

How Does Bilingualism Improve Executive Control? A Comparison of Active and Reactive Inhibition Mechanisms

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It has been claimed that bilingualism enhances inhibitory control, but the available evidence is equivocal. The authors evaluated several possible versions of the inhibition hypothesis by comparing monolinguals and bilinguals with regard to stop signal performance, inhibition of return, and the attentional blink. These three phenomena, it can be argued, tap into different aspects of inhibition. Monolinguals and bilinguals did not differ in stop signal reaction time and thus were comparable in terms of active-inhibitory efficiency. However, bilinguals showed no facilitation from spatial cues, showed a strong inhibition of return effect, and exhibited a more pronounced attentional blink. These results suggest that bilinguals do not differ from monolinguals in terms of active inhibition but have acquired a better ability to maintain action goals and to use them to bias goal-related information. Under some circumstances, this ability may indirectly lead to more pronounced reactive inhibition of irrelevant information.

Keywords: bilingualism, inhibition, executive functions

Speaking more than one language has many advantages. Apart from the obvious extension of one's opportunities to communicate and to express oneself, there are less obvious benefits. As numerous studies have shown, bilinguals at all ages outperform monolinguals in several cognitive tasks and abilities, ranging from creativity tasks (Kessler & Quinn, 1987) and problem solving (Bain, 1975) to perceptual disembedding problems (Duncan & De Avila, 1979) and the Simon task (Bialystok, Craik, Klein, & Viswanathan, 2004).

According to Green (1998) and Bialystok (2001; Bialystok et al., 2004), being raised as a bilingual enhances one's inhibitory control. Being able to speak more than one language presupposes some sort of control over the language used to express

one's thoughts at any given time and, thus, the ability to suppress all but the currently preferred language. The constant exercise of this inhibitory control, so the idea goes, provides bilinguals with an enhanced ability to ignore distracting and irrelevant stimuli, not only in language tasks but in general cognitive processing (Bialystok, 2001; Bialystok et al., 2004).¹

Even though some observations seem to be consistent with the inhibition view (for an overview, see Bialystok et al., 2004), some central findings, such as the reduced Simon effect in bilinguals, seem notoriously difficult to replicate (see Bialystok et al., 2004, for positive evidence based on group differences of several hundreds of milliseconds and Bialystok, Martin, & Viswanathan, 2005, and Bialystok, 2006, for failures to replicate). Moreover, the available accounts have not been particularly precise with regard to the mechanism underlying the ability to inhibit irrelevant or unwanted information and representations. To get a clearer idea about the cognitive advantages

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¹ In more recent publications, Bialystok and colleagues have considered the possibility that bilingualism benefits executive processes other than inhibitory control, such as response suppression and task switching (e.g., Bialystok, Craik, & Ryan, 2006) or context monitoring (Bialystok, Craik, & Ruocco, 2006). However, the present study was motivated by, and thus focuses on, the original claim of an inhibitory-control benefit for bilinguals.

that bilinguals enjoy, we tested the implications of two different ways that inhibitory control may be exerted.²

Let us consider how a target code (target, in short) is selected against an alternative distractor code (noise, in short). As shown in Figure 1, target and noise (e.g., a word in the current language and a word in the alternative language) will compete for selection, which is indicated by the mutually inhibitory link between them (b). Resolving this competition requires some sort of bias that either supports the target or hampers the noise, or both. According to the inhibition view suggested by Green (1998), bilinguals resolve competitions of that sort by inhibiting the noise (e.g., words in the alternative language), as indicated by the inhibitory link from the hypothetical inhibitory system to the noise code (c). Henceforth, we refer to this view as *active inhibition*, thereby indicating that the inhibition is not due to local inhibitory connections but to the intervention of a separate, central inhibitory system (in Green's model, the "language task schema").

Extended experience in inhibiting noise may generalize to non-language codes and thus may benefit any task in which targets need to be selected against noise. If so, this suggests that bilinguals should be good active inhibitors. We tested this hypothesis in Experiment 1 by comparing monolinguals and bilinguals in the classical stop signal task, a task that has been developed to investigate and that has been shown to be indicative of active inhibitory control (Logan, 1994; Logan & Cowan, 1984).

However, as Figure 1 shows, inhibiting noise is not the only way that selection can be successfully biased. Instead of, or in addition to, actively inhibiting competing codes, the target code may be directly strengthened. As suggested by Desimone and Duncan (1995), representations of the task goal may support codes that are consistent with it, as indicated by the facilitative link between the

hypothetical goal system and the target code (a). Supporting the target code not only increases its activation but could inhibit the noise code via the inhibitory link (b). According to this logic and using the terminology of Logan (1994), bilinguals may have learned to suppress (words from) the currently unwanted, alternative language indirectly, through local reactive inhibition, but not "actively."³ That is, bilinguals may not be particularly good inhibitors, but they may be good at maintaining the task goal, so as to provide stronger support for target representations. This view is consistent with other proposals of how bilinguals control their languages. For instance, it is in line with the "complex access, simple selection" view proposed by La Heij (2005; see also Pouliisse & Bongaerts, 1994), in which no active inhibition of words in the unwanted language is assumed. It is also in line with Dijkstra and van Heuven's bilingual interactive-activation model, in which representations of words from alternative languages compete for attention (Dijkstra & van Heuven, 1998; Van Heuven, Dijkstra, & Grainger, 1998) and competition within and across languages is resolved by lateral inhibition. Thus, inhibitory effects may not necessarily be caused by a dedicated inhibitory control system or executive control function but, rather, may result from supporting (priming) relevant information in a highly competitive system. In other words, and somewhat paradoxically, what has been referred to as inhibitory control may be achieved by mechanisms that work through facilitation. We conducted Experiments 2 and 3 to test the implications of such a goal-maintenance view by comparing monolinguals and bilinguals with regard to the inhibition of return task and the attentional blink.

