Available online at www.sciencedirect.com
ScienceDirect
Cognition 106 (2008) 59–86
COGNITION
www.elsevier.com/locate/COGNIT

Bilingualism aids conflict resolution: Evidence from the ANT task

Albert Costa *, Mireia Hernández, Núria Sebastián-Gallés

Parc Científic de Barcelona and Departament de Psicologia Bàsica, GRNC, Universitat de Barcelona, P. Vall d'Hebron, 171, 08035 Barcelona, Spain

Received 24 July 2006; revised 5 December 2006; accepted 10 December 2006

Abstract

The need of bilinguals to continuously control two languages during speech production may exert general effects on their attentional networks. To explore this issue we compared the performance of bilinguals and monolinguals in the attentional network task (ANT) developed by Fan et al. [Fan, J., McCandliss, B.D. Sommer, T., Raz, A., Posner, M.I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340–347]. This task is supposed to tap into three different attentional networks: alerting, orienting and executive control. The results revealed that bilingual participants were not only faster in performing the task, but also more efficient in the alerting and executive control networks. In particular, bilinguals were aided more by the presentation of an alerting cue, and were also better at resolving conflicting information. Furthermore, bilinguals experienced a reduced switching cost between the different type of trials compared to monolinguals. These results show that bilingualism exerts an influence in the attainment of efficient attentional mechanisms by young adults that are supposed to be at the peak of their attentional capabilities.

Keywords: Bilingualism; Attentional control; Speech production; Language and attention

* Corresponding author.
E-mail address: acosta@ub.edu (A. Costa).

0010-0277/$ - see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.cognition.2006.12.013

1. Introduction

One of the most remarkable abilities of bilingual speakers is that of keeping their two languages apart during language processing. When producing and comprehending language bilinguals need to ensure that the correct lexical representations are accessed. Perhaps the domain in which this skill appears to be more relevant is that of speech production given that speakers need to decide the language they want to use. That is, to achieve successful communication bilinguals need to ensure that only lexical representations of the intended language are selected and finally uttered. Otherwise, on many occasions, communication will be disrupted given that the interlocutor may not know the other language of the bilingual. Given this scenario two critical questions emerge. First, what are the attentional/linguistic mechanisms that allow bilingual speakers to focus on the linguistic representations of the response language while preventing massive interference from the non-response language? Second, does the continuous use of such a control mechanism have an impact on other general-purpose attentional mechanisms? The present article aims at answering this second question.

The first question has been the focus of intense research leading to several proposals regarding the lexicalization processes in bilingual speakers (Costa, 2005; Costa, Miozzo, & Caramazza, 1999; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Green, 1998; Kroll, Bobb, & Wodniecka, 2006; La Heij, 2005). Despite some discrepancies, all these proposals agree that bilingual lexical access must involve some kind of attentional control mechanism. For example, according to some authors, bilingual language production entails the active inhibition of the linguistic representations of the language not used in the conversation (e.g., Green, 1998; Meuter & Allport, 1999). That is, in order to achieve successful selection of the lexical representations in the intended language, the activation of those representations corresponding to the other language needs to be suppressed. Accordingly, bilinguals unlike monolinguals use an inhibitory control mechanism in any conversational situation.

Perhaps the most compelling evidence, and relevant in the present context, supporting the hypothesis that bilinguals make use of inhibitory control comes from language-switching studies. An interesting observation from these studies is that low-proficient bilinguals take more time to switch from their weak second language (L2) into their dominant first language (L1) than vice-versa (Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006a; Meuter & Allport, 1999). That is, switching to the stronger language is more costly than switching to the weaker one. This asymmetrical switching cost has been interpreted as revealing that when speaking in a L2 strong inhibition has to be applied to the representations of the much more dominant L1. As a consequence, if on a subsequent trial a response in L1 is required (switch trial into L1) low-proficient bilinguals need to overcome the large inhibition applied to those lexical representations belonging to L1. In contrast, to switch into L2 does not require the overcoming of such inhibition. This is because, when a trial involves naming in L1, the lexical representations of the L2 do not need to be inhibited. Therefore when in a subsequent trial, a L2 response needs to be given, the time cost associated with this switch will be smaller (but see Finkbeiner, Almeida, et al., 2006 and Finkbeiner, Gollan, & Caramazza, 2006; for a different interpretation). Interestingly, highly-proficient bilinguals showed a different pattern: symmetrical switching costs not only when switching between their two dominant languages (L1–L2) but, crucially, also when switching between their L1 and a much weaker third language (L3). These results reveal that while the difference in task difficulty affects the switching performance of low-proficient bilinguals (leading to asymmetrical switching costs) it does not do so for highly-proficient bilinguals. Note, however, that although these results have been taken as revealing the presence of inhibitory control in bilingual speech production, other theoretical approaches of bilingual speech production dispense with the notion of inhibitory control (e.g., Costa & Caramazza, 1999; Finkbeiner, Almeida, et al., 2006; Finkbeiner, Gollan, et al., 2006; La Heij, 2005). It is not the goal of the present article to assess the validity of such models (see Costa, 2005; for a discussion). For the present purposes, it suffices to acknowledge that all models assume the presence of some sort of control mechanism involved in bilingualism.

Let us now consider the second question raised above. Namely, does the continuous use of such a control mechanism have an impact on other general-purpose attentional mechanisms? In other words, do bilingual speakers develop a more complex/efficient general attentional system that will then be used in non-linguistic tasks?

A positive answer to this question has been partially given by the research of Bialystok and collaborators (Bialystok, 1999; Bialystok, 2001; Bialystok & Martin, 2004; Craik & Bialystok, 2006). The first relevant observation of these authors refers to the ability of children to shift between different task criteria. For example, Bialystok (1999) asked children of different ages (4- to 5-year-olds) to first sort a set of cards (blue and red circles and squares) according to their color. After this sorting task, she asked them to sort again the cards but now according to a different criterion (their shape), a task that elicited a number of incorrect responses (see also Zelazo, Frye, & Rapus, 1996). Crucially, bilingual children outperformed monolingual children in this second sorting task, suggesting that bilingualism helps the development of the attentional control mechanism involved in shifting between task rules.

Bilingualism also seems to have a long lasting impact on the attentional control abilities of an individual. Bialystok, Craik, Klein, and Viswanathan (2004) asked several groups of monolinguals and bilinguals of different ages to perform the Simon task, in which participants have to respond according to a dimension of the target stimulus (e.g., color) while ignoring an irrelevant one (e.g., position on the screen). The combination of the two dimensions leads to congruent and incongruent trials. Responses tend to be slower for incongruent than for congruent trials (the Simon effect), an effect that reveals the cost associated with resolving the incompatible information given by the two dimensions. Interestingly, the magnitude of the Simon effect seems to be modulated by the bilingual status of the participants, being smaller for bilinguals (Bialystok et al., 2004). The difference between bilinguals and monolinguals was most clearly present for elderly participants (over 60 years old). Thus, it appears that bilingualism not only facilitates the development of more efficient attentional control mechanisms, but it also delays deterioration associated with cognitive decline (see Craik & Bialystok, 2006; for a review).

Given these observations, one should expect bilingualism to affect the functioning of the attentional processes across the life-span, even at those ages at which individuals are at the peak of their attentional capabilities. However, the research conducted with younger adults has not led to such strong results. In two studies, Bialystok, Craik, and Ruocco (2006) and Bialystok (2006) found small differences in dual-task processing and in the magnitude of the Simon effect respectively between bilingual and monolingual university undergraduate students. Furthermore, a very similar pattern of brain activity was found for both groups, although different correlations between activated regions and reaction times were found between them (Bialystok et al., 2005b). More recent results by (Bialystok, Craik, & Ryan, 2006) have also revealed a (relatively modest) advantage of young bilinguals in comparison to monolinguals in tasks tapping in various components of the executive control system (see also Bialystok et al., 2006). Thus, at present, more evidence is needed to unequivocally show that there is a behavioural difference between bilinguals and monolinguals when they are at the peak of their attentional abilities. And, in fact, it is entirely possible that the bulk of the positive effects associated with bilingualism is present in those developmental stages in which the attentional system of the individual is not at its maximum level of performance. This hypothesis is based on the potential presence of a ceiling effect in the development of the attentional system. If young adults have reached a high-performance level in tasks that require the use of executive control (e.g., doing sports, playing video-games, etc.), there might be little room for bilingualism to exert any extra significant effect. Assessing this issue is one of the goals of this article.

1.1. Bilingualism and attentional networks

According to Posner and Petersen (1990) attentional processes can be fractionated in at least three different components that are subserved by distinct brain networks: alerting (achieving and maintaining an alert state), orienting (selecting information from sensory input), and executive control (monitoring and resolving conflict). These networks are supposed to be relatively independent (but see below).[1]

The first goal of the present experiment is to assess whether the executive control of young adult bilinguals is more efficient than that of monolinguals. We will do so by measuring their ability to: (a) to resolve conflict between congruent and incongruent information, and (b) to switch between different type of trials (see below).

