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Inhibition Efficiency in Highly Proficient Bilinguals and Simultaneous Interpreters: Evidence from Language Switching and Stroop Tasks

Xavier Aparicio[1] · **Karin Heidlmayr**[2] · **Frédéric Isel**[3]

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Abstract The present behavioral study aimed to examine the impact of language control expertise on two domain-general control processes, i.e. active inhibition of competing representations and overcoming of inhibition. We compared how Simultaneous Interpreters (SI) and Highly Proficient Bilinguals—two groups assumed to differ in language control capacity—performed executive tasks involving specific inhibition processes. In Experiment 1 (language decision task), both active and overcoming of inhibition processes are involved, while in Experiment 2 (bilingual Stroop task) only interference suppression is supposed to be required. The results of Experiment 1 showed a language switching effect only for the highly proficient bilinguals, potentially because overcoming of inhibition requires more cognitive resources than in SI. Nevertheless, both groups performed similarly on the Stroop task in Experiment 2, which suggests that active inhibition may work similarly in both groups. These contrasting results suggest that overcoming of inhibition may be harder to master than active inhibition. Taken together, these data indicate that some executive control processes may be less sensitive to the degree of expertise in bilingual language control than others. Our findings lend support to psycholinguistic models of bilingualism postulating a higher-order mechanism regulating language activation.

Keywords Bilingualism · Language control · Stroop task · Active inhibition · Overcoming of inhibition · Language switching

✉ Xavier Aparicio
xaparici@gmail.com

1 Laboratory CHArt – EA 4004, Paris-Est Créteil University - ESPE, Créteil, France

2 Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

3 Laboratory MoDyCo – UMR 7114, CNRS, Paris Ouest Nanterre La Défense University – Paris Lumières, Paris, France

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Introduction

For individuals who master and regularly use two or more languages, it has been observed that there are specific language control demands that are, amongst others, due to the simultaneous activation of languages (Abutalebi and Green 2007; Brysbaert 2003; Dijkstra 2005; Dijkstra and van Heuven 2002; Green 1998; Hoshino and Thierry 2011) and cross-language influences (Blumenfeld and Marian 2013; Costa et al. 2008; Runnqvist et al. 2012). The question of how bilingual individuals who regularly use different languages are able to control the cross-linguistic interferences has been addressed in numerous studies recently. Here, we addressed this issue by comparing two groups of bilinguals who are supposed to differ in their capacity to control multiple languages, namely Simultaneous Interpreters (SI) and Highly Proficient Bilinguals. We hypothesized that according to the specific language control expertise of these two groups of bilinguals, their performance in tasks requiring executive, cognitive or inhibitory control processes should be differentially impacted.

Bilingualism and Cognitive Control

The language non-selective access hypothesis (Dijkstra et al. 1998, BIA model; see also Kroll et al. 2006), postulates that reading a word of a native or non-native language first activates all the lexical candidates overlapping this word. Then, it is assumed that the inappropriate candidates are inhibited by means of lateral inhibition at the lexical level, and top-down inhibition between language nodes, both processes contributing to word recognition. Therefore, in bilingualism, the question of word recognition in competing languages raises the issue of top-down inhibitory control or active top-down inhibition (Abutalebi and Green 2007; Christoffels et al. 2007; Costa and Santesteban 2004; Crinion et al. 2006; Green 1998). Models of bilingual language processing have postulated that active inhibition is involved in the inhibition of the non-target language (Green and Abutalebi 2013; Green 1998). However, in cases of e.g. language switching, another type of control is required, i.e. the overcoming of this inhibition. Here, we focused on the study of active inhibition—designated as inhibition throughout this section—and overcoming of inhibition.

In order to account for inhibition and switching processes in bilingual language use, two different hypotheses on the interplay between language control processes and domain-general executive control have been proposed (Abutalebi and Green 2007; Calabria et al. 2012; Green and Abutalebi 2013). According to the first hypothesis, language control processes are fully subsidiary to the domain-general executive control functioning, and will engage the same set of executive control processes that are involved in non-linguistic activities requiring executive control. If we consider language switching issues, bilinguals would engage exactly the same control mechanisms as when they are asked to switch between non-linguistic tasks in daily life. Nevertheless, few studies are in line with this hypothesis (see Calabria et al. 2012; Green and Abutalebi 2013). The alternative hypothesis considers that bilingual language control may be only partially subsidiary to the domain-general executive control, and that the control exerted by bilinguals on their languages could contribute to the development of control processes specific to language (Costa and Santesteban 2004), suggesting interactions between language-specific and domain-general control processes (Costa et al. 2008b; Bialystok et al. 2004; Hernandez et al. 2010).

To date, most of the psycholinguistic studies that have investigated executive language control in bilingualism have compared monolinguals and bilinguals. Although these studies have indisputably contributed to a better understanding of executive language control, firm conclusions regarding the relation between bilingualism and control processes have not yet emerged. One possible reason to explain the cross-studies inconsistency in this domain is that most of the studies have considered bilingualism as a categorical variable (Kroll and Bialystok 2013). In our view, this is nowadays not sufficient enough, particularly when one refers to the definition proposed by Grosjean (1982) stating that bilingualism is the ability to produce meaningful statements in two (or more) languages, being proficient in at least one language skill (reading, writing, speaking, listening) in another language, and alternate the use of several languages. Therefore, it seems more realistic to consider bilingualism as a continuous multidimensional variable.

In the present study, for approaching the question of the relation between language control and bilingualism from a different angle, we decided to compare two groups of bilingual individuals, i.e. professional Simultaneous Interpreters (SI) and Highly Proficient Bilinguals. These two groups are supposed to differ in their abilities in language control. If both groups used on a daily basis active and overcoming of inhibition processes, SI engage these processes to a greater extent compared to bilinguals that are non-interpreters, i.e. the Highly Proficient Bilingual Group. Here, both professional Simultaneous Interpreters (SI) and Highly Proficient Bilinguals were equivalent in terms of proficiency, and were behaviorally examined while performing an executive task involving either both active inhibition and overcoming of inhibition (i.e. language decision task with repetition and switch trials), or active inhibition/interference suppression solely (i.e. Stroop task). Both groups are thought to have a longtime experience in inhibiting languages, whereas SI additionally have a high expertise in switching (task switching in comprehension/production).

It seems that both simultaneous and successive bilinguals possess a certain ease in switching from one language to another, which necessitates mental flexibility, and to some extent also involves inhibition processes (Bobb and Wodniecka 2013; Costa and Santesteban 2004; Dijkstra and van Hell 2003; Heidlmayr et al. 2016; Meuter 2005). It has been well demonstrated that language switching in bilinguals requires language control processes, and more specifically that an active top-down inhibition mechanism should be applied to refrain interference from the irrelevant language (Abutalebi and Green 2007; Aparicio and Lavaur 2013; Chauncey et al. 2008; Green 1998). In this vein, the inhibitory control (IC) model (Green 1998) is one of the most influential models accounting for language control and language switching processes in bilinguals. More recently, Green and Abutalebi (2013) formulated the adaptive control hypothesis, according to which language control processes adapt to the recurrent demands they have to deal with, depending on the interactional context (single-language, dual-language and dense code-switching). The adaptive control hypothesis constitutes a promising approach, as it allows us to put the study of bilingual language control processes in connection with the language context in which these processes work.