Experiment 1 (Stop Signal)

In the standard stop signal task (Logan & Cowan, 1984), participants are first presented with a stimulus telling them to execute a particular response, which may be followed by a stop signal calling for the immediate abortion of that response. Versions of this task have been used to investigate the efficiency with which various sorts of cognitive processes can be stopped, and so performance on the task can be considered to diagnose the individual efficiency of actively inhibiting one's "thoughts and actions" (Logan, 1994; Logan & Cowan, 1984). In our version of the task, participants responded to the direction of a green arrow by pressing a button with the left or right index finger. The stop signal was

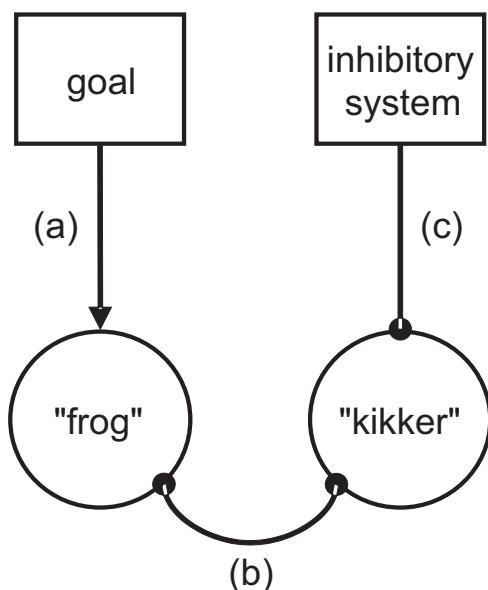


Figure 1. Possible mechanisms involved in selecting a word from one of two competing languages (English and Dutch). The target word (*frog*) is supported by the goal representation through a facilitatory connection (a). Activating *frog* inhibits its Dutch equivalent, *kikker*, through a reactive inhibitory link (b). The incorrect Dutch word may also be actively inhibited through an inhibitory control system (c).

² Note that, as did MacLeod, Dodd, Sheard, Wilson, and Bibi (2003), we explicitly focused on the origin or cause of inhibition (i.e., whether inhibition is produced by a separate "inhibitory control" system or emerges from the interaction of local codes) rather than on inhibitory effects or functions. As we argue later in this article, these aspects are logically different and independent, even though most authors fail to distinguish between them and commonly take for granted that inhibitory effects (e.g., withholding a primed response) must be produced by "suppression" exerted by some inhibitory control system (e.g., Bialystok, Craik, & Ryan, 2006; Logan, 1994). Instead of taking this connection for granted, we sought for empirical evidence that supported or challenged it.

³ Note that Green's (1998) use of the term *reactive inhibition* differs from Logan's (1994) use and, thus, our own. Whereas in Green's model *reactive* refers to the moment at which inhibition is applied (by a central inhibitory system), we use the term to refer to local (lateral) inhibitory links between activated word representations.

a sudden and unpredictable change of the arrow to red, which signaled a deliberate effort to refrain from responding. The performance in the stop signal paradigm can be conceptualized in terms of a race, in which the stop process and the go process compete to finish first (see Logan & Cowan, 1984). If the stop process finishes before the go process does, the response is inhibited. By contrast, if the go process finishes before the stop process does, the response is executed.

To be successful, inhibitory processes have to win a race against concurrent response processes. If the inhibitory processes finish before the response processes do, the response is aborted. The stop signal reaction time (SSRT; see Figure 2) can be computed as an index of inhibitory efficiency (Logan, 1994). If bilinguals are better inhibitors than monolinguals are, they should show significantly shorter SSRTs than monolinguals do.

Method

Participants. Thirty-two healthy young adults served as participants for partial fulfillment of course credit or for a financial reward and constituted the two language groups: monolingual and bilingual. All reported having normal or corrected-to-normal vision, and all were unfamiliar with the purpose of the experiment. Half of the participants were monolingual Spanish speakers who lived in Spain, and the other half were Dutch–English bilinguals who lived in the Netherlands. All participants were tested by the same instructional protocols, although the actual testing was carried out in two different countries. The bilingual participants grew up in “mixed” families (with one parent speaking Dutch and the other speaking English or German), and some of them had lived part of their life in an English-speaking country. They used both Dutch and English on a daily basis throughout their lives. As research with bilingual adults (Kroll & Stewart, 1994) and children (Bialystok, 1988) has revealed that the cognitive and linguistic consequences of bilingualism are more salient for those bilinguals who are relatively balanced in their proficiency, we considered only balanced bilinguals for the present study. The monolingual

Spanish speakers were not functionally fluent in any other language, despite the inevitable language courses in school. All participants in both groups attended university and shared similar middle-class socioeconomic backgrounds, and they were matched for age, gender, and IQ (measured by Raven’s Standard Progressive Matrices; see Table 1).

Apparatus and stimuli. The Spanish participants were tested with a laptop PC (Asus A3Ac with a 15.1-in. monitor), and the Dutch participants were tested with a desktop PC (Switch attached to a Philips 17-in. Real Flat monitor). Responses were made by pressing the Z or ? keys of the QWERTY computer keyboard with the left and right index finger, respectively. Participants were required to react quickly and accurately by pressing the left or right key in response to the direction of a left- or right-pointing green arrow (choice trials) about 3.5×2.0 cm in length.

Procedure and design. The experiment consisted of a 30-min session, in which participants completed a version of the task adopted from van den Wildenberg et al. (2006). Arrows were presented pseudorandomly, with the constraint that they signaled left- and right-hand responses equally often. Arrow presentation was response terminated. Intervals between subsequent choice signals varied randomly but equiprobably, from 1,250 ms to 1,750 ms in steps of 125 ms. During these interstimulus intervals, a white fixation point (3 mm in diameter) was presented. The green arrow changed to red during 30% of the trials, upon which the choice response had to be aborted (stop trials). We used a staircase-tracking procedure that dynamically adjusted the delay between the onset of the choice signal and the onset of the stop signal for each hand separately to control inhibition probability (Levitt, 1971). After a successfully inhibited stop trial, stop signal delay increased by 35 ms in the next stop trial, whereas when the participant was unable to stop, the stop signal delay decreased by 35 ms in the next stop trial. This algorithm ensured that motor actions were successfully inhibited in about half of the stop trials, which yielded accurate estimates of SSRT (Band, van der Molen, & Logan, 2003; see Figure 2). The algorithm compensated for differences in choice RT between participants, between stimulation conditions, and between the left and right hands. The stop task consisted of five blocks of 104 trials, the first of which served as a practice block and allowed us to obtain stable participant performance.