The attentional component of executive control seems to be the most likely candidate to be affected by bilingualism, because it is involved in the determination of the appropriate action in a goal-directed manner, and may involve inhibitory control. This component of executive control is usually assessed by means of tasks that require conflict processing (e.g., Simon task), which involve two different executive

[1] For the sake of simplicity when we use the term attentional networks we refer to three major attentional components (executive control, orientation and alert), rather than to the internal organization of the subcomponents of each of these major networks.

control processes: conflict monitoring and conflict resolution (Posner & Fan, 2004). The first process is in charge of detecting the presence of conflict, considering its degree, and signalling that the situation demands specific action. Thus, conflict monitoring allows not only detecting potentially conflictive situations, but also adjusting the behavioural requirements when shifting from a situation containing no conflict to one where conflict resolution is required and vice versa. After this monitoring process, the individual has to decide the appropriate action that must be taken to perform the task given the specific target configuration (e.g. inhibitory control, rule-holding, planning, etc.). These two processes of the executive component of attention have been found dissociated in the brain: the anterior cingulate cortex seems to be involved in monitoring (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Botvinick, Braver, Barch, Carter, & Cohen, 2001), while lateral prefrontal areas are mainly related to conflict resolution (Casey et al., 1997). A crucial component of conflict resolution, in the present context, is that of inhibitory control. This component is supposed to be involved when two conflicting representations associated with two different responses are active, and participants need to decide which one to produce. This situation resembles the one faced by bilingual speakers during speech production, given that a word and its translation in the other language may become activated in parallel and the speaker has to decide which one to finally produce (see a discussion of the parallel activation of the two languages of a bilingual in Costa, La Heij, & Navarrete, 2006b).

The second goal of this study is to explore whether bilingualism affects also other attentional components. Although executive control is the attentional network more likely to be affected by bilingualism, whether or not such other attentional networks are affected by the language background variable has not been explored yet. Interestingly, some results from a different domain suggest that training in one type of processes may have general effects on other related processes. For example, Green and Bavelier (2003) have shown that extensive training in video-games increases efficiency in a wide range of visual attention abilities and not only in those more related to the training itself. Along the same lines, extensive training on specific abilities appears to have consequences for the development of brain structures, revealing that environmental demands may lead to some brain plasticity even for adults (Maguire et al., 2000).

1.2. The attentional network task: Predictions for bilinguals and monolinguals

To explore the impact of bilingualism on the attentional abilities of young individuals at the peak of their attentional capabilities, we asked monolingual and bilingual speakers to perform the Attentional Network Task (ANT) developed by Fan, McCandliss, Sommer, Raz, and Posner (2002). This task is a combination of a cue reaction time task (Posner, 1980) and a flanker task (Eriksen & Eriksen, 1974), and has been widely used to assess various issues, ranging from genetic studies of attention (Fan, Fossella, Sommer, Wu, & Posner, 2003; Fossella et al., 2002), to developmental studies of attention (Rueda, Posner, Rothbart, & Davis-Stober, 2004; Rueda et al., 2004).

In this task, participants are asked to indicate whether a central arrow (→) points to the right or left (the target stimulus is presented above or below a fixation point). This arrow is presented along with two flanker arrows pointing to the same (congruent trials →→→→→) or different direction (incongruent trials ←←→←←) than the target arrow (see Fig. 1). Responses tend to be slower for incongruent than for congruent trials, revealing the time needed to resolve the conflict between the target stimulus and the to-be-ignored flanker information. This conflict effect has been used to explore the functioning of the executive control network.

The functioning of the alerting network is studied by presenting a cue before the target stimulus: responses are faster when the target is preceded by an alerting cue than when it is not. Finally, the orienting network is explored by presenting a cue that signals the position in the screen where the target stimulus will appear: responses are faster when the cue signals the position of the target than when it does not give information about the target's spatial location.

The ANT has also been used to explore the neural correlates of these three different attentional networks. For example, Fan, McCandliss, Fossella, Flombaum, and

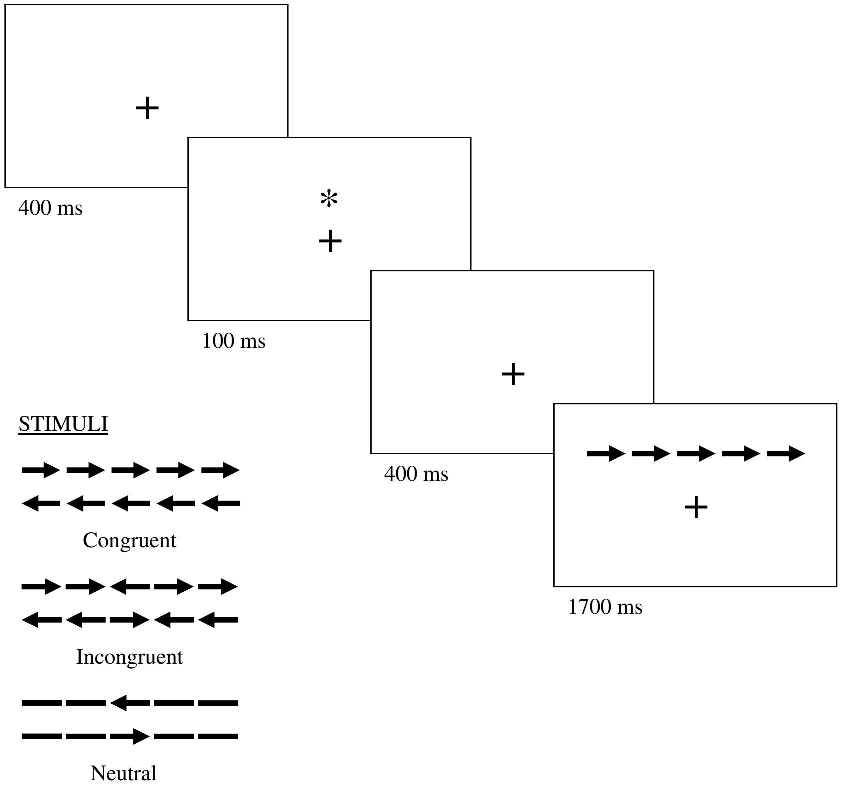

Fig. 1. Schematic representation of the events in a trial of the ANT. The example represents a congruent trial preceded by the presentation of a spatial cue.

Posner (2005) found that fronto-parietal cortical regions and the thalamus seem to sustain the alerting network; the orienting network seems to depend on projection of frontal eye fields and superior parietal lobe sites; and the main anatomical structures of the executive network appear to be the anterior cingulate in addition to right and left frontal areas. However, despite this anatomical differentiation, recent results have revealed some functional influence between the networks. For example, Fossella et al. (2002) found a negative correlation between the magnitude of the alerting and conflict effects (but see Callejas, Lupiáñez, & Tudela, 2004; Callejas, Lupiáñez, Funes, & Tudela, 2005; for a different result with a slightly different implementation of the ANT).

This task is especially appropriate to assess potential differences between monolinguals and bilinguals, since it relies minimally on linguistic and memory processes that may interact with bilingualism. It is important to mention that the way in which the ANT task assesses the functioning of the executive network is somewhat different from the way other previously used tasks do so. For example, the Simon task and the ANT task engage somewhat different attentional components. First, while the Simon task requires holding the stimulus-response rule in working memory (if it is red press left, if it is blue press right), this working memory component is not required in the flanker task. Second, the Simon task involves the suppression of a preponderant response (responding according to the stimulus location rather than to the stimulus-response rule), while this is not the case in the flanker task, given that both flankers and target elicit the same response type. Third, while in the Simon task the distractor (position in the screen) and the target dimensions (e.g., color) have different formats, both dimensions have the same format in the flanker task (both are arrows). However, despite these differences, both tasks appear to involve a common component of the executive control network: inhibitory control. That is, both tasks lead to the activation of two conflicting representations associated with two different responses, and participants need to decide which one to produce. Also, both tasks allow for assessing monitoring processes, given that they include congruent and incongruent trials. Still, one may argue that the flanker task is more suitable to explore the functioning of inhibitory control given that it may be less contaminated by other cognitive factors.

Also, the multidimensionality of the ANT task allows drawing a set of interesting predictions regarding the potential conditions that may be affected by bilingualism. In the following we describe these predictions.

The hypothesis that the continuous use of control mechanisms by bilinguals affects positively the development of the executive control network, and in particular of the inhibitory control component, leads to a clear prediction: the difference between congruent and incongruent trials will be larger for monolinguals than for bilinguals. That is, bilingualism would aid conflict resolution. Furthermore, such a difference in the magnitude of the conflict effect between groups may be attenuated with task practice (see Green & Bavelier, 2003 & Bialystok et al., 2004). That is, an intensive use of the executive control network under the same task requirements may help monolinguals reduce the magnitude of the conflict effect approaching therefore the efficiency level of bilinguals.