These models postulate that language control processes involve domain-general executive functions. Indeed, executive functions, and more specifically active inhibition (*i.e.* interference suppression and response inhibition), play a major role in (language) control processes (Green and Abutalebi 2013). Hence, we shall give a brief characterization of the concepts of inhibition as discussed in the executive function literature. One of the most influential models has been proposed by Miyake et al. (2000), which postulates a distinction of three main executive functions: inhibition of dominant responses (inhibition), shifting of mental sets (shifting), and monitoring and updating of information in working memory (updating). As for inhibition, which is one of the processes of central interest in the present study, the term inhibition is not specific to cognitive psychology, and is defined by the stopping, blocking or slowing down of a physiological, chemical or psychological process (Aron 2007), and is a part of an action. A distinction can be made between automatic inhibition (e.g. lateral inhibition between lexical representations), active/current inhibition (the suppression of an irrelevant response), and overcoming of inhibition (reactivation of an item previously inhibited; see Aron 2007; Mayr and Keele 2000; Mueller et al. 2009). If bilinguals have higher abilities in executive processing due to their use of several languages and capacities to keep them separated on the one hand, and because of their ability to switch between languages on the other hand, it is therefore relevant to investigate their performance in tasks requiring active inhibition as well as in tasks involving language switching. Moreover, language switching involves both active inhibition and overcoming of inhibition, the two control processes investigated in the present study. If bilingual speakers are used to deal with their two languages in the daily lives, and consequently could be considered as experts in managing and resolving language competition, it is even more of interest to consider “extreme” language control, like Simultaneous Interpreting (Christoffels and De Groot 2005; Elmer et al. 2014; Hervais-Adelman et al. 2014; Yudes et al. 2012). By comparing two groups of late proficient bilinguals, we should be able to determine whether efficiency of active and overcoming of inhibition processes among bilinguals is influenced by their experience in their daily lives.

Bilingualism and Executive Functions Training

The use of more than one language is one of the exercises, amongst other activities such as playing music (Bialystok and DePape 2009), playing computer and video games (Bialystok et al. 2006; Dye et al. 2009), or practicing sports requiring high level of bimanual coordination (Diamond 2011) that plays a role in the strengthening of executive functions (Bialystok 2001; Bialystok et al. 2006; Bialystok and DePape 2009; Costa et al. 2008b; Diamond 2010; Heidlmayr et al. 2014, 2015, 2016; Kroll et al. 2012). However, results are far from consensual and several studies reported a clear bilingual advantage for performing various tasks involving executive control (e.g. Bialystok et al. 2004, 2008; Costa et al. 2008b; Heidlmayr et al. 2014, 2015; Linck et al. 2008), while others did not (Carlson and Meltzoff 2008; Duñabeitia et al. 2014; Hilchey and Klein 2011; Humphrey and Valian 2012; Kousaie and Phillips 2012a; Paap and Greenberg 2013; Paap and Sawi 2014). Several studies have highlighted that bilingual individuals have a certain ease to solve conflicts occurring in tasks involving executive control, like the Stroop task (Stroop 1935), the Simon task (Simon and Rudell 1967) or the Tower of Hanoi task (Miyake et al. 2000). An explanation accounting for this advantage is that bilinguals have enhanced inhibitory control, trained by their frequent language switches as well as by language suppression when maintaining activation in only one language in their daily lives, in comparison with “monolingual” individuals (Badzakova-Trajkov 2008; Bialystok et al. 2004, 2008; Costa et al. 2008b; Heidlmayr et al. 2014, 2015). In these tasks, a reduced interference effect and/or faster response times are associated with higher capacities of inhibitory control. Some of these behavioral studies on inhibition controlled for biological age (Bialystok et al. 2008), given that the efficiency of executive functions has been shown to rise and decline over the lifespan (Best and Miller 2010; De Neys and Van Gelder 2009; Diamond 2006; Treitz 2006; Zelazo et al. 2004).

In a study involving successive bilinguals with several combinations of languages, Badzakova-Trajkov (2008) found reduced Stroop interference for Macedonian–English and German–English bilingual young adults in comparison to monolingual young adults (English). In a recent study, Heidlmayr et al. (2014) investigated whether frequency of daily use of a second (L2) and a third language (L3) in successive bilinguals could impact the efficiency of their inhibitory control processes. The authors tested performance on a Stroop task involving both French and German words in successive French–German bilinguals differing in their frequency of L2 and additional L3 usage. The performance of bilinguals with the French words were compared to French monolinguals. Their results clearly indicate that the bilingual advantage was reinforced by the use of a third language (L3), but was also modulated by the duration of immersion in a second language environment. Nevertheless, several studies have failed to show that bilingual young adults had an advantage on inhibitory control in a Stroop task (Kousaie and Phillips 2012a).

A bilingual advantage has also been found in switching tasks, which plausibly include inhibition processes (Kovács and Mehler 2009; Prior and MacWhinney 2010). There is also a wide range of studies focusing on language switching processes during visual word recognition (e.g. Aparicio and Lavaur 2013) or naming (see Bobb and Wodniecka 2013 for a review). The study of Aparicio and Lavaur (2013) investigated language dominance and language switching effects in successive French–English–Spanish trilingual participants. Participants acquired their L2 from the age of 10 and L3 from the age of 12. Basing on the seminal work of Grainger and Beauvillain (1988), they introduced a series of monolingual and generalized lexical decision (one, two or three languages involved). Their results revealed a general slowdown of processing associated with the introduction of additional languages, even for L1 processing. Moreover, they found an asymmetry in language switching, with larger effects when switching from the non-dominant language to the dominant language. A possible explanation accounting for this asymmetry is that inhibition of the first language needs to be strong in order to be efficient, and therefore requires an additional cognitive effort to overcome the inhibition and reactivate the inhibited language.

These latter results suggest that inhibition plays a major role during language switching, and that proficiency could attenuate language switching effects. Nevertheless, in a very interesting and wide review of the literature of language switching (in picture naming), Bobb and Wodniecka (2013) pointed out that switch costs may not be the most reliable index of inhibition in bilingual language control, because asymmetrical switching costs are not always observed. As language proficiency clearly seems to modulate asymmetrical switch cost, in our research we selected bilingual participants with a high level of proficiency in both languages, assessed by self-rating measures (on comprehension, speaking, reading skills in both languages) and more objectively with the DAF test (*Deutsch als Fremdsprache*) which allowed us to evaluate linguistic skills in German. Therefore, we ensured that our group of Highly Proficient Bilinguals had similar language skills in comparison with Simultaneous Interpreters. Indeed, the differences between our two groups are being expected at the language control level, namely that language control will be more efficient in SI (Christoffels and De Groot 2005; Elmer et al. 2014; Hervais-Adelman et al. 2014; Yudes et al. 2012).

The Case of Simultaneous Interpreters

If bilingual speakers are used to practice their two languages in their daily lives, and consequently can be considered as experts in managing and resolving competition between linguistic units, it is of interest to consider “extreme situations” involving between-language control. Few studies (Christoffels and De Groot 2005; Christoffels et al. 2007; Köpke and Signorelli 2012; Proverbio et al. 2004; Yudes et al. 2011) have considered the case of Simultaneous Interpreters (SI). As it was very clearly described by Yudes et al. (2011, see also Christoffels and De Groot 2005; Elmer et al. 2014; Hervais-Adelman et al. 2014), simultaneous interpreting requires to process a spoken message in the source language (SL), and this message must be reformulated and produced in the target language (TL). Given that these processes occur simultaneously, a high level of control and coordination is required to successfully accomplish the task. Simultaneous Interpreters need to process a part of the message in the SL, while they mentally translate and verbally produce previous part of the message in the TL (Gerver 1971; Yudes et al. 2011). Interestingly, Christoffels and De Groot

2005 pointed out that both language systems have to be simultaneously active for comprehension and production. These researches show that executive control is essential for SI, in that simultaneous interpreting implies a high level of coordination between languages in order to switch from one to another (Christoffels and de Groot 2004).

It can be argued that SI show enhanced skills for controlling their attentional resources, in order to limit a possible loss of information and interference between languages. It has been clearly demonstrated that both bilinguals and SI have efficient abilities to deal with interferences from the language that is not in use (Rodriguez-Fornells et al. 2005; Kaushanskaya and Marian 2007), but it is not clear if these abilities are due to greater skills in terms of either cognitive flexibility or inhibition processes. In a recent study, Yudes et al. (2011) have investigated non-verbal executive processes in SI, and compared their performance with bilinguals (non-interpreters) and monolinguals. Participants performed two tasks, the first one thought to index cognitive flexibility (the Wisconsin Card Sorting Test, WCST), and the other one to index inhibitory processes (Simon task). Their results revealed that SI outperformed bilinguals and monolinguals on the WCST, with fewer attempts to infer the rule, as well as fewer errors and fewer perseverations from the previous category. Critically, in the other task, the Simon effect was similar for the three groups of participants, leading the authors to interpret their results as a better cognitive flexibility for SI, rather than a better efficiency in terms of inhibition processes. Therefore, the fact that Simultaneous Interpreters spend more time in a bilingual mode is supposed to train cognitive flexibility, but the lack of difference between groups in the Simon tasks suggests similar performances in terms of active inhibition for SIs and bilinguals.