Language background questionnaire. To check whether our selection criteria had been met, we asked bilingual participants to fill out a questionnaire on language use and fluency in their two languages. The questionnaire addresses the percentage usage of each language at home, at work, with friends, and overall, and the responses indicate the extent to which each language is used daily and the degree to which the participant is functionally bilingual. The self-evaluated proficiency scores of the Dutch–English bilinguals are shown in Table 2. Following the procedure used by Costa, Kovacic, Franck, and Caramazza (2003), we obtained the proficiency scores by a self-evaluation through the questionnaire the participants had filled out before the experiment. The scores are on a 10-point scale, in which 10 represents native-speaker level and 1 represents complete ignorance of the language. Other studies have shown that similar self-report measures correspond well with performance measures of proficiency, such as RT on a verbal categorization task (Dufour & Kroll, 1995; Kroll, Michael, Tokowicz, & Dufour, 2002).

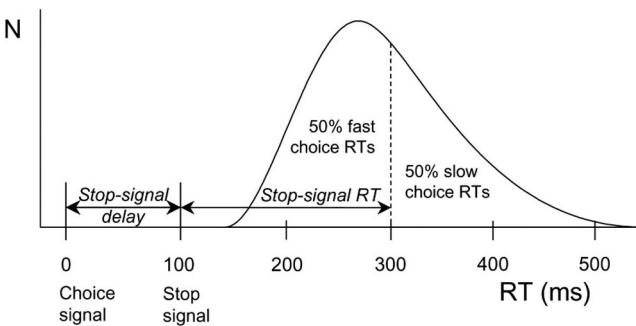


Figure 2. Estimation of stop signal reaction time (RT) according to a race model (Logan, 1994; Logan & Cowan, 1984). The curve depicts the distribution of RTs on choice trials (trials without a stop signal), which represent the finishing times of the response processes. If independence of choice and stop processes is assumed, the finishing time of the stop process bisects the choice RT distribution. Given that the button-press response could be withheld in 50% of stop trials, stop signal RT (200 ms) is calculated by subtracting the mean stop signal delay (100 ms) from the median choice RT (300 ms).

Table 1
Demographic Data Measures and Standard Deviations for the Monolingual (Mon) and Bilingual (Bil) Groups

Measure	Experiment 1		Experiment 2		Experiment 3	
	Mon	Bil	Mon	Bil	Mon	Bil
<i>N</i> (male/female)	16 (4:12)	16 (4:12)	18 (5:13)	18 (5:13)	18 (2:16)	18 (3:15)
IQ, <i>M</i> (<i>SD</i>)	110 (5.3)	113 (5.4)	—	—	110 (3.9)	111 (6.5)
Age, <i>M</i> (<i>SD</i>)	22 (2.3)	22 (2.8)	22 (2.7)	22 (3.6)	22 (0.8)	23 (3.6)

Note. Age is in years. A dash indicates that no data were available.

Results

We tested group differences by means of an analysis of variance (ANOVA). Median RT on go signal showed that bilinguals (RT = 401 ms) did not react significantly faster than monolinguals did (RT = 433 ms), $F(1, 30) = 2.10, p = .15, MSE = 3.922$. We examined mean SSRTs to determine whether inhibition efficiency differed between the groups. SSRTs were estimated separately for each participant and for each group. Overall, participants were able to stop their responses successfully about half the time when a stop signal instructed them to do so. Participants were able to stop on about half of the stop signal trials (49% in monolinguals and 48% in bilinguals, $F < 1$), which indicates that the dynamic tracking algorithm worked well in both groups. The percentage of choice errors to go signals was low and did not discriminate between monolinguals (1.4%) and bilinguals (2.6%), $F(1, 30) = 1.44, p = .24, MSE = 8.273$. Most important, SSRTs were not significantly different in the two language groups (219 ms and 228 ms, respectively, for the bilinguals and monolinguals), $F(1, 30) < 1, MSE = 1.604$.

Discussion

Experiment 1 tested the idea that learning to manage multiple languages requires speakers to develop active inhibition skills, which may in turn transfer to nonlingual cognitive processes. If so, bilinguals should outperform monolinguals in tasks (e.g., the stop task) that tap into active inhibition mechanisms. However, the absence of anything even close to a reliable difference in SSRT between the two experimental groups leaves little room for the assumption that bilinguals are better inhibitors than are monolinguals, at least with respect to the inhibitory processes assessed by the stop signal task.

Experiment 2 (Inhibition of Return)

The outcome of Experiment 1 does not support the hypothesis of better active inhibition skills in bilinguals, or at least not the hypothesis that such skills generalize to nonlingual tasks. However, it is difficult to interpret negative outcomes, especially in the absence of detailed theoretical approaches. We therefore aimed at providing converging evidence by making use of another phenomenon that has been linked to inhibitory processes: inhibition of return (IOR; see Klein, 2000, for an overview). As Posner and Cohen (1984) have shown, cuing the location of a visual target by means of a randomly varying, peripheral stimulus (e.g., a flash at the location where the target will occur) improves performance at

short stimulus onset asynchronies (SOAs) but impairs performance at longer SOAs.

The benefit of spatial cuing at short SOAs is commonly attributed to the potency of abrupt onsets to attract visual attention; even randomly varying (and therefore uninformative) onset cues have been assumed to attract attention to their location, which provides a processing advantage for the target if it appears at the same location (Posner, 1980). That is, the first phase of cuing is commonly considered to be automatic and beneficial. The second phase is more controversial. The costs of spatial cuing at long SOAs have been interpreted as reflecting a foraging mechanism that supports natural searching behavior by inhibiting previously attended locations (Klein, 1988); as constituting a bias against responding to these locations (Fuentes, Vivas, & Humphreys, 1999); or as reflecting both attentional and motor factors (Taylor & Klein, 2000). In any case, the inhibitory nature of the second phase of cuing suggests that it is related to inhibitory mechanisms. Indeed, recent findings have demonstrated that IOR interacts with stop signal performance (i.e., SSRT; Ivanoff & Taylor, 2006; Taylor & Ivanoff, 2003).

If IOR taps into the type of inhibitory skill that bilinguals are assumed to have acquired, randomly varying, peripheral spatial cues should affect monolinguals and bilinguals differently. Although both groups should show comparable performance at short SOAs (i.e., cuing benefits if cue and target appear in quick succession), bilinguals should show a more pronounced IOR (cuing costs) at longer SOAs than monolinguals do.