Besides this crucial prediction there are others that can be derived from the hypothesis put forward above and also from existing results in the literature. Bialystok (2006) has consistently found that bilingual participants tend to be overall faster than monolinguals in tasks that involve inhibitory control such as the Simon task. Interestingly, this difference is even present when considering only congruent trials on which resolution of conflict is not needed, and it has been interpreted as revealing a bilingual advantage in the monitoring processes recruited by the task. The argument goes as follows. Given that the task includes congruent and incongruent trials, participants have to evaluate the behavioural adjustments needed for each trial to determine the subsequently appropriate action. This continuous monitoring process in charge of detecting potentially conflicting information depends also on the executive control network, and consequently bilinguals should be overall better (faster) than monolinguals. Following this rationale, we predict that bilinguals would enjoy a processing benefit throughout the experiment resulting in faster reaction times both for congruent and incongruent trials.

A final prediction in relation to the executive control network refers to the following interesting observation from experiments in which flankers are used: responses to trials preceded by the same type of trial are faster than those to trials preceded by a different type of trial (e.g., Botvinick et al., 1999; Durston et al., 2003). That is, a response to a congruent trial is faster if preceded by a congruent trial than if preceded by an incongruent trial (and the opposite for incongruent trials). This effect, analogous to other switching effects reported in the literature, has been interpreted as revealing the cost associated with changing mindsets (see also Allport, Styles, & Hsieh, 1994; Allport & Wylie, 1999; Allport & Wylie, 2000; Rogers & Monsell, 1995; Yeung & Monsell, 2003a, Yeung & Monsell, 2003b). For example, in an incongruent trial preceded by a congruent one, participants need to suppress the tendency instantiated on the previous trial of responding according to the flankers. This shifting in the mindset may demand more cognitive resources than simple rule-holding (e.g. to keep suppressing the pre-potent response tendency in an incongruent trial preceded by an incongruent trial, and to keep responding according to the dominant response in a congruent trial preceded by a congruent trial). If such a shifting process depends, to some extent, on the executive control network (and in particular involves some sort of inhibitory control), then one may expect the cost associated with switching to be smaller for bilinguals than for monolinguals.

However, it is likely that the differences in switching cost between the two groups will also depend on the direction of the switch. This is because certain transitions seem to require more attentional effort than others. For instance, switching from a difficult task (e.g., naming in L2) into an easy one (e.g., naming in L1) appears to be more costly than vice versa (Allport et al., 1994; Allport & Wylie, 1999; Allport & Wylie, 2000; Davidson, Amso, Anderson, & Diamond, 2006; De Jong, 1995; Meuter & Allport, 1999; Yeung & Monsell, 2003b). In the flanker task, incongruent trials are arguably more difficult than congruent trials, and as a consequence to switch from an incongruent trial into a congruent trial would be more difficult than vice versa. One possible origin of this differential switching cost is the following. When presented with an incongruent trial participants need to inhibit the response associated with the flankers. If the following trial is incongruent participants can keep using the tendency to suppress the response associated with the flankers. However, instead, if the following trial is congruent, participants need to overcome the tendency to suppress the response elicited by the flankers. This is because on congruent trials, the response elicited by the flankers and that elicited by the target is the same. Hence, the cognitive effort to overcome the tendency to inhibit the response elicited by the flankers may incur a time cost. The situation is quite different when the switch is performed between a congruent trial and an incongruent trial, given that the tendency to suppress the response elicited by the flankers may not be instantiated on congruent trials. In this scenario, and if bilingualism exerts an effect in the processes of shifting mindsets, it is likely that the difference between the two groups will be more evident in those conditions in which the task becomes harder (i.e., switching into congruent trials).[2] Given these considerations, and on the assumption that differences in the efficiency of the executive network would be more evident under high processing demand situations, we predict that bilinguals will cope with the extra cognitive load of changing to an easy trial (congruent) better than monolinguals. Thus, we could expect asymmetrical switch costs for monolinguals but not (or reduced ones) for bilinguals.

Summarizing, the following predictions regarding the effects of bilingualism on the executive network will be assessed:

(a) The interference produced by incongruent flankers in comparison to congruent ones (the conflict effect) will be more pronounced for monolinguals than for bilinguals.
(b) Bilinguals will be faster both for congruent and incongruent trials.
(c) Switching between different type of trials will be less costly for bilinguals than for monolinguals (especially when switching to congruent trials).

The predictions regarding the alerting and orienting networks are more exploratory. We certainly expect to find faster responses when an alerting cue is presented than when it is not (alerting network), and even faster when the cue indicates the position on the screen where the target will appear (orienting network). However, the extent to which the magnitude of these two effects will be affected by bilingualism is an open question.

1.3. Experiment: Bilingual vs. Monolingual's performance in the ANT task

In this experiment we use the same implementation of the ANT as used by Fan et al. (2002). Some introductory comments about specific details of the experiment

[2] This prediction is also motivated by the pattern of results observed in language switching tasks (Costa & Santesteban, 2004). In those experiments the magnitude of the switching costs for the easy task (from L1 into L2) was similar for low-proficient and highly-proficient bilinguals. However, the magnitude of the switching costs for the difficult task (from L2 into L1) was larger for the low-proficient group than for the highly-proficient one.

are pertinent here. First, given that previous studies have failed to find a consistent difference between monolingual and bilingual young adults in tasks involving inhibitory control in conflict resolution, the expected difference between groups will most likely be relatively small in magnitude. Thus, to increase experimental power, a large number of participants were tested ($n = 200$).

Second, the use of such a large sample also reduces the chances that other potential confounding variables (e.g., intelligence, motivation, etc.) that might affect performance in this task are unevenly distributed between the two groups of participants. In this respect we also took the following precautions to reduce possible confounds between bilingual status and other variables. Bilingual and monolingual participants were selected from two different populations in terms of their linguistic context. Bilingual participants were living in a bilingual society (Barcelona, Catalonia), while monolingual speakers were living in a monolingual one (Tenerife, Canarian Islands). Thus, their linguistic status (bilingual vs. monolingual) reveals the linguistic environment in which the individuals live and not other factors such as intelligence, motivational factors, socioeconomic status, education, etc. That is, the bilinguals have achieved such a status not because they are more motivated or more intelligent than the monolinguals, but rather because they had been continuously exposed to two languages. Furthermore, all participants were university students under the same educational system (most of them psychology undergraduate students), matched in gender, age and education. As a consequence they all have passed a common mandatory exam to be enrolled in university.

The use of two groups of participants from different geographical locations was unavoidable, given the impossibility of finding a sizable homogeneous group of monolingual speakers in Catalonia. Still, this property of our design may raise the question of whether the individuals in the two groups were comparable in their cultural characteristics. The fact, however, that the participants were mostly psychology undergraduate students immersed in the same educational system, makes it unlikely that cultural differences between them could account for the potential differential behaviour in the ANT task.

Given these precautions, along with the large sample of participants we tested, we can be reasonably confident that the two groups of participants do not differ systematically in any variable that may affect their performance in this task.

1.4. Method

1.4.1. Participants

Two groups of 100 participants each conducted the experiment. In the bilingual group, participants were Catalan-Spanish early and highly-proficient bilinguals ranging in age from 19 to 32 (mean age 22 years). Bilingual participants used both Catalan and Spanish at a native speaker level, i.e., they have a high proficiency level in speaking, comprehending, reading, pronouncing and writing both of the languages. Their dominant and first language was Catalan, but they were exposed to Spanish at a very early age, even before schooling. Thus, these bilinguals could be considered as simultaneous bilinguals, in the sense that the learning of the two languages started almost at the same time, although with different exposure times. All bilingual speakers were educated in both languages and were living in a bilingual context at the time of testing (see Appendix A for a description of the "Language use and skills of the participants" and Appendix B for a description of the "Bilingual Community and of the Languages").

In the monolingual group, participants were Spanish monolingual speakers ranging in age from 17 to 32 (mean age 22 years). They were not functionally fluent in any other language despite having some knowledge of other languages mostly because of the foreign language courses taken at school (see Appendix A). Although the distribution of gender in the experiment overall was not balanced, the same distribution was present for the two groups of participants (bilinguals: 87 women, 13 men; monolinguals: 85 women, 15 men).

1.5. Design

The experiment contained two within factors: "Cue Type" (no cue, center cue, double cue, spatial cue), and "Flanker Type" (neutral, congruent, incongruent). The crossing of these values led to 12 experimental conditions. Each condition was represented by 8 trials in each Block, leading to a total of 96 trials per block. The experiment consisted of three experimental each presented in random order.

The target stimuli consisted of a row of five horizontal black lines, with arrowheads pointing leftward or rightward. The target arrow was the central one. A single arrow or line consisted of 0.55° of visual angle. The contours of the adjacent arrows or lines were separated by 0.06° of visual angle.