Nevertheless, when overcoming of inhibition processes are required, differences arise between SIs and proficient bilinguals. Ibáñez et al. (2010) have compared reading time performances of proficient bilinguals and translators while they were reading and understanding sentences randomly presented in their first language (L1-Spanish) and second language (L2-English). Sentences included cognates or specific words. Their results showed that the group of experienced translators co-activated both languages during reading, with a faster processing of cognate words as compared to control words. However, the bilinguals processed cognate and control words equally rapidly indicating that they were only activating the language in which sentences appeared in each trial. Higher performances for translators is explained in terms of language co-activation whereas bilinguals switch between two monolingual modes. Interestingly, they also found an asymmetrical switch cost (an index of inhibitory process in language selection) for the bilingual group, but not for the translators, suggesting better efficiency in terms of active inhibition for the translators.

In line with these later findings, according to the IC model of Green (1998), language selection is regulated by inhibitory processes, and the selection of the appropriate language is achieved by inhibition of the non-relevant language. In SI, the activation-inhibition account is crucial, because as we mentioned previously both languages are activated simultaneously. To describe inhibition in SI, Paradis (2000) proposed the subset and the activation threshold hypothesis. To sum up, when a bilingual speaks in one language only, the activation threshold of the non-selected language is raised sufficiently to prevent interference during production (active inhibition). Paradis (2000) argued that in SI the threshold of the source language (SL) is higher than the threshold of the target language, because production requires more activation than comprehension. Thus, SI must maintain the goal of their task, and to some extent inhibit the non-relevant language for comprehension, and the non-relevant language for production. Therefore, as proposed by Bialystok et al. (2008) and Diamond (2011), if bilinguals possess particular cognitive control abilities compared to monolinguals, it makes sense to assume that these abilities would be widely developed in SI.

Aim of the Present Study

The aim of the present study was to investigate whether enhancement of language control efficiency can influence bilinguals' performance in tasks involving inhibitory control. A secondary aim was to examine two control processes, the active inhibition of competing representations and the overcoming of inhibition by using two tasks involving inhibition processes (Stroop and language decision tasks). Our study relies on the hypothesis that cognitive control is more efficient in SI than in Highly Proficient Bilinguals. For this purpose, we compared the behavioral performance of two groups of French (L1)–German (L2) bilinguals, with comparable levels of proficiency in both languages as attested by self-ratings in both languages, as well as by a language test (Deutsch als Fremdsprache or DAF) in L2, a standardized language test of German proficiency. However, these two groups reasonably differed in language control expertise, as Simultaneous Interpreters engage different or additional types of inhibition (more specifically active inhibition and overcoming of inhibition) to a greater extent than Highly Proficient Bilinguals.

In order to separate the effects of active and overcoming of inhibition, two response time experiments were designed. In Experiment 1, participants had to perform a language decision task, which means deciding from which language, French or German, the visually presented words of a list belonged to. Language decision tasks have been barely used in the literature (Dijkstra et al. 2000; Font and Lavaur 2004; Grainger and Dijkstra 1992; Grainger and Jacobs 1996; Lavaur et al. 2008). Nevertheless, this task is supposed to access language nodes, and consequently involves successive language switches in some trials. This allowed us to study both mechanisms of inhibition, *i.e.* active and overcoming inhibition. In Experiment 2, the same participants performed a bilingual Stroop task, where the process of active inhibition is specifically supposed to be required to perform the task. According to Mueller et al. (2009), overcoming of inhibition is more difficult to implement compared to active inhibition. Consequently, our general hypothesis is that SI should be distinguished from Highly Proficient Bilinguals when overcoming of inhibition is required in addition to active inhibition (Experiment 1), because of the specific skills of SI in terms of switching and overcoming of inhibition. In contrast, based on previous findings from Yudes et al. 2011, both groups of bilinguals should have comparable performance when only active inhibition is required (Experiment 2).

As an example, a trial contained the following target words at the $n-2$ range, the word GLACE^{ice} (L1), at the $n-1$ range the word HUND^{dog} (L2), and at the n range the word MAISON^{house} (L1). At the $n-2$ range, the mother tongue (L1, French) of the participants is activated, and the level of activation of the L2 remains low. Then, to process the following word at the range $n-1$, participants have to strongly inhibit the automatic L1 to activate the L2 (active inhibition). Finally, at n trial, participants have to overcome the inhibition settled on the L1 on the previous trial, and also inhibit the L2.

Experiment 1: Language Decision Task

In Experiment 1, we focused on the role of both active and overcoming of inhibition mechanisms using a language decision task. This task provides a good way to evaluate language inhibition processes because participants have to access the language of the target word, activate the relevant representation and inhibit the representation of the other language to perform the task, which is a good way to evaluate the mechanism of inhibition. Moreover, in this task, in some trials, participants have to perform language switching, and therefore they have to overcome the inhibition settled at a previous trial of the non-appropriate language to reactivate this language. According to Ibáñez et al. (2010) we hypothesized that participants with highly efficient control processes (here, SIs) present a benefit for overcoming of inhibition and therefore exhibit reduced switch costs. Taking into account the findings from Yudes et al. (2011), performances in terms of active inhibition should be comparable, or non-significant between the two groups. To test this hypothesis, we compared professional Simultaneous Interpreters (SI) and Highly Proficient Bilinguals, both native speakers of French, with German as a second language in a language decision task. We predicted that SI should outperform Highly Proficient Bilinguals in terms of overcoming of inhibition processes and therefore should be less sensitive to switch cost effects.

Method

Participants

Two groups of 12 right-handed participants (Edinburgh Handedness Inventory) were recruited. The first group consisted of 12 proficient late French (L1)–German (L2) bilinguals (8 females, mean age = 28.1, SD = 5.7, ranging from 22 to 36 years old), defined as the Highly Proficient Bilinguals group. All participants of this group acquired their second language around 10 years of age (mean 10.4, SD 1.1) in French schools. The second group of participants was composed of 12 French–German Simultaneous Interpreters, also right-handed, native speakers of French (6 females, mean age = 35.1, SD = 6.2, age ranging from 29 to 44 years old), with a late acquisition of L2 (mean 10.3, SD 0.8). Participants from both groups were asked to auto-evaluate their proficiency in German on a 5-point scale from *excellent proficiency* (response 1) to *poor proficiency* (response 5) for *Comprehension*, *Production*, *Reading* and *Writing*. Furthermore, proficiency in German was objectively measured by means of a standardized test of proficiency of German as a foreign language, the *DAF* test (*Das Zertifikat, DAF–Deutsch als Fremdsprache, Einstufungs- und Diagnostiktest*), together with a post-test of translation. The evaluated proficiency and the objective scores of proficiency are presented in Table 1 below. By their own account, participants had no history of current or past neurological or psychiatric disorders, they had normal or corrected-to-normal vision and normal color vision.