Table 2
Self-Evaluated Proficiency Scores of the Dutch–English Bilinguals

Self-evaluated proficiency	Experiment 1		Experiment 2		Experiment 3	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Production	8.62	1.02	8.66	0.97	8.73	0.73
Comprehension	9.25	0.93	9.39	0.77	9.26	0.93
Writing	8.56	1.03	8.23	0.84	8.31	1.06
Reading	9.06	0.85	9.00	0.84	8.95	0.85

Note. The proficiency scores were obtained by self-evaluation through a questionnaire the participants filled out before the experiment. The scores are on a 10-point scale, in which 10 represents native-speaker level and 1 represents complete ignorance of the language.

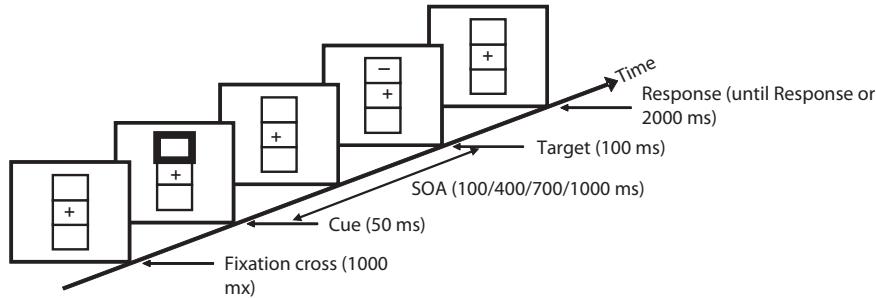


Figure 3. Experimental trial sequence, from bottom left to top right. SOA = stimulus onset asynchrony.

Method

Participants. We recruited 18 volunteers for each of the two language groups by applying the same criteria and matching procedures for all demographic data measures, other than intelligence, that we had used in Experiment 1 (see Tables 1 and 2). The balanced bilingual group comprised 12 bilingual participants from Experiment 1 and 6 additional Dutch–English bilinguals. The monolingual group comprised 18 new participants. As in Experiment 1, the bilingual participants were tested in the Netherlands and the monolingual participants were tested in Spain.

Apparatus and stimuli. All participants were tested with standard desktop PCs. Participants faced three square gray outlines, vertically arranged, as illustrated in Figure 3. From the viewing distance of about 60 cm, each of these frames measured $2.6^\circ \times 3.1^\circ$. Either a vertical line ($0.1^\circ \times 0.6^\circ$) or a horizontal line ($0.3^\circ \times 0.1^\circ$) served as the target, which was presented in light gray in the top or bottom frame. The boxes were displayed in light gray on a black background. On every trial, at varying temporal intervals before presentation of the target, one of the two boxes thickened briefly. This change gave the impression of a brief flicker, which is referred to hereafter as the attentional cue. Responses to the target were made by pressing the left or right shift key of the computer keyboard with the corresponding index finger.

Procedure and design. The experiment was modeled after that of Lupiàñez, Milliken, Solano, Weaver, and Tipper (2001) and consisted of a 30-min session. The sequence of events during each trial was as follows: A fixation point was displayed with the three boxes for 1,000 ms, and then the attentional cue appeared for 50 ms. Following the cue, the fixation point and the boxes remained on the screen for 50, 350, 650, or 950 ms. The target, a horizontal or vertical line, was then displayed for 33 ms, after which the fixation point and the empty boxes were displayed until the participant had responded or 2,000 ms had passed. The next trial began 1,000 ms later. A 1000-Hz computer-generated tone that lasted 100 ms served as error feedback. Half of the participants responded to the vertical and horizontal lines by pressing the left and right keys, respectively, while the other half received the opposite mapping. Participants were instructed to press the response key on the keyboard as quickly as possible and were not informed of the presence of the cue or of the SOA manipulation. All possible combinations of the cue location and target location variables were presented randomly within a block of trials. The experiment was composed of eight blocks containing 40 trials each. Participants

were instructed to press the space bar to continue the experimental session.

Results

Trials with RTs faster than 100 ms or slower than 900 ms (0.9% of the trials) and trials on which an error was made were excluded from the RT analysis. RTs and percentages of errors (PEs) were analyzed by means of ANOVAs, with cuing (cued vs. uncued) and SOA (100, 400, 700, or 1,000 ms) as within-participant factors and group (monolingual vs. bilingual) as a between-participants factor (see Table 3 for means). One monolingual participant was excluded by the analysis because of low performance (PEs higher than 35%).

When we replicated the relevant observations from the comparable discrimination task with mixed SOA blocks, as used by Lupiàñez et al. (2001),⁴ our RT analysis yielded four reliable effects: a main effect of SOA, $F(3, 99) = 67.02, p < .0001, MSE = 756$; an interaction between SOA and cuing, $F(3, 99) = 7.36, p < .001, MSE = 333$; an interaction between group and cuing, $F(1, 33) = 7.35, p = .011, MSE = 557$; and an interaction between SOA and group, $F(3, 99) = 3.80, p = .013, MSE = 756$. As shown in Figure 4A, when averaged across language groups, RTs decreased with SOA; the cuing effect turned from a benefit at short SOAs to a cost at 700 ms SOA and recovered at the longest SOA. Hence, we obtained IOR. However, even if the three-way interaction of SOA, cuing, and group was not significant, cuing seemed to affect the two language groups differently; for example, the average cuing effect was negative for bilinguals (-4 ms) and positive for monolinguals (10 ms). To get a better grip on the overall pattern, we computed individual cuing effects for each SOA (see Figure 4B for means).

The error rates analysis did not yield any significant effects.

Discussion

Experiment 2 tested the hypothesis that bilinguals show a stronger IOR effect. On the one hand, it is clear that the predictions were not confirmed (e.g., that bilinguals do not differ from mono-

⁴ A difference between the two studies was that our participants recovered somewhat faster from inhibition of return at the longest SOA than participants in the Lupiàñez, Milliken, Solano, Weaver, & Tipper (2001) study did. This finding should not affect the interpretation of our results.