The event presentation was as follows: (a) a fixation point (a plus sign) appeared on the center of the screen for 400 ms, (b) a cue (an asterisk) was presented for 100 ms, (c) a fixation period for 400 ms after the cue, (d) the target arrow and the flankers were presented simultaneously until participant's response or up to 1700 ms, (f) the target and flankers disappeared after response and the next trial began. The fixation cross appeared at the center of the screen during the whole trial. Participants were instructed to focus on the centrally located fixation point, and to respond, by pressing a key in the computer keyboard, as quickly and accurately as possible with their left hand when the arrow pointed to the left and with the right hand when it pointed to the right. Before the experiment, a training phase of 24 trials was administered. Stimuli were presented via DMDX (Forster & Forster, 2003), a Win 32 program, on an IBM-compatible personal computer running XP (For an illustration, see Fig. 1).

1.6. Data analyses

In order to address all the different predictions put forward in the Introduction we conducted several analyses taking error rates and reaction times as dependent variables. In the first and general analyses of the data, we considered all conditions together declaring three independent variables "Cue Type" (no cue, center cue, double cue, spatial cue) and "Flanker Type" (neutral, congruent, incongruent) as within-subjects factors, and "Group of Participants" (monolingual, bilingual) as a between-subjects factor (see Table 1 and Fig. 2). These analyses can be found under the subheading "General Analyses".

In a subsequent analyses (under the subheading "Assessing the three attentional networks") we contrasted those conditions relevant to assess the three attentional networks of interest (see Fig. 3). For the executive control network we compared responses to congruent trials vs. incongruent trials (conflict effect). For the alerting network, we compared responses to trials preceded by a double cue to those to trials preceded by no cue (alerting effect). Finally, for the orienting network we compared trials preceded by a central cue to those preceded by a spatial cue (orienting effect). In all these analyses we looked for the crucial interaction between network effect and the participant group, which would indicate a differential performance of bilinguals and monolinguals for the three assessed effects.

Finally, under the subheading "Further assessing the Executive Control Network: Switching effects", we asses the performance of the two groups considering: (a) switch and non-switch trials and (b) congruent and incongruent trials.

2. Results

2.1. General analyses

In the error analyses, the percentage of errors was comparable for monolinguals (2.3 %) and bilinguals (2.1%) ("Group of Participants"; $F < 1$). The main effects of "Cue Type" ($F\ (3,594) = 27.42$, $MSE = .001$, $p = .001$), and "Flanker Type" ($F\ (2,396) = 173.7$, $MSE = .003$, $p = .001$) were significant. The only significant interaction was that between "Cue Type" and "Flanker Type" ($F\ (6,1188) = 10.21$, $MSE = 0.001$, $p = .0001$).

When considering reaction times as the dependent variable, all three main effects were significant: "Group of Participants" ($F\ (1,198) = 11.95$, $MSE = 42603$, $p = .001$); "Cue Type" ($F\ (3,594) = 866.10$, $MSE = 1263$, $p = .001$), and "Flanker Type" ($F\ (2,396) = 1292.99$, $MSE = 2341$, $p = .001$). A significant interaction between "Group of Participants" and "Flanker Type" ($F\ (2,396) = 4{,}07$, $MSE = 2341$, $p = .018$) and a marginal one between "Group of Participants" and "Cue Type" ($F\ (3,594) = 2{,}07$, $MSE = 1263$, $p = .103$) was observed. The interaction between "Cue Type" and "Flanker Type" was significant ($F\ (6,1188) = 7.187$, $MSE = 519$, $p = .0001$) while the three-way interaction was not ($F < 1$) (see Fig. 2 and Table 1).

The main effect of "Group of Participants" is particularly relevant here, since it reveals that bilingual speakers were overall faster than monolingual speakers, regardless of the type of trial [congruent: $t(198) = 3.11$, $p = .002$; incongruent: $t(198) = 3.34$, $p = .001$; and neutral: $t(198) = 3.48$, $p = .001$].

Table 1
Mean reaction times (RT) (a), and error rates (%) (b), along with standard deviations in parentheses for bilingual and monolingual participants broken for Flanker type and Cue type

	Flanker				Conflict effect		
	Congruent		Incongruent				
	Bil	Mon	Bil	Mon	Bil	Mon	Δ Bil–Mon
(*a*) *Cue*							
None	590 (57)	609 (67)	692 (67)	725 (87)	102	116	14
Double	558 (52)	587 (62)	652 (69)	695 (94)	94	108	14
Center	568 (52)	591 (63)	674 (66)	711 (94)	106	120	14
Spatial	489 (62)	517 (68)	585 (74)	621 (97)	96	104	8
Alerting effect	32	22	40	30			
Δ Bil–Mon		10		10			
Orienting effect	79	74	89	90			
Δ Bil–Mon		5		1			
(*b*) *Cue*							
None	0.6 (1.6)	1.1 (2.3)	5.7 (6.3)	6.3 (8.2)	5.1	5.3	−0.2
Double	0.6 (2.2)	0.6 (1.8)	4.2 (5.4)	4.7 (5.5)	3.5	4	−0.5
Center	0.6 (1.7)	1.2 (2.4)	6.3 (7.4)	6.5 (7.3)	5.7	5.3	0.4
Spatial	0.3 (1.2)	0.7 (1.9)	3.5 (4.8)	2.8 (3.9)	3.2	4.1	−0.9
Alerting effect	0	0.5	1.5	1.6			
Δ Bil–Mon		−0.5		−0.1			
Orienting effect	0.3	0.5	2.8	3.7			
Δ Bil–Mon		0.2		0.9			

The Alerting effect is calculated by subtracting responses to “none trials” from those to “double trials”. The Orienting effect is calculated by subtracting responses to “center” from those to “spatial”. The Conflict effect is calculated by subtracting responses to “incongruent trials” from those to “congruent trials”.

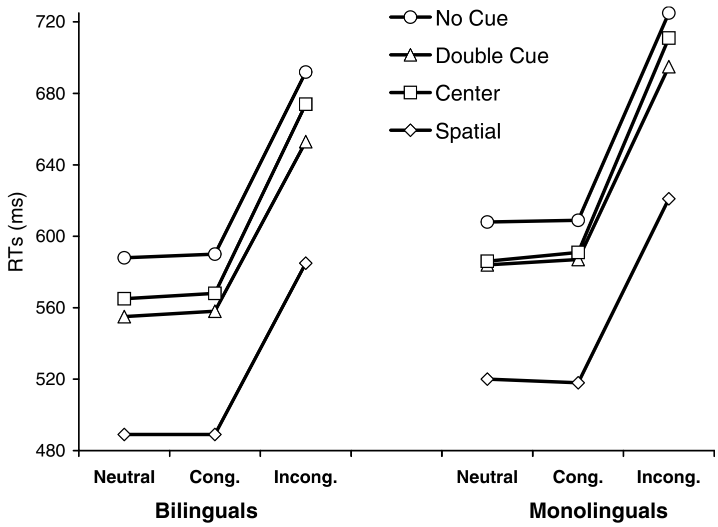

Fig. 2. Overall RTs (ms) for Monolingual and Bilingual participants in the 12 conditions included in the experiment.

2.2. Assessing the three attentional networks

In the following analyses, we assessed the three effects of the attentional networks (as indexed by the conflict effect, the alerting effect and the orienting effect) independently and their relationship with the variables "Block" (Block 1, 2 and 3) and "Group of Participants" (monolinguals vs. bilinguals). In these analyses, an effect of bilingualism will be indexed by an interaction between the above mentioned effects and the variable "Group of Participants" (see Fig. 3 for a summary of the results).

2.3. Executive network

The "*Conflict effect*" (incongruent vs. congruent trials) was significant (F $(1,198) = 1481$, $MSE = 2241$, $p = .0001$), indicating faster reaction times for congruent than for incongruent trials. In this analysis, bilinguals were also faster than monolinguals ["Group of Participants" ($F(1,198) = 11.17$, $MSE = 25389$, $p = .001$)] and reaction times decreased with repetitions ["Block" ($F(2,396) = 24.06$, $MSE = 1178$, $p = .0001$)]. The crucial *interaction between "Conflict effect" and "Group of Participants" was significant* (F $(1,198) = 4.5$, $MSE = 2241$, $p = .035$), revealing that the difference between incongruent and congruent trials was larger for monolinguals than for bilinguals. However, this difference was modulated by the variable "Block" as revealed by the three-way interaction between "Group of Participants", "Conflict" and "Block" ($F(2,396) = 3.17$, $MSE = 453$, $p = .043$).