Stimuli

The linguistic material used in the experiment was composed of 320 content words (160 French words and their translation equivalents in German). The length of the words was kept between 4 and 8 letters length, and matched in terms of frequency of occurrences per million (mean = 82.1, SD = 14.9) using *Lexique* database (New et al. 2004) for French words and *CELEX* (Baayen et al. 1995) for German Words. All the French words and their translation equivalents in German used in Experiment 1 were non-cognate words, that means the words did not present orthographical and phonological similarity like in the case of cognates *CLASSE-KLASSE*, meaning *class* in English. Moreover, as some German words contained informative clusters about the language to which the word belonged to (*e.g. KL* in the German word ***KL****ASSE* is a rare sequence of letters in French, and could have been a bias in the experiment, speeding up the processing of German words by giving a cue about language belonging), we eliminated these words from the stimulus list. Participants were

Table 1 Mean scores and standard deviation (SD) for the evaluation of the participants on their language background and skills

	Highly Proficient Bilinguals		Simultaneous Interpreters		p
	Mean	SD	Mean	SD	
Mean age (years)	28.1	5.7	35.1	6.2	<.01
AoA L2 (years)	10.4	0.8	10.3	0.5	ns
Self-evaluation (mean)	1.7	0.5	1.2	0.2	ns
DAF test	86.7	7.2	95.8	4.2	ns
Frequency of L2 use	41.9	16.3	45.4	4.1	ns

AoA Age of acquisition of L2 (German), Self-evaluation is the mean of several language skills (writing, reading, speaking, understanding) evaluated on a 5 points Likert scale (1 = very good; 5 = very bad), DAF (Deutsch als Fremdsprache) = score in % to a German test to enter into university. *p* values associated with *T* test are reported in the last column

asked to perform a language decision task, i.e. they had to identify which language each presented word belonged to, when words from two (or more) languages were presented. Here, in relation to the central question of interest concerning the efficiency of inhibitory control, the rationale in using a language decision task is that it implies both active inhibition and overcoming of inhibition. In the language repetition condition, two words from the same language are presented successively requiring inhibition of the other language (active inhibition). In the language switching condition, words belonging to two different languages are presented successively requiring the overcoming of inhibition of what is now the target language and strong inhibition of the language of the word preceding the switch (overcoming of inhibition; see Table 2).

The stimulus words were written in all capitals of font "Calibri" in font size 48, and presented individually in white ink on a black background in the centre of the screen.

Procedure

The stimulus presentation design was created with the program *E-Prime 1.2* (Psychological Software Tools, Pittsburgh, PA). French and German words were mixed in an experimental list, in a pseudo-randomized order. The following constraints were respected for the pseudo-randomization with the *Conan* program (Nowagk 1998): no more than three words from the same language were presented in succession, and no more than three words from the same experimental condition were presented in succession. We had as many repetition trials (160) as switch trials (160), and an equal number of language switches (80) in both directions, i.e. L1 to L2 and L2 to L1. Each stimulus word was preceded by a fixation asterisk (*) in the centre of the screen. The duration of the asterisk was kept constant at 500 ms, and immediately succeeded by a target word, which was presented until one of the two answer keys of the keyboard was pressed. The inter-stimulus interval (ISI) was 1.000 ms. Response Time (RT) was defined as the interval between stimulus onset and pressing a response key. Figure 1 displays the timing of a trial.

Participants were seated in front of a laptop (Dell, 14") in the usual writing position with both hands positioned on the keyboard. Good lighting of the experimental room was assured. Participants were given instructions on a sheet, which were repeated orally before running the experiment. They were asked to indicate as quickly and accurately as possible which language the presented word belonged to, *i.e.* French or German, by pressing one of the two

Table 2 Summary of the experimental conditions in the language decision task

LANGUAGE REPETITION				LANGUAGE SWITCH			
L1L1		L2L2		L2L1		L1L2	
n−1	n	n−1	n	n−1	N	n−1	N
VOITURE$^{\text{CAR}}$	MAISON$^{\text{HOUSE}}$	FINGER$^{\text{FINGER}}$	GARTEN$^{\text{PEAR}}$	BIRNE$^{\text{PEAR}}$	CAMION$^{\text{TRUCK}}$	GLACE$^{\text{ICE}}$	MOTOR$^{\text{MOTOR}}$

“n” represents the current trial, “n-1” the preceding trial

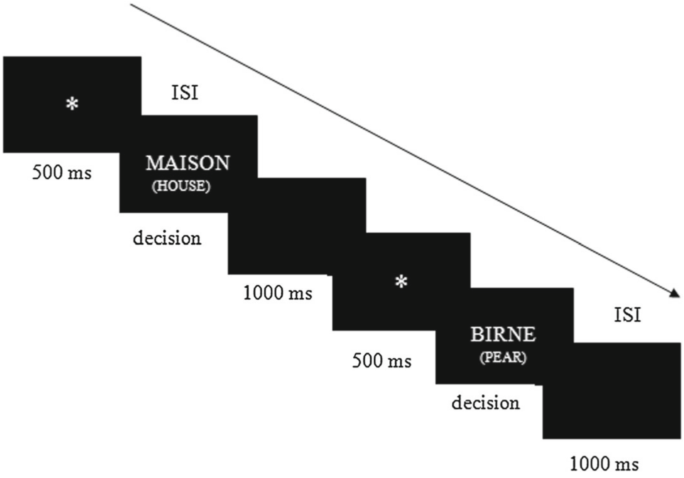

Fig. 1 Example of stimulus presentation during language decision task, here with a switch trial from L1 (*MAISON*$^{\text{-}HOUSE}$) to L2 (*BIRNE*$^{\text{-}PEAR}$)

response keys (keys *s* and *l*). The matching between key and language was counterbalanced across participants, but was kept constant for every single participant.

For familiarizing the participants with the experimental task, a practice block of 40 trials constituted of 20 French and 20 German non-cognate content words, not used in the experiment, was presented before the experiment. When the participants reached 80% of correct answers, the experiment began. Participants were tested in a single experimental list divided in two blocks of 160 words (80 French and 80 German words), including a break between the two blocks. To end the break, the participants simply had to press the spacebar. The experiment lasted about 20 min.

Data Analysis

Reaction times (RTs) were automatically recorded by E-Prime and measured the interval between the onset of the stimulus word and the button press. Time-out was set at 200 ms and 1.500 ms; if participants responded before or after this time window, the response was coded missing. We averaged the RTs for correct answers in the four experimental conditions across participants and across items. RTs that were outside a range of two standard deviations above and below the mean for each participant in each experimental condition were excluded from the data analysis. Moreover, we used eta squared to account for effect size, and d values above are meant to account for the absolute value of the effect.

Results

We subjected the results of erroneous responses (error rate) and RTs (dependent variables) to ANOVAs with Group as a between-subjects factor (2 levels: Highly Proficient Bilinguals and SI), Switching (2 levels: language repetition and language switch) and Language (2 levels: French and German) as within-subjects factors, in order to examine the influence of inhibition training in bilinguals during language switching, which constitutes the central question of our study.

Table 3 RTs and error rates per language (French and German) for Simultaneous Interpreters and Highly Proficient Bilinguals in the two conditions of Switching and Language

		Simultaneous Interpreters		Highly Proficient Bilinguals	
		French	German	French	German
RTs	Repetition	506.6 (28.7)	505.6 (40.4)	554.1 (59.5)	557.1 (58.8)
	Switching	513.6 (39.7)	512.1 (57.8)	574.4 (53.8)	575.1 (51.2)
Ers	Repetition	1.5 (1.2)	1.6 (1.5)	4.8 (2.7)	2.8 (1.7)
	Switching	1.7 (1.7)	1.8 (1.6)	5.0 (3.0)	3.9 (3.2)

The percentage of data missing due to erroneous responding, too early (< 200 ms) and too late (> 1000 ms) responding (outliers) was 1.7% (SD = 0.8) in L1 for SI and 1.8% (SD = 1.1) in L2, and 2.2 % (SD = 1.5) in L1 for Highly Proficient Bilinguals and 2.5% (SD = 2.3) in L2. The percentage of data removed in data correction exceeding MEAN ± 2 SD was 6.5% (SD = 1.8) in L1 for SI and 5.8% (SD = 2.1) in L2, and 7.1% (SD = 2.6) in L1 for Highly Proficient Bilinguals and 7.4% (SD = 2.4) in L2.