Table 3
Mean Reaction Times (RTs) and Standard Deviations for Responses to the Target and Percentages of Errors (PEs) on R2, as a Function of Language Group and the SOAs

SOA	Bilingual				Monolingual			
	Cued		Uncued		Cued		Uncued	
	RT	PE	RT	PE	RT	PE	RT	PE
100	573 (74)	5.69 (6.5)	581 (72)	5.83 (5.6)	569 (64)	1.91 (2.1)	594 (72)	1.91 (1.9)
400	525 (56)	4.58 (5.5)	522 (63)	5.00 (4.5)	539 (53)	1.76 (2.3)	559 (62)	1.91 (2.4)
700	519 (74)	4.17 (5.0)	502 (66)	4.58 (4.3)	537 (62)	1.91 (2.1)	531 (57)	2.35 (3.6)
1,000	507 (82)	5.28 (4.6)	501 (67)	3.19 (3.8)	537 (57)	1.47 (1.9)	542 (60)	0.88 (1.2)

Note. Values in parentheses represent standard deviations. RTs are in milliseconds. SOA = stimulus onset asynchrony.

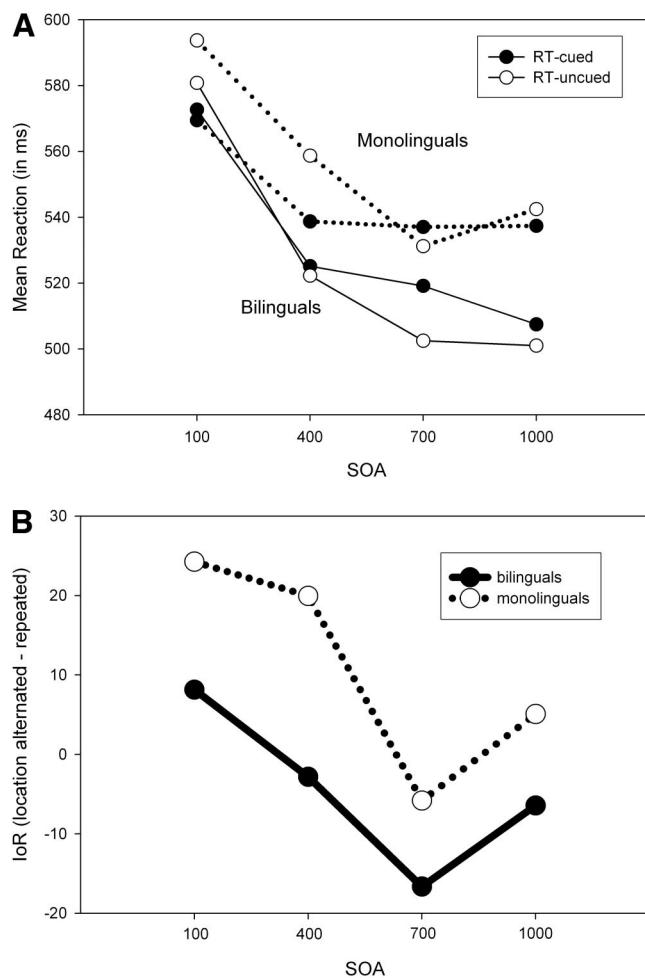


Figure 4. A: Mean reaction time (RT) across stimulus onset asynchrony (SOA) as a function of language group and repetition versus alternation of the cue. B: Time course of cuing effects (facilitation and IoR), calculated as the difference between RT uncued and RT cued, as a function of the language group (bilingual vs. monolingual). IoR = inhibition of return.

linguals by having a more pronounced shift from cuing benefits to cuing costs at longer SOAs). Instead, bilinguals and monolinguals have very similar SOA functions, but bilinguals show more costs than benefits overall. On the other hand, it is clear that cuing effects were affected by bilingualism, even though the way they were affected was unexpected. There are several theoretical options that may account for this outcome pattern.

One theoretical option saves the active inhibition hypothesis by assuming that cue-induced facilitation (at short SOAs) and costs (at long SOAs) are produced by different and independent processes. So, as soon as a stimulus is registered, the facilitatory and inhibitory processes start, and their relative strengths determine the shape of the SOA function. In monolinguals, the facilitatory process may start out stronger than the inhibitory process does, but it decays with increasing SOA, thus letting the costs increase over time. In contrast, bilinguals may have more pronounced inhibitory processes, just as the active inhibition hypothesis maintains; thus, there is a net effect of zero as long as the facilitatory process contributes, and the net effect becomes more and more negative as the SOA increases. This scenario could explain our observations, but the assumption that facilitatory and inhibitory processes are unrelated does not seem to fit with the theoretical considerations discussed in the literature (apart from raising the question why no effect was found in Experiment 1). If IOR reflects a foraging mechanism that prevents the repeated attentional scrutinization of an event (Klein, 1988) or the repeated response to it (Fuentes et al., 1999), why would the prevention begin after no more than 100 ms, at a time when processing of even the first stimulus is unlikely to be complete? In fact, a system with independent facilitatory and inhibitory processes would always run into the danger of impairing its own stimulus processing and/or response selection mechanisms.

An alternative approach can make use of the integration hypothesis suggested by Lupiàñez et al. (2001), who observed that the point in time when cue-induced facilitation turns into costs varies systematically with task difficulty. For instance, costs occur at later SOAs if the target is more difficult to identify. As Lupiàñez et al. pointed out, this systematic variation suggests that people are able to control the size of the temporal integration window they use to construct stimulus representations or object files, in the

sense described by Kahneman, Treisman, and Gibbs (1992). The wider the chosen window, according to Lupiàñez et al., the more likely that cue and target will be integrated into the same representation and thereby prime each other—an assumption that has received support in a recent electrophysiological study (Akyürek, Riddell, Toffanin, & Hommel, 2007). In contrast, the smaller the window, the more likely that cue and target will be integrated into different representations. If cue and target share location information, some sort of competition and, hence, costs may occur. In fact, repetition of some but not all features of an object has been found to impair performance in numerous tasks and paradigms (for an overview, see Hommel, 2004).

From this perspective, our outcome may point to two, not necessarily mutually exclusive, interpretations. It may be that bilinguals tend to have shorter temporal integration windows, which would enable them to create more distinct stimulus representations.⁵ If so, they might always create different representations for the cue and the target, so that facilitation would never occur. Alternatively or in addition, bilinguals may have more reactive inhibition between competing representations. If so, the conflict between cue representations and target representations would lead to more inhibition of the losing competitor (the cue) and its features. As a consequence, repetition of location (or any other feature) would tend to produce more negative consequences in bilinguals than in monolinguals.

