-interval showed that the number of bilingual and monolingual *z*-scores in every 1 *SD*-interval was very similar (see Table 7).

In sum, the results of this omnibus analysis indicate that after largely increasing the statistical power, the bilingual advantage in the switch cost is still absent. Importantly, the omnibus analysis also allows us to assess better the similarity of the switch cost distribution for both groups of participants. As it can be appreciated, such similarity is very large.

General discussion

One of the fundamental differences between bilingual and monolingual language processing is that in many sociolinguistic contexts bilinguals are used to switch between two languages. Previous studies have shown that the ability of bilinguals to perform language-switching seems to benefit general task-switching performance [e.g. Prior & Gollan, 2011 – Spanish–English group; Prior & MacWhinney, 2010; but see Paap and Greenberg (2013)]. The objective of the present study was to advance our knowledge on this collateral effect of bilingualism by examining the performance of monolinguals and bilinguals in three different implementations of the task-switching paradigm that afford the assessment of different components of task-switching.

In a nut-shell the three main results reported in our experiments are:

(1) A reduced restart cost for bilinguals relative to monolinguals in the more cognitive demanding version of the task (i.e. implicit cue) in Experiment 1.
(2) Overall faster response latencies in bilinguals in Experiment 2.
(3) Similar switch costs for bilinguals and monolinguals in all three experiments.

In the following we will discuss the implications of these observations for understanding the potential effects of bilingualism in task-switching. We will pay specific attention to our failure to replicate the previously reported modulation of switch costs by bilingualism.

Which language to speak to whom? On the origin of bilinguals' reduced restart cost and overall faster RTs

Bilinguals, as compared to monolinguals, appear to have a reduced restart cost – indexed in contexts of

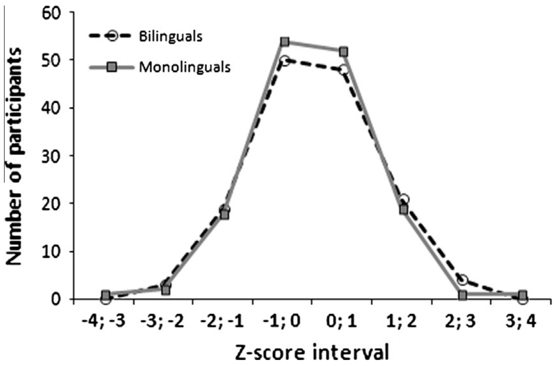

Fig. 4. Density distribution in every 1 *SD*-interval of bilinguals' and monolinguals' *z*-scores of the local-switch cost.

Table 7
Number of bilinguals' and monolinguals' *z*-scores in every 1 *SD*-interval.

z-Score interval	Bilinguals' *z*-scores	Monolinguals' *z*-scores
−2 to −3	3	2
−1 to −2	19	18
0 to −1	50	54
0 to 1	48	52
1 to 2	21	19
2 to 3	4	1
3 to 4	0	1

All $\chi^2 < 1.87$, all $Ps > .21$.

intermittent cueing by the difference in RTs between the first and the second trials after a cue, either if it instructs to switch or repeat. This is observed in switch contexts especially taxing the cognitive system, meaning when implicit cues are used. Restart costs have been interpreted as reflecting the processes of reactivating the S–R mappings relevant to the task at hand. Hence, to the extent that such interpretation is correct, we can conclude that bilingualism aids updating the relevant task-set. This bilingualism effect vanishes, however, when the task explicitly cues the criterion to be used. This difference between explicit and implicit cues might reveal that the S–R mapping reactivation processes are especially demanding when cues do not explicitly afford the criterion to be used. Hence, this context offers more chances to detect potential differences between bilinguals and monolinguals in S–R mapping reactivation.