Analysis of Errors

To test the effect of the influence of inhibition training on the performances of a task involving language control, namely the language decision task, a three-way ANOVA with Group as a between-subjects factor (2 levels: Highly Proficient Bilinguals and SI), and Switching (2 levels: language repetition and language switch) and Language (2 levels: French and German) as within-subjects factors was conducted. Error rates are displayed in Table 3. The analysis revealed a significant main effect of Group by subjects $F_1(1, 22) = 21.96$, $p < .001$, MSE = 169.9, $\eta^2 = 0.26$ and by items $F_2(1, 218) = 30.1$, $p < .001$, MSE = 1388.6, $\eta^2 = 0.28$, with more errors on average for the group of Highly Proficient Bilinguals (5.5%) compared to SI (1.7%; d = 3.8%). In contrast, neither the main effect of Switching nor of Language was significant ($F_s < 1$). Furthermore, the ANOVA showed a significant Group by Switching interaction $F_1(1, 22) = 6.67$, $p < .01$, MSE = 74.13, $\eta^2 = 0.23$; $F_2(1, 106) = 17.9$, $p < .001$, MSE = 713.3, $\eta^2 = 0.16$, reflecting a larger difference (d = 0.6%) between repetition (3.8% of errors) and switching (4.4% of errors) conditions for Highly Proficient Bilinguals, compared to Simultaneous Interpreters (respectively 1.5 and 1.7%, d = 0.2%). Post-hoc comparisons showed a significant effect of Switching for Highly Proficient Bilinguals $F_1(1, 11) = 5.44$, $p < .05$, MSE = 60.28, $\eta^2 = 0.17$; $F_2(1, 106) = 13.8$, $p < .01$, MSE = 208.3, $\eta^2 = 0.21$, but not for SI ($F_s < 1$). In contrast, neither the two-way Group by Language, Language by Switching nor the three-way Group by Language by Switching interactions reached the significance level (F_{1s} *and* $F_{2s} < 1$).

Analyses of RT on the Correct Responses

The ANOVA showed a main effect of Group $F_1(1, 22) = 4.84$, $p < .05$, MSE = 113.4, $\eta^2 = 0.36$; $F_2(1, 218) = 66.8$, $p < .001$, MSE = 788.7, $\eta^2 = 0.51$, indicating that on average SI (505.6 ms, SD = 48.6) responded faster than Highly Proficient Bilinguals (564.3 ms, SD = 73.4). Moreover, a significant main effect of Switching $F_1(1, 22) = 5.13$, $p < .05$, MSE = 127.8, $\eta^2 = 0.33$; $F_2(1, 106) = 18.2$, $p < .001$, MSE = 739.4 $\eta^2 = 0.78$ was found, reflecting faster responses for repetition trials (532.7 ms, SD = 67.2) than for switching trials (544.1 ms, SD = 69.9). In contrast, the main effect of Language did not

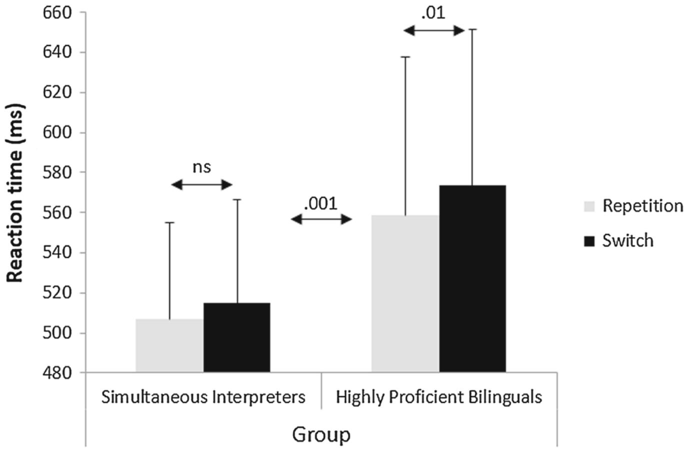

Fig. 2 Mean RT and standard deviation (*error bars*) for Simultaneous Interpreters and Highly Proficient Bilinguals in both Repetition and Switching conditions in the language decision task

reach significance ($Fs < 1$). The interaction between Group and Switching (see Fig. 2) was significant $F_1(1, 22) = 6.8$, $p < .05$, MSE = 127.3, $\eta^2 = 0.23$; $F_2(1, 106) = 18.2$, $p < .001$, MSE = 739.4, $\eta^2 = 0.21$. Further planned comparisons revealed significantly longer RT associated with language switching in Highly Proficient Bilinguals only $F_1(1, 11) = 17.3$, $p < .01$, MSE = 611, $\eta^2 = 0.96$; $F_2(1, 106) = 16.4$, $p < .01$, MSE = 547.6, $\eta^2 = 0.24$, as highlighted in Table 3.

Lastly, the Group by Language by Switch interaction was not significant (F_{1s} *and* $F_{2s} < 1$).

Discussion of Experiment 1

The language decision task was designed in order to examine the effects of language switching during visual word processing in two groups of bilinguals with a high level of proficiency in L2, differing in terms of language control experience. First, the analysis highlights differences in terms of language control, in favor of the group of Simultaneous Interpreters. According to our hypothesis, inhibitory control seems to play a role during language switching, with clear differences by comparing repetition and switching trials in both groups of bilinguals. Indeed, a significant switching effect was only reported for the Highly Proficient Bilinguals, for RT and Error Rate. This finding suggests that the efficiency of overcoming of inhibition is different for the two types of bilinguals tested in Experiment 1. Interestingly, in the Highly Proficient Bilinguals group we failed to show an asymmetrical effect of language switching as usually found with L2–L1 being more difficult than L1–L2 direction (Aparicio and Lavaur 2013; Grainger and Beauvillain 1987). In contrast, both switch directions gave rise to similar effects, 18 ms from L1 to L2 and 20.3 ms from L2 to L1. Asymmetries in language switch have been widely demonstrated in the literature (Grainger and Beauvillain 1987), but were not replicated here. As suggested by Bobb and Wodniecka (2013), a lack of asymmetry could be due to the fact that our participants are very proficient in both languages, with a daily practice of French and German languages (25 h per week for our group of Highly Proficient Bilinguals, 27 h per week for our group of Simultaneous Interpreters), which is also consistent with the absence of a Language effect and the absence of an interaction between Language and Group factors in our analyzes. If the differences between our two groups of participants on language switching trials could be explained in terms of efficiency of inhibitory processes, it remains unclear if this is due to the action of both active and overcoming of inhibition, or if it originates in better efficiency of one of these components more specifically. Indeed, as we mentioned above, the language switching task requires both active and overcoming of inhibition. In the language decision task, the two mechanisms are supposed to be involved, at different levels of processing. Active inhibition is supposed to exclude the irrelevant language, and overcoming of inhibition to reactivate the linguistic information previously inhibited. Experiment 1 did not allow us to distinguish between active and overcoming of inhibition to account for differences between both groups relative to their performance in the language decision task. Therefore, a second experiment was designed to study whether the differences observed between Highly Proficient Bilinguals and Simultaneous Interpreters in Experiment 1 were due to active inhibition or overcoming of inhibition. For this purpose, we used a Stroop task in Experiment 2 to disentangle between the two components of inhibition.

Experiment 2: Bilingual Stroop Task

The Stroop task (Stroop 1935) is a critical test to investigate cognitive control and active inhibition in bilinguals. The classical Stroop task is a color naming task, including a linguistic and a non-linguistic component. Color words are presented in different ink colors, and to succeed in performing the task, participants have to inhibit the automatic reading of the word itself and name the color of the ink (controlled activity). The classical Stroop effect is found by calculating the mean response time difference between the congruent condition (e.g. the word GREEN printed in green ink) and the incongruent condition (e.g. the word GREEN printed in red ink). In the control condition, the stimulus is a non-color word, also printed in different colored inks (e.g. HOUSE printed in green). The size of the Stroop effect obtained (incongruent minus congruent) is supposed to reflect the size of interference and indirectly the amount of active inhibition settled to perform the task (Badzakova-Trajkov 2008; Pardo et al. 1990). According to Badzakova-Trajkov (2008), a small Stroop effect is supposed to reflect less interference that could be due to strong inhibitory control. In our study, we used a bilingual version of the Stroop task (see also Heidlmayr et al. 2014) to investigate cognitive control among languages.