In view of these theoretical possibilities, Experiment 2 must be considered helpful but inconclusive. Hence, on the one hand, we were able to demonstrate that bilingualism affects performance in a task that taps into inhibitory processes (in an arguably more direct way than had previous tasks), but, on the other hand, the outcome pattern did not allow us to distinguish between active and reactive inhibition.

Experiment 3 (Attentional Blink)

The major obstacle to experimental discrimination between active and reactive inhibition is that the mechanisms can commonly be suspected to serve the same purpose: that is, to suppress unwanted information. This is true for the Simon task (Bialystok, 2006; Bialystok et al., 2004, 2005), where the aim of both active and reactive inhibitory mechanisms would be to suppress the often misleading (and task-irrelevant) stimulus location, and for the cuing task used in our Experiment 2, where it was just as reasonable to suppress the randomly varying cue location. To circumvent this logical problem, we thought of an experimental task in which active inhibition makes little sense but reactive inhibition is nevertheless likely to occur. According to our reasoning, tasks producing the so-called attentional blink (AB; Raymond, Shapiro, & Arnell, 1992) meet these criteria.

The AB occurs when two masked (or otherwise difficult to identify) target stimuli appear in close temporal proximity, such as in RSVP (rapid serial visual presentation) tasks with varying lags between the two targets. If the first target (T1) is identified correctly, people have great difficulty in reporting the second target (T2) when it occurs within an interval of about 100–500 ms after T1. Despite minor (often rather metaphorically expressed) details, most of the available approaches assume that processing and consolidating T1 occupies attentional mechanisms to a degree that means too little attention is left for processing and consoli-

dating T2 if it appears before the consolidation of T1 is complete (for an overview, see Shapiro, 2001). However, recent observations are inconsistent with the assumption of a structural bottleneck (Colzato, Spapè, Pannebakker, & Hommel, 2007; Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Hommel et al., 2006). For instance, people can report more than two targets when these targets are presented in a sequence (Di Lollo et al., 2005), which suggests that it is the presence of distractors between two given targets that is responsible for the blink. Hence, at least part of the AB seems to represent a side effect of a mechanism that shields targets against the impact of distractors, as does the mechanism sketched in Figure 1. Indeed, Shapiro, Schmitz, Martens, Hommel, and Schnitzler (2006) observed a trade-off between the amount of resources devoted to T1 processing and the probability of missing T2. In particular, participants who showed more attention-related brain activity while processing T1 were more likely to fail to report T2 in the blink interval. This finding fits with the observation that a more relaxed attitude toward the task improves performance on T2 (Olivers & Nieuwenhuis, 2005). It is also consistent with the finding that successful report of T2 in the interval that typically produces a blink is accompanied by a dramatic suppression of brain responses to the distractors that intervene between T1 and T2 (Gross et al., 2004). In other words, the AB reflects the efficiency of noise suppression. Taken altogether, these studies suggest that people differ in the amount of attention they devote to the processing of a selected target stimulus and that this difference directly translates into their ability or inability to process a temporally close stimulus.

Getting back to our main question, these findings mean that people can indeed be suspected to differ with respect to how much support they provide for a to-be-selected stimulus event and/or how much reactive inhibition this support exerts on competitors (Routes a and b in Figure 1). This support would vary even under conditions in which the competitor is also a target, a fact that renders the presence of active inhibition (Route c) implausible. If so, we would be in the position of making a counterintuitive and rather surprising prediction: To the degree that they produce stronger reactive inhibition, bilinguals should exhibit worse performance (that is, a greater blink) in the AB task than monolinguals should. We tested this prediction by comparing performance of bilinguals and monolinguals in a standard RSVP task with two target stimuli.

Method

Participants. We recruited 18 volunteers for each of the two language groups by applying the criteria and matching procedures

⁵ At this point, this is only a logical possibility, and one may ask why bilinguals would use shorter integration windows. Even though we are not theoretically committed with regard to this point, it may be that shorter windows are just one mechanism subserving a general tendency of bilinguals to emphasize differences rather than commonalities between represented events (cf. Suls & Wheeler, 2007, for an overview of contrast effects). Again, this tendency would serve to make representations of the two acquired languages more distinct and thus easier to separate. Other mechanisms might lead to a stronger weighting of unshared rather than shared features in priming tasks, but more systematic research is necessary to test that possibility.

used in Experiment 1 (see Tables 1 and 2). The balanced bilingual group comprised 12 bilingual participants from Experiment 1 and 6 additional Dutch–English bilinguals. The monolingual group comprised 18 new participants. Three monolingual participants were excluded from the analysis because of excessive error rates (>80%) on T1.⁶ As in Experiments 1 and 2, the bilingual participants were tested in the Netherlands and the monolingual participants were tested in Spain.

Apparatus and stimuli. The experiment was controlled by a standard desktop computer. All stimuli were presented in a resolution of 800 × 600 pixels in 16-bit color on a 17-in. CRT that refreshed at 100 Hz. Participants were seated at a viewing distance of about 50 cm. The fixation mark (+) and all RSVP items were presented centrally in black on a gray background (RGB 128, 128, 128). Each item was set in 16-point Times New Roman font. Letters were drawn randomly without replacement from the full alphabet. Digits were drawn from 1 to 9.

Procedure and design. In the RSVP task, participants were asked to identify and report two digits (T1 and T2) presented in a stream of letter distractors. After they had read the instructions, which included a slow demonstration of the RSVP, and had indicated that they fully understood the task, participants were required to go through 24 trials of training. If more than 50% of the responses were incorrect during the training, the training runs were repeated.

An initial fixation addition sign, which was shown for 2,000 ms, marked the beginning of each trial. After a blank interval of 250 ms, the RSVP commenced; it consisted of 20 items with a duration of 40 ms each and an interstimulus interval of 40 ms. A full session lasted 30 min and contained 360 trials (three locations of T1 × 4 lags × 30 repetitions). Lag was determined by the number of items between T1 and T2. We randomly varied T1 position between Positions 7, 8, and 9 of the stream to reduce the predictability of target onsets. T2 was presented directly thereafter (Lag 1) or after another two, four, or seven distractors (Lags 3, 5, and 8 successively; see Figure 5). Participants were to report both targets directly after the RSVP by pressing the corresponding digit key on the computer keyboard.