The benefit of bilingualism on the process of updating the relevant task-set fits well with previous studies comparing bilinguals and monolinguals in conflict resolution tasks, such as the Simon, Stroop or flanker tasks (Bialystok, 2006; Costa et al., 2008, 2009; Martin-Rhee & Bialystok, 2008). Typically, when these conflict resolution tasks involved high-monitoring demands, bilinguals were faster than monolinguals. These high-monitoring demands are met when different types of trials are intermixed, such as congruent, incongruent and neutral trials. Mixing this sort of trials implies that the participants need to constantly update, for each trial, the need of engaging conflict resolution processes (i.e. inhibitory mechanisms). That is, for each given trial participants need to decide whether to engage or not resolution processes, given that some trials do not need it (neutral and congruent trials). Consider for example Costa et al.'s (2009) observation that bilinguals performed a flanker task overall faster than monolinguals in high-monitoring contexts, where congruent and incongruent trials were mixed (e.g. 50% congruent and 50% incongruent trials). In contrast, the bilingual advantage in overall RTs disappeared in low-monitoring conditions, where the stimuli were more homogeneous throughout the experiment (e.g. 92% congruent trials). In other words, the larger the involvement of monitoring processes, the larger the bilingualism effect.

This effect of bilingualism on updating or monitoring processes has been tentatively associated to the need of updating the language to be used as a function of the specific interlocutor in bilingual contexts where bilingual conversations are not rare. That is, in conversations involving individuals speaking different languages, bilinguals need to reactivate previously established Stimulus–Response mappings continuously when addressing to a given interlocutor. In these mappings, the Stimulus is a given interlocutor (i.e. the participant's mother) and the Response is the language to be used (Spanish or Catalan). Indeed, such conversations are rather frequent in the sociolinguistic context of the Catalan–Spanish bilinguals used in our studies (see Section 'Description of the monolingual and bilingual samples'), as it was also the case in Costa et al.'s (2009) study. Thus, to the extent that the bilingual individuals need to resort to the reactivation of S–R mappings during language processing, such activity might lead to a more efficient S–R mapping process in non-linguistic tasks, consequently affecting the magnitude of restart costs.

The differences in overall RTs between bilinguals and monolinguals in Experiment 2 are consistent with the interpretation put forward above. In that experiment, participants had to continuously reactivate S–R mappings for each trial in the experiment. To the extent that such reactivation processes are more efficient in bilinguals, we should expect an overall effect on RTs. Although this interpretation of the differences in RTs in Experiment 2 is consistent with that put forward for the presence of restart costs, one has to be cautious when drawing strong conclusions from it, mainly because of two potential caveats.

The first caveat refers to the lack of differences in overall RTs in Experiments 1 and 3, where updating processes were also present. If indeed bilinguals had a more efficient monitoring process, one should have expected a difference in overall RTs also in those experiments. Although it is somewhat difficult to compare the effects in the three experiments given the substantial differences between them, one could argue that Experiment 2 is the one that affords greater opportunity to reveal an effect of bilingualism on overall RTs – it is the experiment that arguably involves higher monitoring demands. This is so because the number of cues and S–R mappings were larger in Experiment 2, and also because the different response sets were arbitrarily associated to several different cues.

The second potential caveat refers to the fact that between-groups differences in overall RTs in Experiment 2 might have different origins, such as differences between bilinguals and monolinguals in the learning processes needed to establish the cue-stimuli–response set associations. Along these lines, one may argue that the bilingualism effect in Experiment 2 reflects higher working memory capacity in bilinguals relative to monolinguals. In this respect, although our data do not allow us ruling out this possibility, it is worth mentioning that bilinguals have not shown higher working memory capacities in previous studies (e.g. Bialystok, Craik, & Luk, 2008).

In sum, the effects of bilingualism on the restart cost of Experiment 1 fit well with the hypothesis put forward in previous studies about the presumable effect of bilingualism on the monitoring system. In addition, although the interpretation of the results of Experiment 2 is less straightforward, bilinguals' overall faster RTs are at least consistent with this monitoring hypothesis. The attractiveness of this admittedly tentative association between bilingualism and enhanced monitoring system is the idea of bilingualism affecting domain-general monitoring processes that are engaged to different extent in different EC paradigms (e.g. flanker task, task-switching) (see Hilchey and Klein's (2011) for a similar argument associating bilinguals faster overall RTs with a general processing advantage). In this respect, let us point out here that the fact that the EC system is far from being well understood makes it difficult putting together all previous results.

In any case, and beyond the monitoring hypothesis, what our results show is that there may be different potential cognitive mechanisms affected by bilingualism in task-switching paradigms. Further research both in the field of executive control and in bilingual language processing is needed to understand better the cross-talk between the two domains. At present, caution needs to be exercised when attributing a bilingual advantage (relative to monolinguals) to the enhancement of a specific cognitive ability.