Results from Experiment 1 have highlighted faster response times for SI in comparison to Highly Proficient Bilinguals in the language decision task, as well as a lack of language switch cost for SI only. According to these results, both active and overcoming of inhibition could account for the performance observed in the language decision task. In the bilingual Stroop task, given that only active inhibition is required, better performance in SI would suggest a larger efficiency in active inhibition in comparison with Highly Proficient Bilinguals. Moreover, we hypothesize that Language (French L1 vs. German L2) has an impact on the degree of interference in the Stroop test, as demonstrated by Heidlmayr et al. (2014). Indeed, these authors reported a larger Stroop effect in the L1 than in the L2, and explained this difference in terms of a higher automaticity and activation of L1. The more the cognitive processes are automatic, the more the control processes have to be strong. Higher automaticity of a language is expected to render the control of interference more difficult when automatic processes of color word reading are involved and interfere on the more controlled target processes of color naming.

Method

Participants

The participants of Experiment 1 took part in Experiment 2.

Stimuli

Experiment 2 is an adapted version of the original Stroop test (Stroop 1935; see also Heidlmayr et al. 2014). In this task, participants were asked to identify the print color of the stimuli (manual color naming task). Depending on the experimental condition, stimuli were either color words (e.g. red, blue, etc.) or non-color words (e.g. cat, dog, etc.). The adapted Stroop test consists of color naming, with stimuli presented in three different experimental conditions: congruent, incongruent and neutral. In the congruent condition, there is a match between the meaning of the color word and the printed ink of the word; in the incongruent condition, there is a mismatch between the meaning of the color word and the print color; finally, in the neutral condition, non-color words are presented in equally varying print colors as in the congruent and incongruent conditions. In French (L1), the following four color words stimuli were presented: ROUGE^{red}, BLEU^{blue}, JAUNE^{yellow}, VERT^{green}; in German (L2), the four color words used correspond to those used in L1: ROT^{red}, BLAU^{blue}, GELB^{yellow}, GRÜN^{green}. At last, in the neutral condition, four non-color words—similar to the color words in length and number of syllables– were presented in the same four print colors.

The neutral words selected in L1 were the following: CHAT^{cat}, CHIEN^{dog}, MAIN^{hand}, PIED^{foot} and their translation equivalents in L2 (German): KATZE^{cat}, HUND^{dog}, HAND^{hand}, FUSS^{foot}. The stimulus words, written in all capitals of font "Calibri" in font size 48, were presented individually on a black background in the centre of the screen.

Experimental Procedure

The presentation of the stimuli and the experimental procedure were mainly established from the design used in Bruchmann et al. (2010). The stimulus presentation design was created with the program *E-Prime 2.0* (Psychological Software Tools, Pittsburgh, PA). The procedure was similar as the one used in Heidlmayr et al. (2014). An experimental sequence was presented as follow: a fixation cross was presented in the centre of the screen, with a duration varying from 500 to 1000 ms (500, 625, 750, 875 and 1000 ms, equally distributed and pseudo-randomized among the stimuli), in order to avoid systematic expectancy and strategy to be set up by the participants (Fig. 3). The fixation cross was immediately followed by the stimulus, which was presented until one of the four color-coded keys was pressed, or for a maximal duration of 1500 ms (if no key was pressed). The inter-stimulus interval (ISI) was 500 ms. Response time (RT) was defined as the interval between stimulus onset and pressing a response key. The order of presentation of the stimuli was controlled in order to avoid negative priming and overcoming of inhibition effects: if the word "BLUE" required inhibition (e.g. when printed in RED ink), the following word was not in blue ink. Consequently, no overcoming of inhibition is supposed to be involved in the Stroop task, but only active inhibition processes.

Participants were seated in front of a laptop (Dell, 14" screen), with both hands positioned on the keyboard. They were placed in a sound-attenuated room, with good lighting. The instructions for the experiment were given on paper to the participant, and repeated orally before starting the experiment. The instructions were to indicate as quickly and accurately as

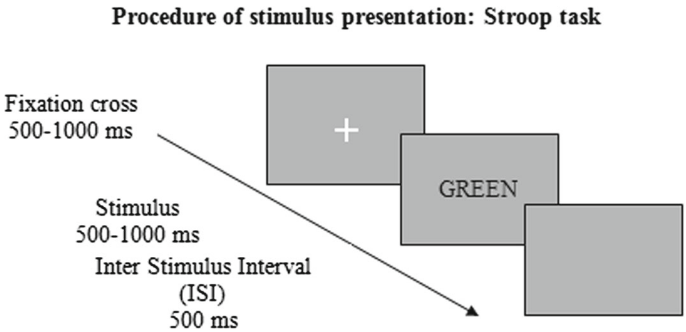

Fig. 3 Time course for a critical trial during the bilingual Stroop task

possible the print color (ink) of the stimulus word, by pressing one of the four response keys (keys *d*, *f*, *j* and *k* of the keyboard, one for each color). The keyboard keys were chosen in order to permit the usual position of the hands on the keyboard. The participants were asked to press the answer keys with the index and middle finger of each hand. The color-finger-assignment was counterbalanced across participants, to vary both finger and hand used for each color, but was kept constant during the experiment for every participant.

In order to allow the participants to learn the color-key matching, two practice blocks of 40 trials each, one in L1 French and one in L2 German, were presented before the six experimental blocks. Both groups of bilinguals performed blocks in French and in German, in a counterbalanced order. Half of them began with a French block, and the other half with a German block. No more than two blocks of the same language were presented in a raw. In each experimental block, the first two trials were removed from the analysis, to avoid a possible effect of language switching between blocks. Feedback about accuracy was given after each practice block. If accuracy was at least 80% after the practice blocks, the experiment could start; if not, the practice blocks were repeated.

Each of the six experimental blocks contained 72 trials. In each block, there were 24 congruent stimuli, 24 incongruent stimuli and 24 neutral stimuli, which were presented in a pseudo-randomized order. For the pseudo-randomization, we respected the following constraints, using the *Conan* program (Nowagk 1998): first, no more than three words of the same experimental condition were presented in succession; then, the first stimulus of each block was a neutral one, and finally no word and no print color were repeated immediately. The participants could take a short break between the blocks, and continue when ready by pressing the space key. The experiment lasted about 25 min.

Data Analysis

Criteria for data analysis were identical to Experiment 1. We averaged the RTs for correct answers in the six experimental conditions across participants and across items. RTs that were outside a range of two standard deviations above and below the mean for each participant in each experimental condition were excluded from the statistical analysis.

Results

We conducted repeated measures analyses of variance (ANOVAs) with erroneous responses (error rate) and RT as dependent variables, Group as a between-subjects factor (2 levels: Highly Proficient Bilinguals and SI), Congruency (3 levels: congruent, incongruent, and

Table 4 Error rates (%) and response times (RT) for Simultaneous Interpreters and Highly Proficient Bilinguals independently of languages

	Simultaneous Interpreters (SI)			Highly Proficient Bilinguals		
	Congruent	Incongruent	Neutral	Congruent	Incongruent	Neutral
RT	508 (31)	530 (34)	517 (33)	603 (85)	631 (88)	616 (92)
% Error	7 (4)	6 (3)	7 (3)	3 (3)	3 (4)	3 (3)

Mean error rates (ER) and response times (RT) in the three experimental conditions (congruent, incongruent neutral) are indicated with the standard deviations in parentheses for both groups

neutral) and Language (2 levels: French and German) as within-subjects factors. Data are displayed in Table 4.

Analysis of Errors

The ANOVA showed that SI made significantly more errors (6.6%, SD = 2.2) than Highly Proficient Bilinguals (3.1%, SD = 3.0) $F_1(1, 22) = 10.92$, $p < .01$, MSE = 77.1, $\eta^2 = 0.33$. In contrast, neither the main effect of Language or Congruency nor the two- and three-way interactions between the above-mentioned factors were significant ($Fs < 1$).