As it can be appreciated in Fig. 4, this triple interaction reveals that the difference in the magnitude of the conflict effect between monolinguals and bilinguals is present

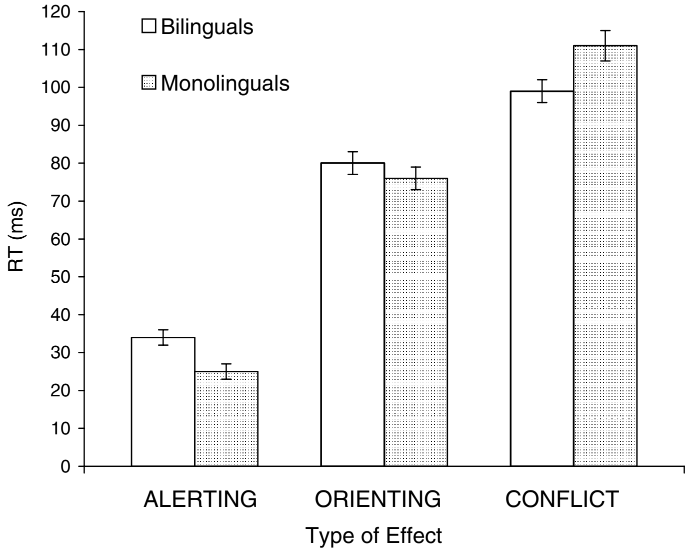

Fig. 3. Magnitude of the three effects (ms) broken by group of participants. Error bars represent standard error.

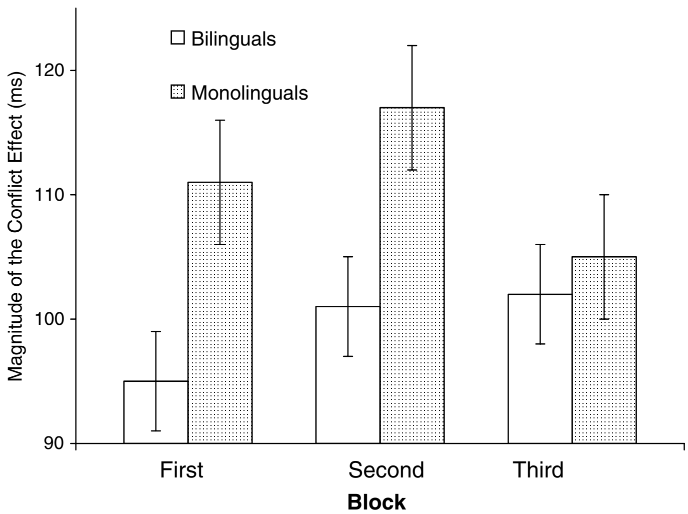

Fig. 4. Magnitude of the conflict effect (ms) broken by group of participants and blocks. Error bars represent standard error.

for the first two blocks but not for the third block. This interpretation is substantiated by the interaction between "Group of Participants" and "Conflict", which was present for the two first blocks (Block 1: $F(1,198) = 6{,}24$, $MSE = 1073$, $p = .013$;

Block 2: $F(1,198) = 5{,}64$, $MSE = 1080$, $p = .019$) but absent in the third (Block 3: $F(1,198) < 1$). That is, it appears that monolinguals suffered more conflict than bilinguals in Blocks 1 and 2, but not in Block 3 (see Fig. 4).

In the error analyses only one significant effect was observed: "Conflict effect" ($F(1,198) = 184.7$, $MSE = 0.003$, $p = .0001$).

2.4. Alerting network

The "*Alerting effect*" (no cue vs. double cue trials) was significant ($F(1,198) = 329$, $MSE = 793$, $p = .0001$) revealing faster reaction times for trials preceded by a double cue than for those preceded by no cue. In this analysis, reaction times for bilinguals were faster than for monolinguals ["Group of Participants" ($F(1,198) = 11.5$, $MSE = 20872$, $p = .001$)] and they also decreased with repetitions ["Block" ($F(2,396) = 15.32$, $MSE = 1242$, $p = .0001$)].

Importantly, the *interaction between "Alerting effect" and "Group of Participants" was significant* ($F(1,198) = 7.92$, $MSE = 793$, $p = .005$) revealing that bilinguals benefited from the presence of an alerting cue more than monolinguals. None of the other interactions were significant.

In the error analyses only one significant effect was observed: "Alerting effect" ($F(1,198) = 9.8$, $MSE = 0.001$, $p = .002$).

2.5. Orienting network

The "*Orienting effect*" (center cue vs. spatial cue) was significant, ($F(1,198) = 1038$, $MSE = 1750$, $p = .0001$) revealing faster reaction times for trials preceded by a spatial cue than for those preceded by a central one. As in the previous analyses, bilinguals were overall faster than monolinguals ["Group of Participants" ($F(1,198) = 11.19$, $MSE = 23273$, $p = .001$)] and reaction times decreased with repetitions "Block" ($F(2,396) = 28.54$, $MSE = 1182$, $p = .0001$). Importantly *the interaction between "Group of Participants" and "Orienting" was not significant* ($F < 1$), revealing that the benefit produced by the orienting cue was similar for both groups of participants.

The only significant interaction was that between "Block" and "Orienting" ($F(2,396) = 4.98$, $MSE = 567$, $p = .007$). In the error analyses only one significant effect was observed: "Orienting effect" ($F(1,198) = 60.98$, $MSE = 0.001$, $p = .0001$).

The results reported in this section revealed that both groups of participants showed conflict, alerting and orienting effects. However, bilinguals in comparison to monolinguals: (a) were overall faster both on congruent and incongruent trials; (a) suffered less interference from incongruent flankers (congruent trials minus incongruent trials – conflict effect), and (b) took more advantage of an alerting cue (trials with double cue minus trials with non cue – alerting effect). These results indicate that bilingualism exerts an effect on the executive control and on the alerting networks. Furthermore, the difference in the magnitude of the conflict effect between both groups is reduced with practice, and not present at the end of the experiment.

In contrast, the difference in the magnitude of the alerting effect between both groups remains constant across the experiment.[3]

2.6. Further assessing the executive control network: Switching effects

In this section we analyse the pattern of switching costs between congruent and incongruent trials or vice versa for both groups of participants. To do so, we performed an analysis declaring the factors "Block", "Type of Trial" (switch trials, non-switch trials)[4] and "Group of Participants" (bilinguals, monolinguals). There was a main effect of "Type of Trial" (F (1, 198) = 33.41, MSE = 988, p = .0001), revealing that reaction times on switch trials were slower than on non-switch trials (switching cost). More interesting, however, is the *significant interaction between "Type of Trial" and "Group of Participants"* (F (1, 198) = 4.26, MSE = 988, p = .04) which reveals that monolinguals suffered a greater switching cost than bilinguals (see Fig. 5a). The three-way interaction was not significant ($F < 1$).[5] The error analysis also revealed a main effect of "Type of trial" (F (1, 198) = 48.39, MSE = 0.001, p = .0001). These results indicate that bilinguals suffer a smaller switching cost than bilinguals and that this difference is stable across blocks. However, this observation needs to be interpreted in the context of the following results.

To asses whether the magnitude of the switching cost was affected by the different switching conditions we analysed this magnitude for incongruent and congruent trials separately. In the first comparison, we included two factors: "Group of Participants" and "Switch to Incongruent Trials". In this latter factor, we compared responses to incongruent trials when: (a) preceded by an incongruent trial, and (b) preceded by a congruent trial. The main effect of "Switch to Incongruent trials" was significant [F (1, 198) = 11.1, MSE = 763, p = .001], showing that reaction times for incongruent trials were slower when they were preceded by a congruent trial than when preceded by an incongruent trial. More importantly, monolingual and bilingual speakers showed a similar switching cost for incongruent trials, as revealed by the non-significant interaction between "Switch to Incongruent trials" and "Group of Participants" (F (1, 198) < 1). That is, for incongruent trials both groups

[3] Regarding the relationship between the networks, the interaction between "Conflict effect" and "Alerting effect" was significant (F (1, 198) = 5.37, MSE = 530, p = .021) revealing that the conflict effect was larger in the no alerting condition than in the alerting one. Also, the interaction between "Conflict effect" and "Orienting effect" was significant (F (1, 198) = 14.48, MSE = 611, p = .001) revealing that the conflict effect was smaller when the target was preceded by a spatial cue. However, crucial for our interests here, none of these effects interacted with "Group of Participants", revealing that whatever the relationship held by the networks is, it is the same for both groups of participants.

[4] The level "switch trials" collapses all congruent and incongruent trials that involved shifting the mindset between trials, while the level "non-switch trials" includes those congruent and incongruent trials that do not involve switching between different types of trials.

[5] Note however, that the advantage of bilinguals over monolinguals in the conflict effect was also present when we consider only non-switch trials ("Conflict effect" and "Group of participants" (F (1, 198) = 4.27, MSE = 1099, p = .04) (bilinguals: 100 ms., monolinguals: 114 ms.). That is, even for the easiest trials and those that elicited fastest responses, there is an effect of bilingualism.