Does bilingualism modulate the switch cost? Putting evidence together

Perhaps the most important and surprising result of the present article is the lack of a modulation of the switch cost by bilingualism. This is at odds with Prior and colleagues' reports of a reduced switch cost for bilinguals relative to monolinguals (but see Paap & Greenberg, 2013). Note that this is not just a failure to replicate a given phenomenon in a single experiment, but rather a more pervasive observation across three different instantiations of the task-switching paradigm. Several considerations need to be discussed on this respect.

First, the lack of a modulation of the switch cost by bilingualism was fully consistent across our three experiments. Note that the considerable differences in task-design across these experiments make it unlikely that we missed the bilingualism effect due to sticking to an implementation not suitable for switch cost modulations. The three different versions gave place to different task-difficulty conditions, and as a consequence, the magnitude of the switch costs differed considerably across them (ranging from 14 ms to 180 ms). Hence, the different task-switching versions allow for a more solid conclusion than previous studies, and at the very least our results reveal that the bilingual effect on the switch cost is a rather elusive phenomenon. In addition, the fact that in our Experiment 3 we used the same task-switching implementation as in Prior and colleagues' makes it even more implausible that the lack of replication is bound to the particular task-switching implementation we used.

Second, the different task implementations used were all sensitive to various robust effects previously reported in task-switching literature: local and restart costs (Experiment 1), cue-explicitness effects (Experiment 1), bivalency effects (Experiment 2), switch and mixing costs (Experiment 3).

Third, the large number of participants tested across the three experiments makes it unlikely that individual differences affecting EC mechanisms (other than bilingualism) were positively weighted towards the monolingual participants. Furthermore, not only the magnitude in the switch costs was comparable between the groups, but also the distribution of such magnitudes were very similar as revealed by the final omnibus analysis including 145 bilinguals and 147 monolinguals.

Where does all of this leave us in relation to the presence of a bilingualism effect on switch costs? A definite answer to this issue is difficult because of the relatively small number of studies testing the effects of bilingualism on task-switching. Table 8 shows that to Prior and colleagues' studies and ours we can only add Garbin et al.'s (2010) and Paap and Greenberg's (2013). Considering all the different task versions included in those studies, there are only eight experiments examining the bilingual modulation of the switch cost – Paap and Greenberg tested three samples of the same type of bilinguals, the same type of monolinguals, and the same task-switching implementation; therefore, we consider the joined results across the three testing phases. Out of those eight experiments only two of them showed a reduced switch cost for bilinguals relative to monolinguals: Prior and MacWhinney (2010), and Prior and Gollan (2011, English–Spanish group). Similar switch costs for bilinguals and monolinguals were observed in all other six experiments. Furthermore, and with the exception of Garbin et al.'s (2010) study, where bilinguals did not show a switch cost in RTs, we can discard an origin of the discrepancy between studies in terms of potential ceiling/floor effects.

Moreover, one can detect some inconsistencies between Prior and Gollan's (2011) hypothesis and previous findings. Prior and Gollan (2011) reported differences between bilinguals and monolinguals in switch costs only for those bilinguals that tend to switch more often between languages (i.e. the Spanish–English group but not the Mandarin–English-group). The authors argued that the effects of bilingualism on the switch cost are a matter of day-to-day language-switching frequency. However, their observation and the consequent argument does not seem to be consistent with Soveri et al.'s (2011) not finding a correlation between the rate of everyday language switches and switch costs. Note, however, that contrary to what Prior and Gollan (2011) found, Soveri et al. (2011) indeed found a correlation between language-switching and mixing costs. Soveri et al.'s (2011) data clearly contradicts Prior and Gollan's hypothesis (see also a recent study by Yim and Bialystok (2012) showing that the spontaneous and intentional switching from one language to the other within a single speech event correlates with language-switching costs but not with non-linguistic switch costs).