Analysis of Response Times

The ANOVA revealed a main effect of Group $F_1(1, 22) = 13.49$, $p < .001$, MSE = 304.9, $\eta^2 = 0.38$, reflecting faster responses for SI (518 ms, SD = 32) than for Highly Proficient Bilinguals (617 ms, SD = 88). Moreover, the ANOVA also showed a main effect of Congruency $F_1(1, 22) = 41.49$, $p < .001$, MSE = 141.5, $\eta^2 = 0.31$. Complementary post-hoc analyses indicated that congruent trials (557 ms, SD = 81) were processed significantly faster than incongruent ones $F_1(1, 22) = 43.37$, $p < .001$, MSE = 131.4, $\eta^2 = 0.52$; this difference constitutes the Stroop effect (22 ms). Moreover, a significant difference between incongruent and neutral trials was found $F_1(1, 22) = 8.65$, $p < .01$, MSE = 170.4, $\eta^2 = 0.44$, with incongruent trials (578 ms, SD = 82) processed slower than neutral trials (567 ms, SD = 85); this difference constitutes the so-called inhibition effect (11 ms). Finally, the analysis also revealed a significant difference between congruent and neutral conditions $F_1(1, 22) = 11.69$, $p < .01$, MSE = 117.8, $\eta^2 = 0.69$, with congruent trials processed faster (557 ms, SD = 81) than neutral trials (567 ms, SD = 85), revealing a facilitation effect (10 ms). A paired sampled t-test was performed between inhibition and facilitation effects, to determine if the results could be explained in a wider extent by inhibition or facilitation mechanism, but it came out as non-significant $t(23) = -1, 525$, $p = .141$, indicating that inhibition and facilitation effect sizes contributed to an equal degree to the Stroop effect size. Moreover, neither the main effect of Language nor the Group × Congruency interaction were significant ($Fs < 1$). In contrast, the interaction between Congruency and Language was significant ($F_1(1, 22) = 7.95$, $p < .01$, MSE = 105.1 $\eta^2 = 0.37$). Further paired comparisons revealed that the Stroop effect (calculated by comparing congruent and incongruent conditions) was larger in L1 (29 ms) $F_1(1, 11) = 47.81$, $p < .001$, MSE = 248.4, $\eta^2 = 0.52$ than in L2 (15 ms) $F_1(1, 11) = 13.75$, $p < .01$, MSE = 163.1 $\eta^2 = 0.40$ (Fig. 4).

Further analyses showed that the inhibition effect (incongruent minus neutral conditions) was significant in L1 (20 ms; $F_1(1, 22) = 19.23$, $p < .001$, MSE = 244.8, $\eta^2 = 0.60$) but not in L2 (2.5 ms, $F_1 < 1$). Furthermore, the facilitation effect was significant for both L1

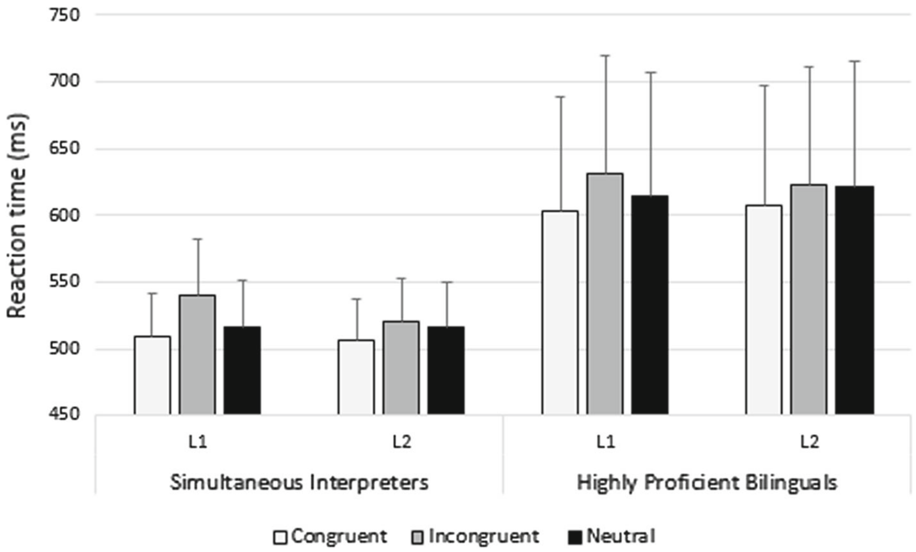

Fig. 4 Mean RT and standard deviation (*error bars*) for French (L1) and German (L2) languages in the three experimental conditions (Congruent, Incongruent and Neutral), according to Group

$F_1(1, 22) = 5.86$, $p < .05$, MSE = 170.8 $\eta^2 = 0.32$, and L2 $F_1(1, 22) = 12.13$, $p < .01$, MSE = 149.5 $\eta^2 = 0.37$. Finally, the interaction between the factors Group, Language and Congruency was not significant ($F_1 < 1$).

Discussion of Experiment 2

In Experiment 2, Simultaneous Interpreters and Highly Proficient Bilinguals were asked to perform a bilingual Stroop task. The aim of this experiment was to determine whether the degree of inhibition efficiency also plays a role in a task involving only active inhibition. First, the analyses revealed general differences between both groups of bilinguals. SI were faster to manually respond to the color of the printed word compared to Highly Proficient Bilinguals. These results are in line with previous studies (Blumenfeld and Marian 2011; Costa et al. 2008b; Prior and MacWhinney 2010), in which language control experience was associated with better performance in both language control and cognitive control tasks, in that bilinguals were faster compared to monolinguals. Here, the even better efficiency of inhibitory control in SI could explain their overall faster responses in the Stroop task. Moreover, it is consistent with the findings from Hilchey and Klein (2011), arguing that overall faster RTs could indicate better conflict monitoring. Nevertheless, despite these differences, the analyses revealed no differences in terms of amplitude of the Stroop effect between the two groups (Stroop effect of 18 ms for the SI, 22 ms for the Highly Proficient Bilinguals). This lack of difference between the two groups is in line with the idea that different inhibition processes are required to perform successfully in the language decision task and in the Stroop task. As we mentioned above, the Stroop task does not require the overcoming of inhibition, but only active inhibition. These results suggest that active inhibition process is not influenced by simultaneous interpreting expertise, but may be more related to proficiency and frequency of usage of the second language.

Moreover, we replicated the bilingual Stroop effect, with a larger effect in L1 than in L2. This effect is due to the fact that incongruent trials were more disturbing in L1, which, due to its high level of activation, is required to be strongly inhibited when a L2 trial is presented. On the contrary, the residual level of activation of L2 is lower, and consequently the L2 language may be easier to inhibit. In addition, the reduced automaticity of printed lexical access in L2 might also account for the smaller Stroop effect in L2.

General Discussion

Language Control Experience

Two groups of French-German bilinguals, differing in their inhibition experience (Simultaneous Interpreters and Highly Proficient Bilinguals), were asked to perform two tasks, *i.e.* a language decision task and a Stroop task involving differentiated inhibition processes (active inhibition in both language decision and Stroop tasks; overcoming of inhibition in language decision task only). SI are considered to be more efficient at cognitive control due to their usage of two switching mechanisms in their daily lives, *i.e.* language switching (from L1 to L2 and *vice versa*) and task switching (i.e. comprehension in a language and production in another language), while Highly Proficient Bilinguals are only used to language switching, but both are supposed to be very efficient in tasks involving conflicting information (*e.g.* Simon test or Stroop test, see Bialystok et al. 2012; Diamond 2011; Kroll et al. 2012). Moreover,Köpke and Signorelli 2012; see also Köpke and Nespoulous 2006) have analyzed working memory performance in SI and pointed out an advantage in free recall working memory tasks compared to bilinguals. If, as we expected, bilinguals' skills are improved in SI, in terms of overcoming of inhibition, it is of major scientific interest to deeply investigate their cognitive mechanisms, in order to increase our knowledge of cognitive control efficiency in a general perspective, not only in relation to the field of bilingualism, but for every individual.