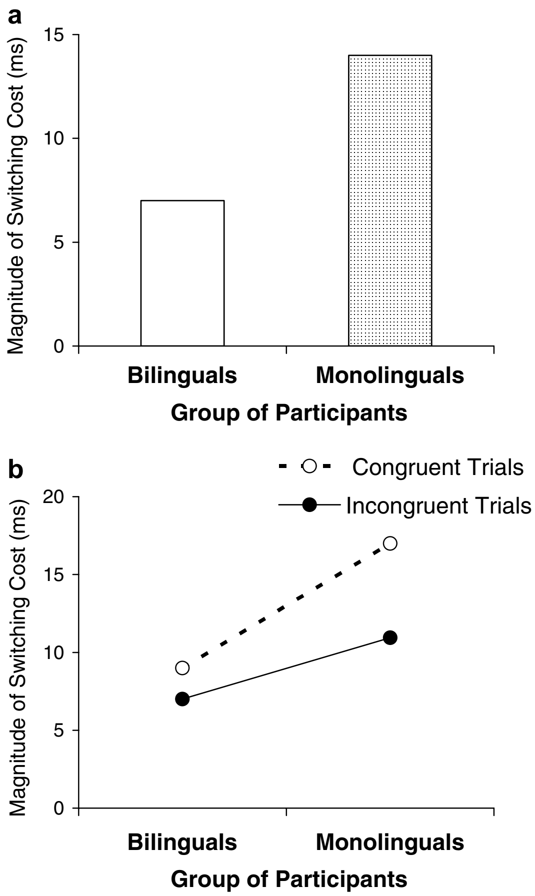

Fig. 5. (a) Magnitude of the overall switching costs broken by group of participants. (b) Magnitude of the switching costs for switching into congruent and incongruent trials broken by group of participants.

of participants experienced similar switching costs. The same analyses, but now including the factor "Switch to Congruent trials" in which only responses to congruent trials were included, led to a main significant effect of "Switch to Congruent Trials" ($F(1,198) = 37.9$, $MSE = 456$, $p = .0001$). That is, responses to congruent trials were slower when these trials were preceded by incongruent than by congruent trials. Of particular interest is the fact that this switching cost was more pronounced for monolinguals than for bilinguals, as revealed by *the significant interaction between "Switch to Congruent Trials" and "Group of Participants"* ($F\ (1,198) = 4.03$, $MSE = 456$, $p = .046$). (see Fig. 5b). That is, for congruent trials, monolinguals experienced a larger switching cost than bilinguals. No differences between the two groups were observed in the error analyses (all Fs < 1).

Summarizing, the results reported in this last section reveal several effects. First, responses for a given trial were affected by whether or not the previous trial was of the same type (switching cost). Second, the magnitude of the switching cost was larger for congruent than for incongruent trials. Third, for incongruent trials monolinguals and bilinguals showed similar switching costs, while for congruent trials bilinguals experienced a smaller switching cost than monolinguals.

3. General discussion

Bilingual and monolingual language processing differs in several aspects, the most relevant one perhaps being the need of bilingual speakers to continuously control the language in which the speech act needs to be conducted. That is, bilingual speakers not only need to attend to the ideas they want to express and to the language-specific manner in which they want to do so, but they also have to avoid interference from their other language. The issue that we explored in this article is whether such continuous involvement of attentional control mechanisms during bilingual speech production exerts any effect on the efficiency of the general attentional system of the individual. To do so, we assessed the performance of monolingual and bilingual participants in an experimental task (ANT) containing several conditions that arguably can inform us about three different attentional networks: the alerting, the orienting and the executive control network.

The overall pattern of results of both groups of participants in the ANT closely replicates previous observations (e.g., Fan et al., 2002), revealing that the outcomes of this task are highly robust. Participants were faster when: (a) a cue was presented before the target than when it was not (alerting network), (b) the cue indicated the location of the target stimulus than when it did not (orienting network), and (c) the flankers around the target arrow pointed to the same direction than when they pointed to the different direction (executive control network). That is, we were able to find sizeable effects of the three attentional networks that the ANT is supposed to tap on.

Although the pattern of results for the bilingual and the monolingual groups are qualitatively similar, there are important quantitative differences between the two groups. The four most relevant differences are the following:

(a) Bilinguals were faster than monolinguals irrespective of whether the trial was congruent or incongruent.
(b) Bilinguals suffered less interference from incongruent flankers than monolinguals.
(c) Bilinguals suffered less switching cost (especially for congruent trials) than monolinguals.
(d) Bilinguals took more advantage of the alerting cue than monolinguals.

The observation that bilinguals were overall faster than monolinguals, even on those trials on which faster responses were found (congruent trials) and on which no conflict between the flankers and the target was present replicates Bialystok

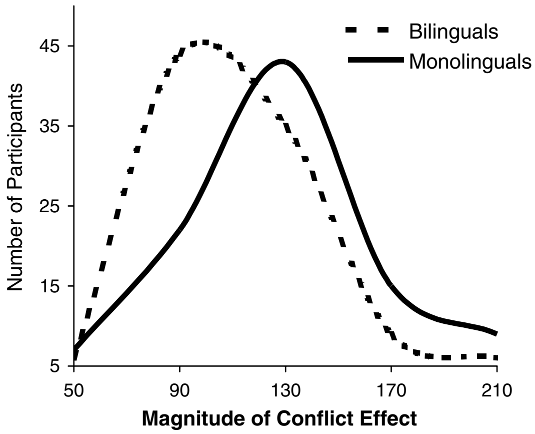

Fig. 6. Distribution of the magnitude of the conflict effect for monolinguals and bilinguals considering only the blocks in which the difference between the two groups was significant (first two blocks). The size of the intervals is 40 ms.

et al. (2004), Bialystok, Martin, & Viswanathan (2005a), Bialystok et al. (2006) ('s)observations. Interestingly, it appears that this overall difference between participants disappears when the task includes only congruent trials (Bialystok, 2001; Bialystok, 2006). Thus, these observations suggest that the inclusion of incongruent trials in a task that requires monitoring taxes the cognitive resources in such a way that this affects those trials on which no conflict resolution is needed. As a consequence, individuals with a more efficient executive control mechanism will be less affected by these additional attentional demands, thereby responding faster even in trials on where conflicting information is not present.

Although bilinguals' overall faster reaction times suggest that they enjoy a more efficient executive control network, a better proof of such a hypothesis comes from the perhaps most relevant result of our study: *the difference between congruent and incongruent trials was larger for monolinguals than for bilinguals.* That is, bilinguals suffered less interference from incongruent flakers than monolinguals, suggesting that the mechanisms involved in conflict resolution are more efficient for the former group.[6] This observation replicates and expands previous research revealing that bilingualism affects the performance of young adults in tasks that require attentional control and that do not involve language. As it can be appreciated in Fig. 6, the distributions of the conflict effect in the two groups are similar but the one of the monolinguals is shifted towards a greater magnitude. It is important to note that the

[6] This advantage may come about because bilingualism either helps to ignore information irrelevant for the task at hand (the flankers), or because it helps to resolve the conflict when giving a response. At present our results cannot adjudicate between these two possibilities. However, both interpretations relate to the functioning of the executive control network, and as a consequence both call for the positive effects that bilingualism exerts on the efficiency of this network.

bilingual advantage was present for most part of the experiment (in the first and second blocks), but it went away in the third block. The reduction of the bilingual advantage came about because, while bilinguals showed the same amount of conflict in Blocks 2 (101 ms) and 3 (102 ms), monolinguals showed a reduction of the magnitude between these two Blocks (Block 2: 117 ms; Block 3: 105 ms). This observation is in line with results from Bialystok et al. (2004) and probably reveals that the advantage of bilinguals over monolinguals is more likely to be observed in conditions requiring high attentional control demands (see also below). That is, presumably, when the task is overpracticed, it recruits fewer attentional demands, and as a consequence the effects of bilingualism are reduced. However, even after having had quite an extensive practice with the task, the conflict experienced by the monolingual group in the third block was still numerically larger than that of the bilingual group in the first block. Despite these considerations, one could take this observation as an indication that the bilingual advantage can be easily overcome by monolinguals. We believe that such a conclusion is not granted by the present set of results, since it is not known whether these practice effects would generalise to other cognitive tasks involving inhibitory control. Thus, in order to assess the actual impact of bilingualism and its relationship with task practice it is crucial that future studies address the generalization of practice (see Fan et al., 2005; for evidence that similar conflict tasks activate different brain areas).

Further evidence that bilingualism has an impact on the executive control network comes from the third observation summarized above. Overall, responses to those trials that were preceded by a different type of trial were slower than to those preceded by the same type of trial. This result replicates previous observations coming from the switching literature (Allport et al., 1994; Allport & Wylie, 1999; Allport & Wylie, 2000; Botvinick et al., 1999; Rogers & Monsell, 1995; Yeung & Monsell, 2003a; Yeung & Monsell, 2003b). Importantly, and although a switching cost was present for both groups of participants, its magnitude was larger for monolinguals than for bilinguals. Interestingly, the pattern of switching costs was also somewhat different for both groups of participants. In fact, bilinguals and monolinguals behaved very similarly when they had to switch from congruent to incongruent trials; that is when switching into the difficult trials. However, switching from incongruent to congruent trials was more costly for monolinguals than for bilinguals. Arguably, switching into congruent trials is more difficult than switching into incongruent trials, and as consequence one would expect the difference between monolingual and bilingual speakers to be maximal in this condition. In other words, the more demanding the switching task is, the more pronounced the effect of bilingualism.