In our view, all these results suggest that the effects of bilingualism in the magnitude of the switch cost are rather frail, hard to replicate, and relatively elusive. However, there is still the possibility of speculating about various factors that may contribute to the presence/absence of a bilingual advantage in switch costs. We believe that some of these factors may have to do with the characteristics of the bilingual samples used in different studies. The most obvious difference between our sample and that for which bilingualism effects on switch costs have been reported is the typological similarity of the two languages. While the typological similarity between the languages of the participants tested in our study is very high (Catalan and Spanish are both Romance languages), that of the participants tested by Prior and colleagues is not – Spanish vs. English in Prior and Gollan (2011); English against a mix of different languages including Mandarin, Korean, Spanish, Russian, Cantonese, Japanese, Hebrew, Italian, Bengali, Bosnian, Marathi, Hindi, French, and Greek in Prior and MacWhinney (2010). Although it is not immediately obvious how differences between the two language typologies may affect the bilingual advantage in switch costs, it is worth aiming future research to explore this issue.

A second important feature that differentiates the samples in these studies refers to the socio-linguistic contexts in which they are immersed. As described in Section 2, our

Table 8
Summary of the results of task-switching studies comparing bilinguals and monolinguals in the magnitude of the switch cost.

Study		Switch cost	Bilingual advantage
Garbin et al. (2010)	Bilinguals (N = 19) Monolinguals (N = 21)	No reliable switch cost in RTs	Bilingual advantage in accuracy only
Prior and MacWhinney (2010)	Bilinguals (N = 47) Monolinguals (N = 45)	144 ms 206 ms	Yes
Prior and Gollan (2011)	Spanish–English bilinguals (N = 41) Mandarin–English bilinguals (N = 43) Monolinguals (N = 47)	17.5 of relative switch cost 27.3 of relative switch cost 27 of relative switch cost	Reduced switch cost in the Spanish–English group relative to the other two groups when considering the relative switch cost (switch cost divided by the mean RTs on repeat trials)
The present study			
Experiment 1 – Implicit-cue version	Bilinguals (N = 50) Monolinguals (N = 50)	162 ms 182 ms	No
Experiment 1 – Explicit-cue version	Bilinguals (N = 37) Monolinguals (N = 37)	43 ms 37 ms	No
Experiment 2	Bilinguals (N = 20) Monolinguals (N = 21)	35 ms 39 ms	No
Experiment 3	Bilinguals (N = 38) Monolinguals (N = 39)	164 ms 165 ms	No
Paap and Greenberg (2013)	Bilinguals (N = 109) Monolinguals (N = 144)	223 ms 211 ms	No

bilinguals are immersed in a community where both languages are simultaneously used in all everyday contexts. That does not seem to be the case of Prior and colleagues' bilinguals, whose first language is not used by most part of the individuals in the community where they live. This means that they are probably more immersed in a *diglossic* bilingual context relative to the Catalan–Spanish bilinguals we tested. Note, however, that if anything this difference should increase the chances of finding an effect of bilingualism on switch costs for the sample of participants tested in our study.[1]

In any case, further research needs to be conducted to make sure that the effects of bilingualism on the magnitude of the switch cost are indeed replicable.

To conclude, combining the participants tested in three different task-switching implementations, we have compared the task-switching performance of 145 Catalan–Spanish bilinguals and 147 Spanish monolinguals. The overall pattern of results reveals that bilingualism affects the restart but not the local component of the switch cost. To the extent that these two effects reveal the processes of reactivating S–R mappings and reconfiguring S–R mappings (respectively), we can conclude that bilingualism affects the former but not the latter process, at least for bilinguals of two typologically similar languages. Further research is needed to shed light into how the bilingual advantage in domain-general task-switching varies as a function of the task-settings as well as the characteristics of the bilingual population.

[1] The boundaries regarding the degree of the bilingual status of both monolingual and bilingual samples used in Paap and Greenberg (2013) do not seem clear enough for us to hypothesize on the effects that the specific linguistic context of Paap and Greenberg's samples may have played in them finding no bilingual effects (not only in task-switching but also in tasks requiring overriding conflicting responses such as the flanker task) – e.g. An individual was considered bilingual if s/he reported at least being able "*to converse with little difficulty with a native speaker on most everyday topics, but with less fluency than a native speaker* (p. 237)"; an individual was considered monolingual even if he knew a second language as long as s/he "*can converse with a native speaker on most everyday topics, but with some difficulty* (p. 237)". Nevertheless, this aspect of Paap and Greenberg's study reinforces the need of future research to consider the influence that different types of bilingualism may have on the observation of the bilingual advantage in domain-general EC tasks.

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