According to the findings highlighted with this study, we propose that SI' specific expertise may mainly improve the efficiency of overcoming of inhibition. Indeed, in the first experiment (language decision), we observed clear differences between the two groups in terms of overcoming of inhibition. In both tasks, the results indicate clear differences between the two groups, namely that SI' responses are generally faster and more accurate compared to the Highy Proficient Bilinguals. In the language decision task, language switching trials require the participant to inhibit the language previously activated and to overcome the inhibition put on the other language in order to re-engage the previously inhibited language. The first interesting result is that SI are faster to make an accurate decision compared to Highly Proficient Bilinguals, irrespective of the condition (repetition or switch), showing an advantage that can be compared to the bilingual advantage above monolinguals. In addition, our data highlight that repetition trials elicit faster decision times compared to language switch trials, a finding already strongly demonstrated in the literature (Aparicio and Lavaur 2013; Grainger and Beauvillain 1987).

But here, the major finding is that the language switching effect has a statistical significance only for Highly Proficient Bilinguals, while there was no difference between repetition and switching conditions in SI. Given that both groups are equivalent in terms of proficiency and percentage of daily usage of the second language, the difference is reasonably attributable to their differences in executive language control expertise. Indeed, for SI, the absence of a language switching effect reflects a strong control of languages, and an important ease to switch from one language to another, even in the most complicated situation, i.e. switching from L2 to L1. The absence of any switching costs in SI suggests that they have a high capacity in reactivating information inhibited in a previous trial. This could be due to their professional ability to keep both languages activated in a situation of interpreting, and to switch simultaneously between reception and production.

Thus, under the hypothesis that SI keep active both languages, their capacity to handle the interplay of activation and inhibition may in part be explained by the task switching they have to do between comprehension and reception. This is consistent with the findings from Ibáñez et al. (2010), highlighting an asymmetrical switch cost for their group of bilinguals, but not for the group of translators. Their findings suggest that translators possess a better efficiency in terms of overcoming of inhibition.

Nevertheless, in the Stroop task, a group effect was again demonstrated in favour of the SI with shorter global RT, but the interaction between Group and Congruency was not significant, suggesting similar performance in terms of active inhibition. This means that both SI and Highly Proficient Bilinguals obtained a similar performance in the Stroop task (similar Stroop effect size, difference in performance on incongruent and congruent trials). As we mentioned before, the Stroop task involves specifically active inhibition of the non-appropriate orthographic representation of the target word. The faster RTs of SI could be explained by their professional experience in processing information quickly when interpreting, which is congruent with the overall RT advantage demonstrated by Yudes et al. (2011; see also Hilchey and Klein 2011 for a review). Moreover, correlation analyses highlighted a negative correlation between Stroop effect and frequency of use of the second language (German), showing that the higher the frequency of L2 usage, the smaller the Stroop effect in L2 ($r = -0.36$, $p < .05$), replicating similar findings with frequency of additional L3 use from Heidlmayr et al. (2014). In addition, we obtained a strong partial positive correlation between Inhibition and Stroop effects ($r = 0.574$, $p < .01$), indicating that participants' ability to inhibit determines the size of the Stroop effect. These results appeared to be contradictory because the more the L2 is used, the more its automaticity increases. Nevertheless, it seems that in the learning of a second language, there may be a period during which even if L2 is frequently used and progressively automated, L1 remains dominant and its activation level remains high, that means its activation threshold is low (less input is needed to activate the dominant language), because L2 is not entirely automated (see the BIA-d model, Grainger et al. 2010).

Given that SIs were significantly older than Highly Proficient Bilinguals, we performed regression and correlational analysis to ensure that the differences obtained could not be age-related. A multiple regression analysis was conducted in order to predict the size of the L2 Stroop effect from the following predictors: Age, Age of Acquisition (AoA), Self-evaluation of L2 proficiency (mean of the four evaluated criteria), Performance on the L2 proficiency test (*DAF*) and Frequency of L2 use. The results of the regression indicated that the five predictors explained 40% of the variance of the Stroop effect size ($R^2 = .400$, $F(6, 17) = 3.56$, $p < .05$). It was found that AoA significantly predicted L2 Stroop effect size ($\beta = -.604$, $p < .01$) indicating that the later the L2 was acquired the smaller was the L2 Stroop effect size. Interestingly, age does not seem to explain the differences obtained between the two groups in terms of Stroop effect. No significant results were obtained with the multiple regression analysis aiming to predict language switching effects in the first task. To sum up, due to their specific expertise, SI seem to have an advantage over Highly Proficient Bilinguals in overcoming of inhibition when switching languages or tasks. Our results suggest that active inhibition abilities are potentially not affected by specific SI expertise, and are comparable between SI and Highly Proficient Bilinguals.

Language Effects

In the language decision task, participants were asked to process words from French (L1) and German (L2), in repetition and switching conditions. Here, our results demonstrate that SI processed words from both languages faster than bilinguals, but interestingly, both groups reaction times associated with language decision were comparable in French and German. These results could be explained by the high level of frequency of use of both languages in our two groups (42% for Highly Proficient Bilinguals, 45% for SI), which can be assumed to compensate for the acquisition of the second language at a late age. In addition, we expected an asymmetry between L1 and L2, showing a higher cost in the L2 → L1 direction of switch, given that all participants learned German from the age of 10 years on (Aparicio and Lavaur 2013; Font and Lavaur 2004; Grainger and Beauvillain 1987). Language asymmetries in late learners of a second language have been well replicated in the literature (see the revised hierarchical model of lexical and conceptual representation in bilingual memory proposed by Kroll and Stewart 1994; Kroll et al. 2010; see also Aparicio and Lavaur 2013). Here, language switching effects were significant only for Highly Proficient Bilinguals, but an absence of asymmetry was highlighted in language switching. This could be due to the high level of proficiency of bilinguals in both languages, and to their high frequency of usage of the second language, Schoonbaert et al. (2009) have also demonstrate an absence of asymmetry in a masked translation priming study. They suggest that L1 and L2 are both represented by "a similar lexico-semantic architecture in which L2 words are also able to rapidly activate semantic information" (Schoonbaert et al. 2009 page 1). Therefore, the differences between L1 and L2 representations should be quantitative rather than qualitative.

In the Stroop task, based on findings from Heidlmayr et al. (2014) and previous studies, we hypothesized that the Stroop effect should be larger in the L1 compared to the L2, given that L1 processing is considered to be more automatic than L2, and therefore may cause more interference. Our results are in line with the results of Heidlmayr et al. (2014), given that a stronger Stroop effect was highlighted in French in comparison with German. According to the BIA+ model (Dijkstra and van Heuven 2002, see also BIA-d model from Grainger et al. 2010), the access to semantic and phonological codes is supposed to be delayed in L2 in comparison to L1, and therefore German takes more time to be activated than French. As a consequence, if lexical access to L2 is slower, interference of German words should be reduced in the Stroop task. Nevertheless, we may also consider that the nature of the Stroop task, which is sensitively different from the language decision task, plays a role in our results. Taken together, our results bring to light that in the current study performances in terms of overcoming of inhibition are not related to proficiency in the second language, given that both groups were equivalent in this respect, but rely on the ability to overcome inhibition and to re-engage a task previously disengaged (overcoming of inhibition, a cognitive process well mastered in SI expertise).

Further investigations are needed to address the question of the influence of the typological distance between L1 and L2 on the efficiency of the mechanisms of inhibition, as the degree of inhibition of specific grammatical information should vary as a function of the degree of similarity/dissimilarity between the two languages under investigation. However, due to the fact that it is not possible to establish a general measure of distance between languages, such a study will necessarily have to be conducted by examining processing of linguistic information at a specific level of functioning with strong underlying hypotheses on the distance of the

L1 and the L2 at this level. This would bring the first stones for constructing the bridge that Kroll and Bialystok (2013) proposed to establish between the studies of cognitive control, in general, and the more applied study of control, such as the one used in second language processing for managing cross-language interference. This would open fruitful perspectives in educational domains, in particular in improving methods of second language learning.

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