Another way to look at this differential switching performance is the following. While bilinguals were unaffected by the difference in difficulty of the switching trials, monolinguals were. That is, bilinguals showed the same switching cost when switching into easy trials than when switching into difficult trials, while monolinguals experienced a larger cost when switching into the easy trials. This is an interesting observation that parallels some results obtained with the language switching task (Costa & Santesteban, 2004; Costa et al., 2006a). In those studies low proficient bilinguals (that could be considered L2 learners) showed asymmetrical switching costs: i.e., they took more time to switch from their weak language (L1) into their dominant language (L2) than vice versa. In contrast, highly-proficient bilinguals showed symmetrical switching costs when asked to switch between their two strong languages, but also when they were asked to switch between their L1 and a much weaker L3. That is, while the switching performance of L2 learners was affected by the difference between the difficulty of the two tasks (strong L1, weak L2) (leading to asymmetrical switching costs), the performance of highly proficient bilinguals was not affected by this difference between tasks (strong L1, weak L3). Similarly, in the present experiment the difference in the difficulty between the two trial types (congruent vs. incongruent) affected the magnitude of the switching cost for monolinguals but not for highly-proficient bilinguals. This convergence of effects from two rather different tasks (ANT and language-switching) suggests that the executive control mechanisms involved in both of them are shared to some extent and that, more importantly, they are affected by bilingualism. This is a hypothesis that surely needs further investigation.

In the Introduction we argued that the executive attentional system is composed of different mechanisms: monitoring mechanisms and conflict resolution mechanisms. The first consist of detecting the presence of potentially conflictive situations and evaluate the need of behavioural adjustments when shifting between different type of trials. The second mechanisms are more related to the processing in charge of conflict resolution between incongruent information and determining the appropriate action that must be taken to perform the task. One may take the switching effect as an index of the first type of mechanisms and the conflict effect as an index of the second type of mechanisms. On this assumption, it appears that the efficiency of both mechanisms of the executive control network is affected by bilingualism. However, although the two mechanisms are related to the same network, they are affected by bilingualism in a relatively independent manner. This is because the magnitude of the conflict effect does not correlate with the magnitude of the switching effect ($R = .11$). That is, an improvement in the efficiency of the monitoring processes is not necessarily tied to an improvement in the conflict resolution processes. Further research on how these two components of the executive control network interact with each other is required. Our contribution here is the observation that both of them seem to be affected by bilingualism.

Up to here we have discussed those results indexing the positive effects of bilingualism on the efficiency of the executive control network. However, our experiment also provides some information about the impact of this linguistic variable on two other attentional networks: the alerting and orienting networks.

Regarding the alerting network, our results reveal that bilingual participants took more advantage of the presentation of an alerting cue before the target item than monolingual participants (see Fig. 7). Although this effect is relatively small in magnitude (25 ms for monolinguals vs. 34 for bilinguals), it accounts for an increment of 27% of the size of the effect for bilinguals in relation to monolinguals, and it is highly significant. This effect reveals that bilingualism may help individuals to reach and/or to maintain a state of alertness allowing them to prepare the system

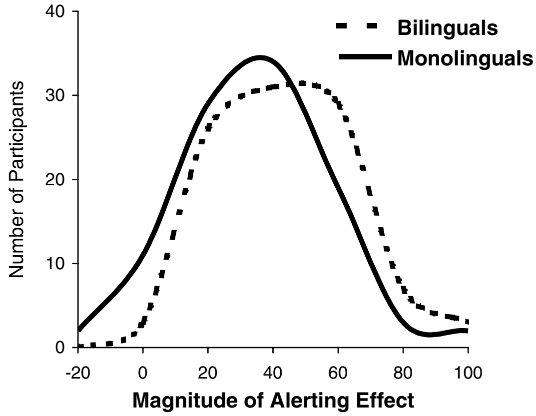

Fig. 7. Distribution of the magnitude of the alerting effect for monolinguals and bilinguals. The size of the intervals is 20 ms.

for monitoring and conflict resolution. Interestingly, it appears that the alerting network and the executive network are related in complex ways, given that the magnitude of the alerting effect correlated negatively with the magnitude of the conflict effect ($R = -.26$; $p < .01$). That is, the more gain from an alerting cue a participant had, the smaller the magnitude of the conflict she experienced. This type of relationship between the two effects has already been observed in the study conducted by Fossella et al. (2002). However, it appears that this interaction between networks is very sensitive to various properties of the specific design used, given that other studies have found the opposite observation (Callejas et al., 2004, 2005). In any case, the influence between the alerting and the executive network may raise some concerns regarding the origin of the bilingual advantage in conflict resolution. This is because the better conflict resolution by bilinguals may stem from their better efficiency to use the cue rather than from a better efficiency to resolve conflict. However, this does not seem to be the case given that the difference in the magnitude of the conflict effect between the two groups was similar when the alerting cue was present (13 ms) than when it was not (14 ms). That is, bilinguals are better at solving conflict even in the absence of the alerting cue. At present we do not have enough available experimental information to give an account of why bilingualism affects the alerting network. Future research needs to be conducted to explore the origin of this effect.

Finally, both groups of participants showed a significant orienting effect. However, this effect was not modulated by the bilingual status of the participants, suggesting that this attentional network is not affected by bilingualism. This result indicates that differences between bilinguals and monolinguals are not present in all cognitive capacities (not even in all of those that are part of the attentional system). Importantly, it also helps us to be more confident, along with the precautions we took when selecting the participants (matched in age and level of education, etc.), about the comparability of the two groups of participants.[7]

4. Conclusion

The results reported in this article allow us to conclude that bilingualism has a positive effect on the achievement of more efficient functioning of two attentional networks: the alerting network and the executive control network. These observations add to the existing literature on the cognitive benefits of bilingualism, showing that such benefits are not only present during the development (and decline) of the attentional processes. Rather, bilingualism also seems to affect positively the attainment of a high level of efficiency when individuals are at the peak of their attentional capabilities. Thus, to the extent to which the task used in our experiment and those used with children and elderly people shared some of the components involved in the executive control network, we can conclude that bilingualism exerts a positive effect throughout the life of an individual. Furthermore, our results suggest that these beneficial effects are present for two subcomponents of the executive control network: monitoring processes and conflict resolution.

Finally, the observations reported here (among others) open several questions for further research. Do the positive effects of bilingualism also emerge for late bilinguals? Does such an effect arise also for bilinguals that are not in a sociolinguistic situation in which the two languages are at play on a every-day basis? Does the magnitude of such effects depend on the similarity between the two languages of bilinguals? What is the relationship between the different attentional networks that lead bilingualism to affect the alerting and executive one but not the orienting one? Answers to these questions will bear on brain plasticity and cross-talk between seemingly different cognitive domains.

Acknowledgments

This research was supported by a grant from the Spanish Government (SEJ - 2005), a grant from the European Science Foundation (BFF2002-10379-E), by the McDonnell Grant "Bridging Mind Brain and Behavior", and by a grant from the HFSP (RGP68/2002). Mireia Hernández was supported by a Pre-doctoral fellowship from the Catalan Government. Requests for reprints should be addressed to Albert Costa. The authors are grateful to Dr. Rueda, Dr. Fuentes, Dr. Santesteban, Dr. Navarrte, Dr. Soto, and Ms. Ivanova for their comments on previous versions of this manuscript.

[7] Perhaps a better evidence of the comparability of the two groups of participants in terms of their general speed of processing could have been to further test them in a task that does not require conflict resolution (see a light, press a key). Unfortunately, we do not have such experimental evidence in this study.

Appendix A. Language use and skills of the participants

Language use of the bilingual participants: language use scores were obtained by a questionnaire administered after the experiment. Language use scores represent the percentage of the time using the two languages by means of a 7-point scale (1 = *only Spanish*, 7 = *only Catalan*).

	Preschool age	Childhood	Adolescence	Adulthood
School	–	5.2	4.9	4.8
Home	5.4	5.6	5.6	5.5
Other places	–	4.9	4.8	4.7

Language skills of the participants. Language skill scores were obtained by a questionnaire administered after the experiment. Language skill scores represent the level of language proficiency according to a 4-point scale (0 = *very bad*, 4 = *native speaker*). Foreign language represents the language learned in a formal context (e.g. courses in school).