Results

Two measures were computed individually and as a function of lag between T1 and T2: the (unconditional) percentage of trials on which T1 was correctly reported and the conditional percentage of correct T2 reports given that T1 was reported ($T2|T1$). An ANOVA of T1 accuracy with language group varying between participants and lag varying within participants yielded a main effect of lag, $F(3, 93) = 203.72, p = .0001, MSE = 0.005$, but no other effects. As shown in Figure 6A, performance dropped at the shortest lag, a common observation that indicates T1 and T2 compete for selection if they appear in direct succession (Hommel & Akyürek, 2005; Potter, Staub, & O'Connor, 2002).

More important for our purposes was performance on T2. An ANOVA of conditional T2 report revealed a significant effect of lag, $F(3, 93) = 38.76, p = .001, MSE = 0.009$, that was involved in a two-way interaction with group, $F(3, 93) = 5.23, p = .002, MSE = 0.009$. As shown in Figure 6B, a standard AB was obtained in both groups: Performance was good when the two targets appeared in direct succession, the so-called Lag-1 sparing (Visser,

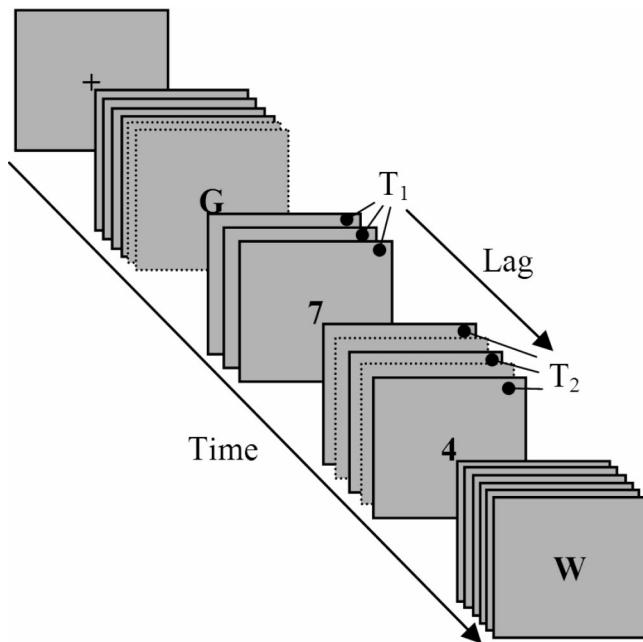


Figure 5. Events in a rapid serial visual presentation trial. The stimulus onset asynchrony was 80 ms, and the blank interstimulus interval was 40 ms (i.e., each stimulus appeared for 40 ms). The two-digit targets in the letter stream (T1, T2) were separated by one, three, five, or eight nontargets after T1; the number of nontargets defined the lag. The first digit was presented as either the fourth or the fifth display.

Bischof, & Di Lollo, 1999); dropped as soon as at least one distractor appeared between the two targets (i.e., at Lag 3); and recovered slowly with increasing lag. However, it is obvious that this blink around Lag 3 was more pronounced in bilinguals than it was in monolinguals. Indeed, when we compared the size of the blink around Lag 3 obtained for the participants in the two groups in a t test, the difference was clearly significant, $t(31) = -2.15, p = .039$ (two-tailed).

Discussion

Experiment 3 was carried out to test whether bilinguals would show more reactive inhibition in reporting two targets from a RSVP stream than monolinguals would. If they did, they should exhibit a larger AB, that is, a more pronounced decrement in performance at shorter lags. This is exactly what we observed: The two language groups were comparable in most measures, but bilinguals showed a larger dip of T2 report—a bigger blink, that is—at Lag 3. As it made little sense for participants to actively inhibit T2 in this task, we attribute the outcome to more reactive inhibition in bilinguals.

General Discussion

Numerous studies have shown that balanced bilinguals differ from monolinguals in various cognitive tasks, and it has been

⁶ The error rates at T1 for the remaining participants averaged 35% in the bilingual group (range 23%–52%) and 30% in the monolingual group (range 17%–45%).

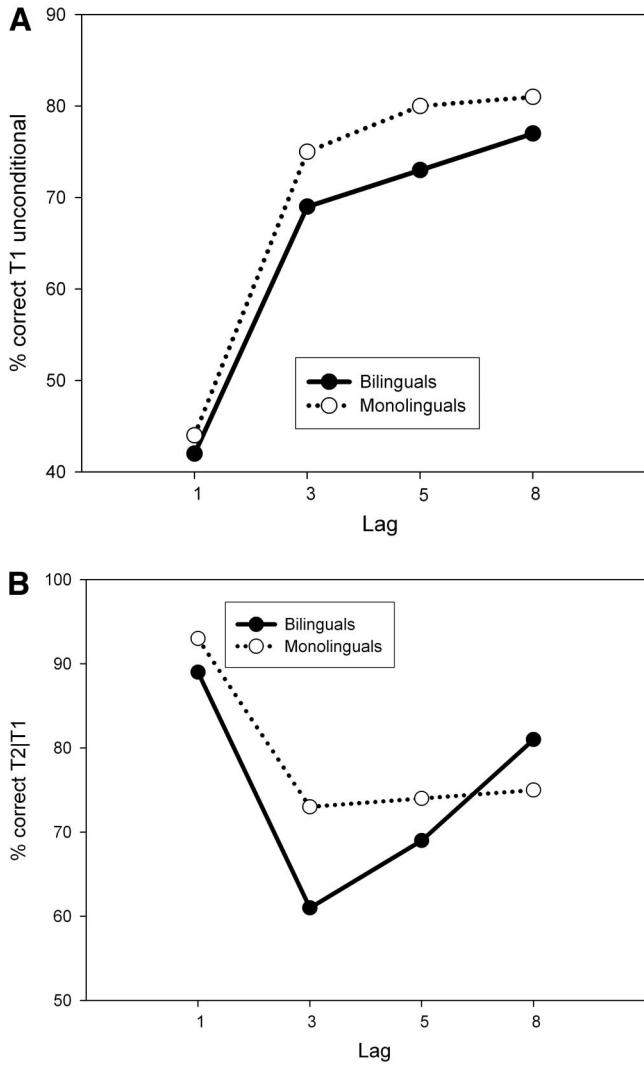


Figure 6. A: T1 (unconditional) performance as a function of the language group (bilinguals vs. monolinguals). B: T2 performance, given T1 correct as a function of the language group (bilinguals vs. monolinguals). T1 = Target 1; T2 = Target 2.

suggested that greater inhibitory efficiency on the part of the bilinguals may play a role in creating these differences. However, the outcome patterns are not always systematic and replicable, and the hypothetical inhibitory processes are not well specified. In an attempt to clarify this picture, we aimed to distinguish between active inhibition, which would reflect processes carried out with the main purpose of excluding particular information from processing, and reactive inhibition, which may be a side effect of facilitatory processes in a capacity-limited system.