Language skill	Group	Spanish	Catalan	Foreign language
Comprehension	Bilingual	4.0	4.0	2.7
	Monolingual	4.0	–	2.3
Reading	Bilingual	4.0	4.0	2.8
	Monolingual	4.0	–	2.4
Speaking	Bilingual	3.8	4.0	2.2
	Monolingual	4.0	–	2.0
Pronunciation	Bilingual	3.7	4.0	2.2
	Monolingual	4.0	–	1.9
Writing	Bilingual	3.9	3.9	2.5
	Monolingual	4.0	–	2.1

Appendix B. Description of the bilingual community and of the languages

In Catalonia, Catalan and Spanish are both official languages. In many families, both languages are spoken. In kindergarten (ages 4–5), special Catalan programs are offered to children from monolingual Spanish families. The current education system requires that at the end of the primary school (year 11/12), children are able to read, write, speak, and understand both Catalan and Spanish. In high school, some classes are taught in Catalan and others in Spanish. At the university, classes and tests can be in either language – quite often half of the test is in Catalan, other half in Spanish. Radio and television programs broadcast in Catalan and in Spanish. Furthermore, newspapers contain articles written in Catalan and Spanish. Our group of participants was relatively homogenous with respect of bilingual proficiency. They were all native speakers of Catalan (they spoke Catalan with at least one of their parents) and they were first exposed to Spanish at a very early age. All the participants passed the Catalan–Spanish language proficiency exam that is required for enrollment at the university. In order to pass this exam students must be very proficient in all aspects of the two languages (vocabulary, grammar, etc.). Participants reported to use both languages in their daily life.

Catalan and Spanish are two Romance languages with a large similarity at different linguistic levels. For example, at the lexical level the formal similarity between translation words is quite common, since about 70% of them could be considered cognate words. Also, nouns of both languages are overtly marked for gender (masculine vs. feminine) and number, and such grammatical features govern agreement inside the noun phrase. At the syntactic level both languages are also rather similar. They are SVO languages with relatively free word order, allowing the omission of the subject of the sentence (pro-drop languages). Perhaps the most relevant differences between the two languages are at the phonological level. The two languages have different vowel repertoires: Spanish has a relatively small inventory of five vowels (/a/,/e/, i/i, /o/, *lul)*, which can be realized both in stressed and unstressed positions; Catalan has eight vowels (/a/, /e/, /ɛ/, /i/, /O/, /o/, /u/, and /ɘ/, with vowel reduction in unstressed position (a, e, and /ɛ/ are reduced to schwa /ɘ/, and /o/ is reduced to /u/). The consonant repertoire is also different: the consonants /ø/, /v/, and /x/ can be found only in Spanish, and the consonants /Z/, /S/, /w/, /j/, and / z/ can be found only in Catalan. There are also differences in the orthographic systems: Only Spanish has the grapheme ñ and only Catalan has the graphemes ï, and ç. The phoneme /Í/ is realized by the graphemes *ch* and *tx* in Spanish and Catalan, respectively. Finally, in Catalan two signs are used to indicate stress (as in é and è) but only one in Spanish (é).

References

Allport, D. A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltá & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconsious information processing* (pp. 421–452). Cambridge, MA: MIT Press.

Allport, D. A., & Wylie, G. (1999). Task-switching: Positive and negative priming of task-set. In G. W. Humphreys, J. Duncan, & A. M. Treisam (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 273–296). Oxford University Press.

Allport, D. A., & Wylie, G. (2000). "Task-switching," stimulus-response bindings, and negative priming. In S. Monsell & J. S. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 35–70). Cambridge, MA: MIT Press.

Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development, 70*, 636–644.

Bialystok, E. (2001). *Bilingualism in development: Language, literacy, and cognition*. New York: Cambridge University Press.

Bialystok, E. (2006). Effect of bilingualism and computer video game experience on the Simon task. *Canadian Journal of Experimental Psychology, 60*(1), 68–79.

Bialystok, E., Craik, F. I. M., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005b). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *NeuroImage, 24*, 40–49.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging, 19*, 290–303.

Bialystok, E., Craik, F. I. M., & Ruocco, A. C. (2006). Dual-modality monitoring in a classification task: the effects of bilingualism and ageing. *The Quarterly Journal of Experimental Psychology, 59*, 1968–1983.

Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified antisaccade task: effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(6), 1341–1354.

Bialystok, E., & Martin, M. (2004). Attention and inhibition in bilingual children: evidence from the dimensional change card sorting task. *Developmental Science, 7*, 325–339.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005a). Bilingualism across the lifespan: the rise and fall of inhibitory control. *International Journal of Bilingualism, 9*, 103–119.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Reviews, 108*, 624–652.

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature, 402*, 179–181.

Callejas, A., Lupiáñez, J., Funes, M. J., & Tudela, P. (2005). Modulations among the alerting, orienting and executive control network. *Experimental Brain Research, 167*(1), 27–37.

Callejas, A., Lupiáñez, J., & Tudela, P. (2004). The three attentional networks: on their independence and interactions. *Brain and Cognition, 54*, 225–227.

Casey, B. J., Trainor, RJ., Orendi, J. L., Schubert, A. B., Nystrom, L. E., Giedd, J. N., Castellanos, F. X., Haxby, J. V., Noll, D. C., Cohen, J. D., Forman, S. D., & Dahl, R. E. (1997). A developmental functional MRI study of prefrontal activation during performance of a go-no-go task. *Journal of Cognitive Neuroscience, 9*, 835–847.

Costa, A. (2005). Lexical access in bilingual production. In J. F. Kroll & A. M. B. De Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches*. New York: Oxford University Press.

Costa, A., & Caramazza, A. (1999). Is lexical selection in bilingual speech production language-specific? Further evidence from Spanish-English and English-Spanish bilinguals. *Bilingualism: Language and Cognition, 2*(3), 231–244.

Costa, A., La Heij, W., & Navarrete, E. (2006b). The dynamics of bilingual lexical access. *Bilingualism: Language and Cognition, 9*(2), 137–151.

Costa, A., Miozzo, M., & Caramazza, A. (1999). Lexical selection in bilinguals: do words in the bilingual's two lexicons compete for selection?. *Journal of Memory and Language 41*, 365–397.

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language, 50*, 491–511.

Costa, A., Santesteban, M., & Ivanova, I. (2006a). How do highly-proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. *Journal of Experimental Psychology: Learning, Memory and Cognition*.

Craik, F. I. M., & Bialystok, E. (2006). Cognition through the lifespan. *Trends in Cognitive Sciences, 10*(3).

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*(11), 2037–2078.

De Jong, R. (1995). Strategic determinants of compatibility effects with task uncertainty. *Acta Psychologica, 88*, 187–207.

Durston, S., Davidson, M. C., Thomas, K. M., Worden, M. S., Tottenham, N., Martinez, A., Watts, R., Ulug, A. M., & Casey, B. J. (2003). Parametric manipulation of conflict and response competition using rapid mixed-trial event-related fMRI. *NeuroImage, 20*, 2135–2141.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16*, 143–149.

Fan, J., Fossella, J., Sommer, T., Wu, T., & Posner, M. I. (2003). Mapping the genetic variation of executive attention onto brain activity. *Proceedings of the Natlional Academy of Sciences of the United States of America, 100*(12), 7406–7411.

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *NeuroImage, 26*, 471–479.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340–347.

Finkbeiner, M., Almeida, J., Janssen, N., & Caramazza, A. (2006). Lexical selection in bilingual speech production does not involve language supression. *Journal of Experimental Psychology: Learning, Memory and Cognition, 32*(5), 1075–1089.

Finkbeiner, M., Gollan, T. H., & Caramazza, A. (2006). Lexical access in bilingual speakers: what's the (hard) problem?. *Bilingualism: Language and Cognition 9*, 153–166.

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments & Computers, 35*, 116–124.

Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., & Posner, M. I. (2002). Assessing the molecular genetics of attention networks. *Biomedical Central Neuroscience, 3*(14).

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*, 67–81.

Green, C., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534–537.

Kroll, J. F., Bobb, C., & Wodniecka, Z. (2006). Language selectivity is the exception, not the rule: arguments against a fixed locus of language selection in bilingual speech. *Bilingualism, 9*(2), 111–135.

La Heij, W. (2005). Selection processes in monolingual and bilingual lexical access. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of Bilingualism* (pp. 289–307). Oxford: Oxford University Press.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., et al. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academu of Scieces, 25/97*(9), 4414–4416.

Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming. Asymmetrical costs of language selection. *Journal of Memory and Language., 40*, 25–40.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 41A*, 19–45.

Posner, M. I., & Fan, J. (2004). Attention as an organ system. In J. R. Pomerantz (Ed.), *Neurobiology of perception and communication: From synapse to society*. Cambridge UK: Cambridge University Press.

Posner, M. I., & Petersen, S. E. (1990). The attention systems of the human brain. *Annual Review of Neuroscience, 13*, 25–42.

Rogers, R. D., & Monsell, S. (1995). Costs of predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in Childhood. *Neuropsychologia, 42*, 1029–1040.

Rueda, M. R., Posner, M. I., Rothbart, M. K., & Davis-Stober, C. P. (2004). Development of the time course for processing conflict: an event-related potentials study with 4-year-olds and adults. *BioMed Central Neuroscience, 5*(39).

Yeung, N., & Monsell, S. (2003a). Switching between tasks of unequal familiarity: the role of stimulus-attribute and response-set selection. *Journal of Experimental Psychology: Human Perception and Performance, 29*(2), 455–469.

Yeung, N., & Monsell, S. (2003b). The effects of recent practice on task switching. *Journal of Experimental Psychology: Human Perception and Performance, 29*(5), 919–936.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*, 37–63.