Experiment 1 can be considered a direct test of active inhibition, and, yet, the performance of bilinguals and monolinguals was identical. This result undermines strong, general claims about better developed processes subserving active inhibition in bilinguals. It should be emphasized that the stop signal task can be viewed as assessing a broad range of the inhibitory processes but is unlikely to cover all of them, a fact that implies we cannot rule

out a role for the inhibitory benefits of bilingualism in tasks other than those tested here. Experiment 2 was also thought to index inhibition, but the outcome was equivocal. On the one hand, bilinguals differed systematically from monolinguals, and they did so in a way that may be attributed to inhibitory processes. On the other hand, the fact that their performance differed with respect to not only the second, inhibitory phase of the impact of random spatial cues but the first, facilitatory phase makes it difficult to determine whether active or reactive inhibitory processes were responsible. A clearer picture was provided by Experiment 3, in which active inhibition was less likely to occur. Bilinguals had significantly greater difficulties than monolinguals did in processing a temporally close second target while still processing the first. Given that there was no indication that bilinguals have fewer attentional resources than monolinguals do, this performance difference must have to do with the side effects of processing the first target.

Apparently, bilinguals invest more of their resources in processing a target (Route a in Figure 1) and/or processing a target leads to a stronger inhibition of competitors (Route b). Either way, differences in the performance of bilinguals and monolinguals seem to reflect side effects of selecting stimulus events for action rather than differences in some general inhibitory mechanism. We thus propose that the cognitive processing advantages that bilinguals enjoy are not due to the constant exercise in inhibiting, as previous findings were taken to suggest. Rather, we propose that learning to keep two or more languages separate leads to a general improvement in selecting goal-relevant information from competing, goal-irrelevant information—a view that seems to converge with more recent considerations of Bialystok and collaborators (e.g., Bialystok et al., 2006).

This improvement may be achieved by the stronger maintenance of goals in working memory, so they can provide more and stronger support for goal-related cognitive representations. How this maintenance may work has been studied by Byrne and Bovair (1997), who used a cognitive simulation work on the role of goal support in simple procedural tasks, and more recently by Egner and Hirsch (2005), who used event-related functional magnetic resonance imaging. The latter authors analyzed the brain processes that are triggered by the detection of response conflict, which was induced through Stroop-type stimuli. Rather than reducing the activation of irrelevant stimulus representations (which would indicate active inhibition), conflict detection led to the stronger activation of relevant representations. Connectivity analyses revealed that this increase in activation was induced by signals from dorsolateral prefrontal cortex (DLPFC), which were assumed to translate the action goal into top-down support for goal-related processes (e.g., Desimone & Duncan, 1995; Miller & Cohen, 2001). Recent observations have linked DLPFC to bilingualism (see Rodriguez-Fornells, de Diego Balaguer, & Münte, 2006, for a recent review). For instance, the switch from one language to another is accompanied by higher DLPFC activation (Hernandez, Dapretto, Mazzotta, & Bookheimer, 2001), and stimulation of the left DLPFC by means of TMS—a common treatment for depression—induces unexpected language switches (Holtzheimer, Fawaz, Wilson, & Avery, 2005). Taken together, these findings suggest that bilinguals outperform monolinguals by building up and maintaining goal representations more efficiently and/or by

translating these representations more efficiently into top-down support of goal-relevant activities (see Route a in Figure 1).

Whether and to what degree bilinguals and monolinguals differ with respect to reactive inhibition mechanisms (Route b in Figure 1), or at least with respect to the amount of reactive inhibition they are commonly facing, is difficult to judge at this point. At first sight, one may consider a selection mechanism based on top-down support sufficient. However, many selection models are based on a winner-takes-all principle, which implies a direct, negative relationship between the activation of target representations, on the one hand, and distractor representations, on the other (for an overview, see O'Reilly, 1998). Such a relationship presupposes inhibitory links between target and distractor representations, just as depicted in Figure 1. To the degree that these links really exist, the assumption that bilinguals enjoy more top-down support of target representations via Route a necessarily implies that bilinguals experience more reactive inhibition along Route b. However, whether and to what degree this more pronounced reactive inhibition actually affects performance depends on the details of cortical decision making (for an overview, see Bogacz, 2007).

According to so-called race models of decision making, alternative cognitive representations collect evidence in their favor (i.e., are activated to the degree that the alternative representations are consistent with the current stimulus) and trigger a response as soon as their activation exceeds a particular threshold (e.g., Vickers, 1970). On such an account, stronger top-down support would be sufficient to explain better performance in bilinguals, irrespective of whether reactive inhibition takes place. According to the diffusion models, which are biologically more realistic (e.g., Ratcliff, 1978), a decision for one alternative is made only if its activation exceeds the activation of all competitors to a particular degree. Thus, it is difference in activation rather than absolute activation that counts, and this difference is much more easily created between codes that (reactively) inhibit each other. On such an account, bilinguals would not necessarily require stronger inhibitory links but the hypothesized stronger top-down support they enjoy would translate into greater reactive inhibition. We doubt that sufficient empirical evidence is available to allow us to decide between these theoretical alternatives at this point, and we share Bialystok et al.'s (2006) view that more types of executive functions may need to be considered. However, we do hope that distinguishing between different types of inhibition and considering the interplay between goal maintenance and reactive inhibition will provide interesting avenues for further research on bilingualism.

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